Guiding Inservice Mathematics Teachers in Developing a Technology Pedagogical Knowledge (TPCK)

Margaret Niess, KwangHo Lee, Pejmon Sadri, Gogot Suharwoto
Department of Science and Mathematics Education
Oregon State University
Corvallis, OR 97331 USA
niessm@onid.orst.edu, leekw@onid.orst.edu, sadrip@onid.orst.edu,
suharwog@onid.orst.edu

Abstract: Few teachers have used spreadsheets as tools for learning mathematics, leaving many of them unprepared to guide students in learning mathematics with spreadsheets. Current teachers have not had any preparation that develops technology pedagogical content knowledge (TPCK) - the intersection of the knowledge of mathematics with the knowledge of technology (spreadsheets) and with the knowledge of teaching and learning. This professional development program focused on guiding teachers in developing TPCK for teaching mathematics with spreadsheets. Actual teaching opportunities were extended by classroom observations and support as teachers implemented their developing ideas. Research results revealed potential key attributes of a TPCK professional development program along with a preliminary model for describing the developmental progress of the inservice teachers in their growth in TPCK.

Spreadsheets offer a technology readily available among classroom technologies to support students in learning mathematics. However, its use is limited or even nonexistent in most mathematics classrooms largely because mathematics teachers have not been prepared to use spreadsheets in thinking about mathematics, nor have they been prepared to integrate spreadsheet technology as a tool for teaching and learning mathematics. If spreadsheets are to be included as tools for learning mathematics, then mathematics teachers need opportunities to develop their personal knowledge and skills of using spreadsheets as tools for exploring and learning mathematics. They need support in redesigning the mathematics curriculum to include spreadsheets as tools for exploring mathematics while also guiding their students' development of knowledge and basic skills with spreadsheets. They need support in guiding student thinking of mathematics with spreadsheet tools. Inservice teachers need a preparation that they likely have not experienced as they learned mathematics nor as they learned to teach mathematics. And, as inservice teachers who are actively engaged in teaching, they have limited time for extensive educational programs that require such a significant shift in what and how they teach. When and how will they gain these new skills for teaching mathematics in the 21st century? What type of professional development will meet the teachers' needs in ways

that guide them in developing a pedagogical content knowledge for teaching mathematics with spreadsheet – a technology pedagogical content knowledge or TPCK?

A. Objectives

An obvious challenge for all professional development programs is to prepare inservice teachers in ways and at times that meet their schedules, locations, and support mechanisms. With respect to the emergence and application of technologies in education, more and more professional development programs must focus on guiding teachers to teach from an integrated knowledge structure of teaching their content with technology. These teachers need programs that help them in developing a particular knowledge for teaching their content (such as mathematics) with technology – a knowledge that is the intersection of their knowledge of mathematics with their knowledge of technology and their knowledge of teaching and learning; these teachers need programs that help them develop and enhance their technology pedagogical content knowledge (TPCK).

The key to TPCK is the integration of multiple domains of knowledge in a way that supports teachers in teaching their students the subject matter with technology (Margerum-Leys & Marx, 2004; Mishra & Koehler, 2006; Niess, 2005; Pierson, 2001). But, what exactly is meant by TPCK as knowledge that is the interconnection and intersection of content, pedagogy and technology? Shavelson, Ruiz-Primo, Li and Ayala (2003) propose a heuristic framework useful in conceptualizing the comprehensiveness of TPCK. They hypothesize a knowledge structure as consisting of *declarative knowledge* (knowing that), *procedural knowledge* (knowing how), *schematic knowledge* (knowing why by drawing upon both declarative and procedural knowledge), and *strategic knowledge* (knowing when, where and how to use domain-specific knowledge and strategies, such as planning and problem solving as well as monitoring progress towards a goal). Table 1 suggests one analysis of a teacher's use of TPCK knowledge with respect to each of the knowledge dimensions when planning to teach about linear functions with spreadsheets. Ultimately, a professional development program focused on TPCK needs to prepare teachers so that they gain a strategic knowledge for teaching mathematics with technologies such as spreadsheets.

Table 1. Teaching about linear functions with spreadsheets

Knowledge Dimension	**Content**	**Pedagogy Teaching & Learning**	**Technology**
Declarative	Recognizes $y = mx + b$ and $ax+by = c$ as linear functions.	Students need experiences in recognizing linear functions in various symbolic, tabular, graphical and visual forms.	Spreadsheets can be used to graph linear functions, showing multiple representations of linear functions (tabular, graphical, and symbolically); spreadsheet graphs can be superimposed on digital images to

			represent the slopes of linear images.
Procedural	Knowing how to graph a linear function, with two points, with one point and slope, and with the slope and y-intercept.	Students solving for slope and y-intercept and graphing the linear function: Perhaps use a teacher demonstration followed by student work with spreadsheets. Provide experiences in converting among the various forms of linear equations.	Use spreadsheets to display linear functions accurately and efficiently with tables, graphs and symbolic representations.
Schematic	Explain why the slope of a horizontal linear function is zero and the slope of a vertical linear function is undefined; why some slopes have negative values and some have positive values	Whole class exploration to form conjectures about shifts in the linear function and how these shifts affect the slope and y-intercept of the slope-intercept form	Create dynamic spreadsheets as a way of more easily engaging in "what if" explorations where students are able to propose conjectures based on changes in their graphs with changes in the important variables.
Strategic	Apply real life problems to the use of linear functions in solutions: for example, compare two cell-phone companies to determine which offers the best plan for most teenagers.	Student collaboration to compare various models of cell phone plans.	Use created dynamic spreadsheets to enter various changes in the cell phone plan variables as a means of comparing the plans toward finding to the best plans for cell phone services for teenagers.

