

## Developing Teachers' Technological Pedagogical Content Knowledge (TPCK) with Spreadsheets

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Spreadsheets offer a technology readily available among classroom technologies with the potential for supporting students in meeting higher-level content objectives in both the mathematics and science curricula. In particular, student development of dynamic spreadsheets supports them in learning important science/mathematics by exploring problems beyond their initial solution. Unfortunately, spreadsheet use is limited or even nonexistent in most science/mathematics classrooms primarily