Inservice teachers typically have few experiences with spreadsheets and probably have not used them as learning tools in mathematics. Their textbooks at best provide sidebars suggesting the use of spreadsheets for exploring particular mathematical concepts. In these cases teachers must design and plan how (1) students gain the needed experiences to use the spreadsheet capabilities and (2) students are to learn to use spreadsheets to explore mathematical problems. With the reality of constantly emerging computer technologies, spreadsheet capabilities are continually being enhanced. Thus, the development of a teachers' TPCK for using spreadsheets requires that they develop an attitude of continuous learning about and with emerging capabilities, about how the discipline of mathematics shifts because of the capabilities and about how the capabilities support students' learning of the essential mathematics.

This study was framed to identify a professional development program that supports teachers in developing a TPCK for teaching mathematics with spreadsheets.

The program was designed to guide teachers in scaffolding mathematics lessons that have incorporated learning about spreadsheets while also learning mathematics. More importantly, this professional development program was designed to provide teachers with opportunities and support in planning and teaching their students mathematics with spreadsheets. Essentially, the study of the professional development program was framed by three questions:

1. How does the professional development program affect the development of teachers' TPCK for teaching mathematics with spreadsheets?
2. What are the effects of the professional development program on the development of teachers' plans to scaffold their students learning of mathematics with spreadsheets?
3. What is the impact of the professional development program on teachers' implementation of their plans in their own mathematics classroom where they are responsible for guiding student learning of mathematics with spreadsheets?

B. **Theoretical Perspective**

The vision for a professional development program to result in the development of teachers' TPCK evolved from multiple pedagogical content knowledge (PCK) research studies. Niess (2005) extended Grossman's four central components of PCK (Grossman, 1989, 1990) as a guide for the incorporation of technology (i.e., TPCK) in a professional development program for teachers in teaching with spreadsheets; more specifically, the program needs to help teachers gain: (1) an overarching conception of teaching mathematics with technology; (2) knowledge of instructional strategies and representations for teaching mathematics with technologies; (3) knowledge of students' understandings, thinking, and learning in mathematics with technology; and (4) knowledge of curriculum and curricular materials that integrate technology. From this perspective, the professional development for mathematics teachers must guide the development of their knowledge and thinking in a manner that considers the knowledge required for scaffolding student learning of mathematics as they also learn about the technology. The professional development needs to challenge the experienced teachers to reconsider their subject matter content, and to develop their knowledge of the technology along with its impact on the comprehension of that subject itself as well as on teaching and learning that subject. But, this attention also must recognize the importance of the process of learning to teach - a "constructive and iterative" process during which teachers must interpret "events on the basis of existing knowledge, beliefs, and dispositions" (Borko & Putnam, 1996, p. 674).

Shreiter and Ammon (1989) argued that teachers' adaptations of new instructional practices are a process of assimilation and accommodation that result in changes in their thinking. This perspective suggests that TPCK professional development programs must provide numerous experiences to engage these experienced teachers in investigating, thinking, planning, practicing and reflecting. Numerous studies have yielded consistent findings on differences in the thoughts and instructional practices of expert and novice teachers (Borko & Livingston, 1989; Leinhardt, 1989; Livingston & Borko, 1990; Westerman, 1992). Yet, with respect to the development of TPCK, even experienced mathematics teachers are novices. From a constructivist perspective, their actions largely

grow from an understanding based on having been taught mathematics without the use of technology; they need a professional development program that provides experiences and instructional practices to encourage and allow their beliefs, knowledge and thinking to mature. In essence then, professional development for guiding experienced teachers in developing TPCK must include active learning - not only about the technology but also about teaching and learning mathematics with the technology. The program must provide follow-up support to assist the teachers in implementing their instructional plans that adopt new curriculum and instructional strategies for guided student learning of mathematics with technologies such as spreadsheets (Feist, 2003).

Furthermore, a professional development program focused on developing TPCK must establish some way to think about the teachers' developing TPCK. In this case, the teachers are confronting an innovation – an innovation that integrates a new technology tool, new teaching and learning strategies, and revision of their subject matter content as a result of the availability of the new technology. Everett Rogers (1995) provided one way to view the progress that teachers make when working with innovations. He envisioned a five-step process in the ultimate decision of whether to accept or reject a particular innovation such as teaching mathematics with spreadsheets. Rogers' five-step process suggested a beginning framework for considering the teachers' development of TPCK focused on teaching mathematics with spreadsheets:

1. **Knowledge** where teachers become aware of integrating spreadsheets with learning mathematics and has some idea of how it functions;
2. **Persuasion** where teachers form a favorable or unfavorable attitude toward teaching and learning mathematics with spreadsheets;
3. **Decision** where teachers engage in activities that lead to a choice to adopt or reject teaching and learning mathematics with spreadsheets;
4. **Implementation** where teachers actively integrate teaching and learning of mathematics with spreadsheets;
5. **Confirmation** where teachers evaluate the results of the decision to integrate teaching and learning mathematics with spreadsheets.

The question for this professional development research was to determine actions that describe and influence the teachers' growth in their TPCK for integrating teaching mathematics with spreadsheets. This research was designed to propose a descriptive model for analyzing the teachers' TPCK growth process.

C. Methodology

With respect to the first two research questions, a professional development summer program was designed to guide experienced mathematics teachers in scaffolding lessons that integrated learning about spreadsheets concurrently with learning mathematics. The study, supported by a collaboration of mathematics educators and computer scientists, offered a four-week summer session for 10 mathematics teachers teaching in grade 7-14 directed at the development of their TPCK and in guiding them in developing, practicing, and preparing to integrate instruction focused on the design of dependable spreadsheets as mathematical tools in their day-to-day teaching of mathematics. In the four-days-per-week, three-hours-per-day summer coursework, the teachers were registered for a three-credit graduate course focused on the basics of

dependable spreadsheet design, use of spreadsheets as tools for learning mathematics, exploring real-world problems, and the importance of testing spreadsheets in order to minimize the possibility of errors in their designs. Daily journals were used to gather each teacher's developing knowledge about teaching with spreadsheets. Ultimately, by the end of the four weeks, the teachers completed plans for teaching with spreadsheets upon their return to the regular school classrooms.

The instruction during the first week introduced the capabilities of spreadsheets, examined the role of spreadsheets in mathematics teaching with examples of scaffolding student learning with spreadsheets, collecting resource ideas for mathematics lessons that involved students in the use of the spreadsheet as mathematics tool, designing dynamic and dependable spreadsheets, and planning lessons that integrate spreadsheets with mathematics instruction. Models of specific mathematics lessons were used to provide the teachers with experience in scaffolding student learning of mathematics with spreadsheets (Niess, 2005b). The key for this first week was for the teachers to identify skills that their students needed for learning with spreadsheets and to identify mathematics content that can be displayed through the development of the spreadsheet skills. In essence during this first week, they were expected to begin thinking about how they might scaffold their students learning of these ideas throughout the year.

The second week, the teachers had opportunities to design and practice teaching specific lessons. Using a peer-teaching format, the teachers taught each other, followed by a reflective exploration of the advantages of the models and any improvements that might aid in integrating the learning experiences about spreadsheets and about mathematics. By the end of this week, the teachers had designed a sequence of lessons that they planned to teach to a group of students in grades 7-11 during the following week.

During the third week, the teachers were organized to share the teaching of the sequence of lessons to the students. Some of the teachers presented the warm-up activities for the mathematics to be explored, others prepared the students for working with the spreadsheets, others guided the students as they worked on the spreadsheets, and others helped the students in discussing the ideas learned in the lessons. Each day, at least two teachers were assigned as observers/reviewers to provide a follow-up analysis of the teaching and guide the teachers' reflection on the lesson.

During the fourth week, the teachers' knowledge of spreadsheet capabilities that were useful in solving mathematics problems was extended. The teachers were also engaged in finalizing their own specific plans for teaching with spreadsheets when they returned to their own classrooms.

In response to the third research question, the professional development program followed the teachers to their school sites as they worked to integrate their knowledge from the summer work. For this experience, the teachers were registered for a two-credit graduate course. The instructors/researchers maintained contact with the teachers to provide support as they finalized their plans for teaching and, at least quarterly, to observe their instruction with their students. The intent of these activities was to gather how the teachers relied on their personally developing TPCK level for teaching students mathematics with spreadsheets. Prior to each observation, the teachers provided the observer with the plans for the lesson and were interviewed. After the observations, the teachers reflected on the lessons in a post-observation interview where they considered what worked and what might have helped their lessons to meet their objectives.

D. Data Sources

Multiple data sources were used to collect information about the teachers' progress. Daily journal prompts in the summer program (Appendix A) gathered the individual teacher's developing TPCK; each teacher's instructional sequence plans for integrating spreadsheet instruction in mathematics classes provided a preliminary view of their developing TPCK by the end of the summer session. All assignments during the summer session (resource cards, lesson plans for practice in peer teaching and for teaching with the students from grades 7-11 were analyzed to assess the teachers' progress in integrating teaching mathematics content and spreadsheet skills and thus developing their TPCK) were collected and analyzed. Observations and interviews of teachers prior to and after teaching mathematics with spreadsheets in their own classrooms expanded the view of their TPCK using an interview protocol (Appendices B and C) adapted from the Horizon Research, Inc. (2000) teacher interview protocol. An observation check list (Appendix D) was adapted and developed from (1) Shulman's (1987) checklist of observable behaviors of PCK and (2) Pilburn's, et al. (2000) Reformed Teaching Observation Protocol (RTOP).

E. Results

The teachers' development of TPCK was evident throughout the summer session of the professional development program. As expected, all the teachers demonstrated a well-developed PCK prior to the summer program in that they presented clear conceptions for motivating and encouraging students to think about mathematics. However, their TPCK for teaching mathematics with spreadsheets was at best described as beginning or novice even though half of the teachers had prior experiences with spreadsheets; information from the demographic questionnaire indicated that their knowledge was limited to spreadsheet operations, rather than an integration of spreadsheets as tools for teaching and learning mathematics. Participants with more than 10 years of teaching experience (even those with prior knowledge of spreadsheets) tended to plan lessons that were teacher-centered and focused on directing student exploration with spreadsheets rather than allowing students to have more freedom to explore the ideas with spreadsheets. However, after the teaching experiences (peer teaching and teaching the summer grade 7-12 students), all but one of the teachers accepted the idea of integrating spreadsheets in teaching mathematics and began to adapt new strategies for integrating spreadsheets as tools for exploration of mathematics problems.

Moreover, the notion of "scaffolding" mathematics lessons that developed student expertise with spreadsheets as mathematical tools (Niess, 2005b) was new for these teachers. In the context of teaching mathematics with technology, Niess defined scaffolding as explorative mathematics lessons that engage students in learning specific and integrated applications of spreadsheets. Given this definition, in the beginning, the participants did not understand what was meant by the term until the model lesson demonstrated the process of scaffolding student understanding of mathematics with spreadsheets. The introduction of the model was pivotal in shifting these teachers' thinking about integrating spreadsheets with learning mathematics in that they were then

able to begin discussing and planning to incorporate scaffolding activities within their instructional sequence plans for the coming year. By the end of the summer session, the teachers were able to describe and discuss scaffolding with respect to integrating technology in mathematics lessons. They recognized advantages for using spreadsheets to solve complicated mathematics problems, motivate students, and provide opportunities for students to extend problems when considering hypothetical situations.

The teachers' plans for teaching mathematics with spreadsheets, however, were sketchy at the end of the summer session. Despite their experience and strength of PCK in teaching mathematics, their plans appeared more like those of novice teachers. Even though several of them had strong content knowledge of spreadsheets, their knowledge of teaching and learning of mathematics with spreadsheets was at a beginner's TPCK developmental level. Part of this problem may have been their dependence on mentally planning lessons, rather than preparing written descriptions of the plans.

Multiple teaching opportunities during the summer program supported these teachers in improving their teaching of mathematics with spreadsheets. Observations of their teaching demonstrated a relative tentative nature to their TPCK similar to the tentative nature of PCK that beginning teachers typically display. They had difficulty accepting students' ideas while engaging students in an exploration of spreadsheets because those ideas may redirect the lessons to areas in which the teachers were unsure; they preferred to give answers rather than guide student thinking. They demonstrated their novice levels of working with spreadsheets as they failed to notice advancements in student thinking. Their preparation of materials for teaching with spreadsheets was limited because they were concerned with over-planning and creating a scripted lesson that limited student creativity. Yet, they restricted unguided student exploration. In essence, they were comfortable with the mathematics and their personal activities with spreadsheets, but they tailored their mathematics lessons with spreadsheets to fit their comfort level in working with spreadsheets. As one teacher indicated, "If I guide them, they won't make a mistake that I am not able to troubleshoot." In essence, their concerns for controlling the activities resulted in teacher-centered, teacher-directed activities that lacked opportunities for students to explore mathematics and spreadsheets capabilities.

By the time the school year began, the teachers had had sufficient time to reflect on their summer experience in its entirety. They had plans and were mentally prepared to integrate spreadsheets in at least one of their mathematics classes during the Fall term. The observations were focused on identifying ideas for improvement and detecting barriers that restricted teachers in scaffolding their teaching of mathematics lessons with spreadsheets. The researchers were able to observe 7 of the 10 teachers teaching with spreadsheets. Of the three who were not observed, one teacher was unable to find a suitable unit for integrating spreadsheets, one indicated that spreadsheets would detract from his student learning of mathematics and one had not been able to find a teaching position and was restricted to substitute teaching.

Four of the seven teachers observed during Fall term exhibited similar patterns in sequencing their lessons. They began their lesson sequences by first covering the mathematics concepts on one day and on a separate and following day they reviewed the same mathematics topics using spreadsheet applications. Three of the observed teachers began their spreadsheet lessons with real-world problems. All four of these teachers cited a lack of sufficient time to teach new content and new technology during the same class

session as the main reason for this decision. During the observation period, the teachers demonstrated numerous differences in how they integrated spreadsheets as learning tools in their classes.

The three teachers with fewer than five years of teaching experience (Ms. Anderson, Mr. Carson and Mr. Donald) taught middle school students; they began the summer program with little to no experience with spreadsheets or with mathematics lessons that incorporated the nature of mathematics and real life applications. In her first fall term observation, Ms. Anderson talked to her class about spreadsheet cells and how they could identify the contents of a cell through its column and row headings rather than integrating this instruction within a mathematics idea as was modeled in the summer instruction. Much of her lesson focused on basic spreadsheet terminology where, as she entered numbers into different cells, she asked students to identify the location of each cell's content using row and column headings. At this stage, Ms. Anderson was not confident in developing a more elaborate mathematics lesson with spreadsheets. She had not yet found a mathematics content lesson with which she was comfortable in integrating spreadsheets as a tool for learning. Thus, a consideration of the three domains of knowledge in TPCK revealed little interconnection of her knowledge of mathematics, pedagogy and spreadsheet technology.

Mr. Carson began his lesson based on a previous problem solving experience, where the students had solved the problem using charts created on paper using colored pencils. The students had already determined the relationship between the degree of an angle and the percent of area in a pie chart. Mr. Carson demonstrated how to input the data and make pie charts using spreadsheets. Students entered their own data into the spreadsheets and made a pie chart based on their data. Mr. Carson moved around the class, directing the students who had finished the data input in creating a spreadsheet pie chart. In the interview he explained that his lack of preparation was due to the newness of the curriculum.

Mr. Donald's lesson clearly displayed the lack of interconnection of the multiple knowledge domains in TPCK. His lesson was rigidly mathematical and did not include any scaffolding components. He prompted his students to create a multiplication table using the spreadsheet. Even then, in the middle of his lesson, his computer crashed and as he lost his ability to demonstrate to the class while also losing lost control of the class. His lesson not only highlighted his lack of confidence in working with the technology but indicated a lack of understanding in planning a lesson with technology. At this early point in the school year, the researchers were unable to detect any interconnecting features of TPCK linked to his progress by the end of summer professional development session.

On the other hand, another teacher, Mr. Miller, with more than 10 years teaching experience who taught at a high school, but who was a beginner in using spreadsheets and their applications, designed a thorough lesson that took into account the scaffolding features as well as a strong connection of the mathematics context to real life problems at the end of the summer professional development session. However, his lesson was quite different from the lesson that he did in the summer program. This Fall term lesson prompted his students to search the web for high and low temperatures of all major cities across the state of Oregon. The students were to list these temperatures and the names of the locations for which the temperatures were listed on a worksheet that he had designed

and distributed to his students. After filling out the worksheet, students were to enter the data into a spreadsheet and analyze it for its mean, median, mode, and range. Overall, his lesson included solid process expectations and technical scaffolding features with connections to real-life problems. In comparison to Ms. Anderson's, Mr. Carson's and Mr. Donald's lessons, Mr. Miller's lesson highlighted the importance of teaching experience that supported him in successfully adapting a new instructional strategy.

When considering the differences among these teachers' efforts, an important concern was that Mr. Miller taught in a school with three computer labs that allowed teachers to request access for times they wished to teach their subjects with technology. Though, Mr. Miller indicated that competition among teachers for the computer labs was intense, the technology resources available to him were far better than those available to Mr. Donald, Mr. Carson, and Ms. Anderson. In addition, more computers were at the students' disposal in the library at Mr. Miller's school, providing important access for student practice. This relative ease of access to technology played an important role in helping Mr. Miller plan, develop, and practice his TPCK.

Another teacher, Mr. Fletcher, who possessed strong teaching experience as well as spreadsheet skills at the end of the summer program, however, was hampered in the design of his lesson because of the type of students he taught; he was a teacher at a high school for "troubled teens." Although Mr. Fletcher's lesson had elements that supported and assisted in scaffolding his students' mathematical understanding in a spreadsheet-based lesson with connections to real-life problems, the implementation of the lesson did not meet its intended objectives. His plans for the lesson incorporated clear scaffolding elements designed around the concept of linear equations within a real-life problem setting. He identified a candy manufacturers' problem for the students to explore with the use of technology. The problem incorporated building a physical simulation of a spreadsheet prior to a student hands-on computer work that provided experience with the appearance and operations of a spreadsheet. This lesson was a direct adaptation of a lesson modeled for the teachers in the professional development program. While the original summer problem had considered a comparison of three companies with respect to the cost of their calculators, Mr. Fletcher's problem used the costs for purchasing three brands of candies from two different manufacturers. This result highlighted the importance of teachers' practice with examples that modeled important preliminary, off-computer experiences prior to the more abstract computer spreadsheet experiences; while the teachers were experienced in teaching mathematics, they were novices in teaching with technology in the process of developing their TPCK. The significance of this conclusion was more noteworthy with the recognition that Mr. Fletcher was actually an experienced user of technology himself. Nevertheless, as he admitted in his first interview, the knowledge to teach with technology in the process of developing his TPCK came only after he was exposed to the ideas and the models in the summer program.

Two other teachers, Mr. Taylor and Mr. Smith, possessed strong backgrounds in technology and mathematics, and showed a strong ability to plan their lessons based on their instructional plans submitted at the end of the summer program. Nevertheless, in the first round of observations, their strength in planning lessons did not necessarily translate to planning lessons that scaffolded experiences toward developing students' understanding of the mathematics and spreadsheets. For example, Mr. Smith expected the students to complete too much in the allotted time. This problem forced the students

to focus on following the technical instructions in an automatic fashion without allowing time and freedom to explore and reflect on a solution of their own. Thus, the lesson, though rich in substance and scaffolding elements, became teacher-centered and teacher-tell, as Mr. Smith guided them in completing the work. In his interview, Mr. Smith cited the lack of time as the major determinant for his instructional strategy choice. The 40-50 minute class time did not allow him enough time to adequately scaffold his students' understanding of mathematics and spreadsheet concepts using a student-centered environment as he challenged himself to work toward integrating technology with teaching mathematics and developing his TPCK. The lack of time in one class period was seen as a barrier rather than a challenge for ways to assure students had sufficient time by using multiple days to build the ideas.

Mr. Taylor, a teacher with nearly 10 years of teaching experience and even a longer term of exposure to technology use, was another teacher who was able to enhance his TPCK in teaching mathematics. His lessons provided students with a series of minimum and maximum travel times for cars going through a series of intersections. The students' task was to obtain the average travel time through each stoplight intersection and compute an overall average time of travel from the first stoplight to any of the other stoplights thereafter. His lesson had a strong connection with real-world situations. With respect to scaffolding, Mr. Taylor's problem statement and the organization of the raw data he provided to his students were designed in such a way that prompted simultaneous scaffolding of content and spreadsheet concepts in the minds of his students. The data were organized in a manner that the students had to initially determine how to complete the operation mathematically and then to identify spreadsheet tools and functions that allowed them to automate their computations. Once again, this more experienced teacher's development of TPCK was supported by his strong personal knowledge about spreadsheets.

E. 1 Analysis of Teachers' Developing TPCK

From the Fall term observations and Rogers (1995) five-step process, the researchers developed a preliminary model to identify and discuss these inservice teachers' developing TPCK.

- **Recognizing**: Recognizes capabilities but rarely thinks about incorporating spreadsheets, only considers spreadsheets as a low level tool for learning mathematics.
- **Accepting**: Completes the program requirements, practices with different capabilities of spreadsheets but spreadsheets are not a consistent thought.
- **Adapting**: Tries ideas for incorporating spreadsheets in teaching - but in teaching students, at best has students use drill and practice of the ideas with the spreadsheets.
- **Exploring**: Investigates different ways of teaching mathematics content - willing to demonstrate new ways of thinking about concepts with spreadsheets, able to manage the classroom with worksheets that carefully guide students toward gaining the mathematical and spreadsheet ideas.

- **Advancing**: Willingly considers using spreadsheets in a variety of ways in building concepts - encourages student hands-on explorations and experimentation, incorporates spreadsheets in student assessment.

Table 2 describes the teachers' progress with TPCK at two points of the study to date: (1) at the end of the summer session and (2) at the end of the fall term.

Table 2: Teachers' Developing TPCK

Teacher	End of Summer	End of Fall
Mr. Taylor	Exploring	Exploring
Ms. Morrison	Exploring	Not observed
Mr. Smith	Exploring	Exploring
Mr. Fletcher	Exploring	Exploring
Ms. Anderson	Adapting	Exploring
Mr. Donald	Adapting	Adapting
Mr. Carson	Adapting	Adapting
Mr. Miller	Accepting	Advancing
Ms. Johnson	Accepting	Not Observed
Mr. Zeer	Recognizing	Not Observed

As previously indicated, a variety of reasons led to an inability to observe three of the teachers during the fall term. Ms. Morrison was unable to gain access to the computer lab until winter term because of the overuse of the lab for testing. Ms. Johnson was only hired as a substitute for this year and did not have an opportunity to explore teaching with technology. However, Mr. Zeer explained that he did not believe that students should use spreadsheets in learning mathematics and that they needed to use the traditional paper/pencil algorithms in learning the concepts. While he himself was able to use spreadsheets to explore mathematics problems, he did not believe that students learned mathematics when using such tools. Despite the course credit expectations requiring the implementation of teaching with spreadsheets, Mr. Zeer was not convinced that the experiences were consistent with how the students needed to learn mathematics. Thus, his personal beliefs restricted him from complying with the requirements for passing the course.

The teachers who were observed described additional barriers that impacted their implementation of their plans to teach with technology:

- Difficulty with handling students with access to hands-on use of technology;
- Lack of school support;
- Lack of access to technology;
- Technical requirements when incorporating technology;
- Lack of preparation;
- New mathematics curricula.

Alternatively, the teachers who were able to further develop their TPCK through their classroom work fall term (Mr. Smith and Mr. Miller), suggested that the following situations supported their improvement:

- School support and encouragement from others such as the principal;
- Access to computer labs;

- More practice working with students and working with the technology in mathematical lessons.

F. Implications and Significance of the Study

This study analyzed the results of a specific professional development program focusing on the development of mathematics teachers' development of a TPCK for integrating students' learning of mathematics while also learning about spreadsheets as technology tools and as tools that supported learning mathematics. The significance of the study was twofold: (1) the identification of potential key attributes of a professional development program aimed at the development of TPCK and (2) the identification of a model for describing and discussing the teachers' TPCK development.

Professional development programs with respect to preparing experienced teachers to teach with technology are highly varied and often limited. While many focus on teaching the teachers to use technology, few extend that work to provide the teachers with important experiences in preparing to teach their subject matter. The program for this study was based on the recognition that teachers need experiences in learning their subject with the technology, they need experiences that model teaching their subject with the technology, they need experiences in practice teaching and reflecting on the instructional experiences, and they need support as they begin to implement the ideas in their own classrooms. Equally important, this program was focused on more than just the development of *declarative and procedural* knowledge aspects; the schematic and strategic knowledge aspects were emphasized through the scaffolding of lessons directed toward real-world problem solutions with spreadsheets. The teachers were guided in developing a broad TPCK knowledgebase. For these reasons, this program incorporated more than a four-week summer session focused on the development of the teachers' TPCK rather than only on their gaining knowledge about spreadsheet technology. The teachers were expected to demonstrate specific real-life mathematical problems that required the use of the mathematical ideas. And, as recommended by Feist (2003), the program followed the teachers into their school sites, to continue their work beyond the summer session. As the teachers indicated during the Fall observation period, multiple barriers were encountered as they planned to teach in their school sites. Without the requirement for the observations, the barriers would probably result in the cancellation of plans to teach with the technology. The course obligation provided an important incentive for following through with the plans.

The summer session program included several attributes that were identified as supporting the teachers' efforts during the Fall observation period. Modeling was an important instructional strategy in the program that engaged the teachers in teaching mathematics with spreadsheets as tools and demonstrated the idea of scaffolding learning about spreadsheets when focused on learning mathematics. Several teachers noted the value of these models as they designed their own work. Opportunities to practice teach also provided the teachers with important opportunities to test out their plans, experience responding to student questions, and reflect on ways to improve the instruction. While these experiences were less rigid with respect to classroom management expectations, the

teachers noted the value of focusing on the integration of spreadsheets with learning mathematics and the practice in scaffolding student development. Thus, the teachers were able to focus their reflections on that aspect of the teaching, rather than the more global concern of classroom management.

The expectations of the summer session directed the teachers in thinking about mathematics content given the capabilities of spreadsheets as tools for exploration and were focused toward preparing to teach students during the summer session. The teachers had little if any understanding of how to incorporate spreadsheets in their curriculum and instruction. Their mathematics textbooks provided some ideas for teaching mathematics with spreadsheets; however, these ideas were primarily relegated to the sidebars as applications of the concepts rather than using spreadsheets as tools for learning the mathematical concepts. The teachers were expected to collect resources that could provide some direction for identifying the spreadsheet skills needed for the application or how to guide students in learning those skills. While the models were useful along with the collection of the resources, as the teachers prepared for their own classes, they did struggle trying to find the "correct" content for teaching about the various spreadsheet capabilities. As a result, in at least one case, Ms. Anderson prepared a more generic lesson about spreadsheet cells, rather than encasing the lesson in a mathematics problem. Clearly, teachers need help in learning to integrate spreadsheets with learning mathematics. This result suggests that the follow-up support during the school year might be more effective if teachers are able to share their ideas with each other, perhaps through incorporating an online bulletin board.

The integration of learning spreadsheet skills with mathematics demonstrated in this study specifically embraced the development of important teacher knowledge for teaching in today's schools - technology pedagogical content knowledge. Through extensive data collection and observation of the teachers teaching in their own classrooms, the researchers developed a preliminary model for describing and discussing the teachers' progress in implementing their new knowledge about planning and teaching with technology – their developing TPCK. The model allows for teachers whose beliefs about how and what to teach are counter to an integration of technology such as a spreadsheet for exploring mathematics. Mr. Zeer's beliefs and often contradictory views about teaching with technology kept him from implementing the use of spreadsheets even though he *recognized* that spreadsheets were useful in displaying mathematical ideas. Yet, he was unwilling to consider integrating spreadsheets in teaching mathematics at the middle school level because of his beliefs; he believed that they needed to be able to solve problems and complete computations using paper and pencil. The teachers identified at the *exploring* level had developed a TPCK where they were willing to explore the spreadsheet as a tool for investigating mathematical content. This level identified an acceptance stage with the potential for moving to the *advancing* level, where the teacher's thinking is consistently open to the technology as an acceptable mathematical tool. At this advancing level, the teachers willingly accept the use of spreadsheets as a tool for exploring mathematics and accept a new view on what and how mathematics need to be known and learned.

In essence, then, the model presented from this study initiates a mechanism for describing and discussing inservice teachers' developing TPCK with respect to integrating spreadsheets as a tool for learning mathematics. As more and more

technologies become available for teaching and learning mathematics, the model will benefit from an extended description and clarification. Certainly many questions will evolve about what mathematics students should be learning, how that mathematics should be taught, and what preparation mathematics teachers need to have in order to teach mathematics with technology. Perhaps many of the currently accepted paper and pencil mathematics procedures will give way to the use of various technologies to accomplish the same results. In all likelihood, what teachers learn may not be what they will be expected to teach; their TPCK will necessarily be a knowledge that supports them in learning how capabilities of technology change what and how students learn mathematics.

The notion of TPCK with respect to technology integration in teaching and learning is in its infancy that will mature as technology capabilities are developed and linked with teaching and learning. The establishment of a beginning model that helps teacher educators in describing and discussing levels of TPCK development provides an important step for working with inservice teachers in a variety of subject areas with a variety of technologies. Important questions are exposed through the development of this model, including:

- What is the role of school administration in alleviating the barriers to technology use in mathematics classrooms?
- How robust or persistent anti-technology beliefs are among mathematics teachers in school environments where administrations are supportive of the overall reform movement?
- With respect to the development of teacher's TPCK, what is the impact of the teacher's beliefs about their content?
- What experiences do teachers need in order to encourage their students' explorations in learning and teaching with technology?
- What support mechanisms do teachers need to seek and evoke in their interaction with students in an atmosphere of teaching with technology?

Additional questions will certainly be asked with continued research as technologies evolve and provide capabilities with the potential for thinking and understanding multiple subject areas.

References

Borko, H. & Livingston, C. (1989). Cognition and improvisation: Differences in mathematics instruction by expert and novice teachers. *American Educational Research Journal,* 26(4), 473-498.

Borko, H. & Putnam, T. (1996). Learning to teach. In D. C. Berliner, & R. C. Calfee (Eds.), *Handbook of educational psychology* (pp. 673-708). New York, NY: Simon & Schuster Macmillan.

Feist, L. (2003, June). Removing barriers to professional development. *T.H.E. Journal Online Technological Horizons in Education*, Retrieved June 6, 2005, from http://www.thejournal.com/magazine/vault/articleprintversion.cfm?aid=4442

Grossman, P. L. (1989). A study in contrast: Sources of pedagogical content knowledge for secondary English. *Journal of Teachers Education, 40*(5), 24-31.

Grossman, P. L. (1991). Overcoming the apprenticeship of observation in teacher education coursework. *Teaching and Teacher Education, 7*, 245-257.

Horizon Research, Inc. (2000). *Inside the classroom: Teacher interview protocol*. Retrieved March 14, 2006 from http:// www.horizon-research.com/instruments/clas/interview.pdf

Leinhardt, G. (1989). Math lessons: A contrast of novice and expert competence. *Journal for Research in Mathematics Education,* 21, 372-387.

Livingston, C., & Borko, H. (1990). High school mathematics review lessons: Expert-novice distinction. *Journal for Research in Mathematics Education 41*(3), p. 3-11.

Margerum-Leys, J. & Marx, R. W. (2004). The nature and sharing of teacher knowledge of technology in a student teachers/mentor teacher pair. *Journal of Teacher Education,* 55(5), 421-437.

Mishra, P. & Koehler, M.J. (2006). Technological pedagogical content knowledge: A framework for integrating technology in teacher knowledge. *Teachers College Record,* 108(6), 1017-1054.

National Council of Teachers of Mathematics (2000). *Principles and standards for school mathematics*, Reston, VA: NCTM.

Niess, M. L. (2005). Preparing teachers to teach science and mathematics with technology: Developing a technology pedagogical content knowledge. *Teaching and Teacher Education,* 21(5), 509-523.

Niess, M. L. (2005). Scaffolding math learning with spreadsheets, *Learning and Leading with Technology,* 32(5), 24-25, 48.

Pierson, M. E. (2001). Technology integration practices as function of pedagogical expertise. *Journal of Research on Computing in Education,* 33(4), 413-429.

Pilburn, M., Swanda, D., Falconer, K. Turley, J. Benford, R., Bloom, I. (2000). *Reformed Teaching Observation Protocol (RTOP)*. Arizona Collaborative for Excellence in Preparation of Teachers (ACEPT) in support from NSF IN-003.

Rogers, E. (1995). *Diffusion of innovations.* New York, NY: The Free Press of Simon & Schuster Inc.

Shavelson, R. Ruiz-Primo, A. Li, M, & Ayala, C. (August 2003). Evaluating new approaches to assessing learning (CSE Report 604). Los Angeles, CA: University of California, National Center for Research on Evaluation.

Shreiter, B & Ammon, P. (1989). *Teachers' thinking and their use of reading contracts.* Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco.

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review,* 57(1), 1-22.

Westerman, D. A. (1992). Expert and novice teacher decision making. *Journal of Teacher Education,* 42(4), 292-305.

Acknowledgements

Note: This work is partially supported by the National Science Foundation under the grant IRT-0324273 and by the EUSES Consortium (http://eecs.oregonstate.edu/EUSES/).

APPENDIX A

Daily Journal Prompts

These prompts were distributed throughout the four-week summer program to match the work that was to be accomplished during the day:

1. From your own perspective, what is the value of teaching mathematics with technology?
2. What are the barriers you envision for integrating spreadsheets as a tool for learning in the mathematics class?
3. From your perspective at this time, what might be the role for spreadsheets in your mathematics classroom?
4. How do you propose to use spreadsheets to engage your students in learning mathematics in your classroom?
5. How do you envision using error-checking devices (such as the prototypes you have been introduced to in class) for helping students understand mathematics?
6. What are some challenges when planning to incorporate the spreadsheet prototypes in lessons focused on teaching mathematics?
7. How did you get your ideas for the lessons you will do in peer teaching?
8. Why do you think the math content you plan to teach (in peer teaching) will benefit by the use of spreadsheets as a tool for learning?
9. What features of spreadsheets do you think students will incorporate in solving mathematics problems?
10. What points would you make with your principal to encourage the addition of spreadsheets as tools for mathematics learning in your school?
11. Now that you have worked with students, how might the prototypes be useful in guiding student learning of mathematics with spreadsheets?
12. How do you see the use of spreadsheets in mathematics useful for enhancing students' reasoning skills?
13. How has your initial view of the value of spreadsheets as tools for mathematics changes now that you have had a chance to use them as teaching tools?
14. What are your concerns about teaching mathematics with spreadsheets?
15. What helped you the most in this course in preparing to integrate spreadsheets when teaching mathematics?

APPENDIX B

Pre Observation Interview Protocol

1. Please tell us your students' grade levels and ability levels.
2. What should students know prior in order to be prepared for the work in this lesson?
3. What is the purpose of the lesson? What are your primary mathematics goals/objectives for students in this lesson? What are your goals/objectives for spreadsheets?
4. Would you tell us the sequence of the lesson?
5. What encouraged you to select this topics or concept for integration of spreadsheets?
6. Are spreadsheets used in the lesson your own creation, or obtained from another source(s)?
7. What ideas and exercises do you think about or prepare for teaching with spreadsheet?
8. How have you been prepared for using spreadsheet in teaching?
9. Have you taught the lesson before? If you have, did you make any changes? If so, what kind of changes did you make?
10. With the amount of math content you currently have to teach to your students each year, how often do you think it is feasible for you to incorporate spreadsheets in your lessons?
11. How did the incorporation of spreadsheet affect your preparation for the lesson? (Did you prepare differently?)
12. Do you think the integration of spreadsheets with learning mathematics is a good idea? Why or why not?

APPENDIX C

Post-Observation Interview Protocol

Planning and preparation

1. How did your planning for teaching this lesson change? Did you feel prepared to teach this lesson with spreadsheets?
2. For this lesson, how did you redesign your years' plans for teaching this lesson/unit? Why did you make the changes?

Expectations in your plans

3. What were your reasons for incorporating spreadsheets in this lesson (other than the expectation of our program)?
4. What did you expect that students learned about spreadsheets in this lesson? Was this expectation met?
5. What did you expect that students learned about mathematics in this lesson? Was this expectation met?

During the lesson

6. What aspects of your teaching of the mathematics topic with spreadsheets went well and supported student learning? Please explain.
7. What aspects of your teaching needed improvement?
8. How comfortable are you with using spreadsheets in teaching mathematics?
9. What unexpected events happened when teaching this lesson with spreadsheets?
10. What were the difficulties in guiding students to use spreadsheets with this mathematics lesson?
11. Describe the student attention in this lesson? Were they engaged? Did they act differently than in regular lessons?
12. What did the students say about learning with spreadsheets in this mathematics lesson? (Attitude, learning, motivation, understanding)
13. How did you integrate the spreadsheet - as a research tool? A problem-solving and decision-making tool? A communication tool? Some other reason?

Post-review of teaching

14. Did your students learn the mathematics topic in this lesson? Was it the same as teaching without the use of spreadsheets?
15. Do you think the students' conceptual understanding of the mathematics focus of the lesson was improved with the integration of spreadsheets? Please explain
16. Did the integration of spreadsheets overcome the mathematics expectations? If so can you describe what happened? If not, how did it support the mathematics expectations?

17. Have you taught this lesson before? How did you teach it before incorporating spreadsheets
18. Was the integration of the spreadsheet perspective helpful in teaching the mathematics in this lesson or did you incorporate the spreadsheet in preparation for future lessons?
19. Will you teach other mathematics concepts using spreadsheets? If so which? If not why not?
20. What of the summer professional development program prepared you to teach this content with spreadsheets?
21. Do you think that more technology-oriented professional development programs are needed to improve your teaching of mathematics with spreadsheets?
22. After teaching this lesson, what preparation do you think you need to do for another lesson that integrates spreadsheets as tools for learning?
23. Do you think the integration of spreadsheets with learning mathematics is a good idea? Why or why not?
24. What are your future ideas for integrating spreadsheet learning with learning mathematics?

APPENDIX D

Observation Checklist

Comprehension: ___ Purposes ___ Ideas within and outside the mathematics ___ Meeting the standard (National Council of Teachers of Mathematics [NCTM], 2000) ___ Meeting the technology standard ___ Meeting the State/district Math assessment ___ Mathematical concepts in the lesson ___ Connections with other content disciplines ___ Basic knowledge and skill of spreadsheet	
Transformation: ___ Preparation of the given text or material ___ Preparation of technology being selected ___ Representation of the ideas in the form of analogies, metaphors and hands on activities ___ Instructional selections from among an array of teaching methods and models ___ Technology selections from among appropriate choice of availability ___ Adaptation to the characteristics and levels of the students ___ Indicate students misconceptions ___ Tailoring the adaptations to the specific students in the classroom	
Instruction: (Rate: 1: deficient, 2: acceptable, 3: outstanding) ___ Management ___ Presentations of the lesson ___ Encourage generation conjectures, alternative solution strategies, and/or different ways of interpreting evidence ___ Use divergent questions ___ Communicate easily by using spreadsheet ___ Using spreadsheet to trigger students' idea	

___ Motivate students' learning ___ Use students' experience ___ Use real world situation ___ Accept various students' ideas ___ Engagement ___ Respect students' idea, questions, and contributions ___ Interactions through technology ___ Teacher and students ___ Students and students ___ Group work with technology ___ Individuals ___ Pairs/small groups ___ Whole group work ___ Humor in teaching with technology ___ Questioning that involves the use of technology	
Technology: Using spreadsheet ___ Involvement: How often the teacher use the following: ___ Graph (what kind) ___ _____ ___ Format worksheet ___ Trouble shooting ___ Web connection ___ Formulas and math function ___ Dynamic models ___ Other properties ___ Appropriateness of students' mathematical learning	
Evaluation ___ Checks student understanding ___ **Reflection**: Checks his or her own teaching ___ **Improve comprehensions**: Develops and improves plans for future teaching with spreadsheets	

General Notes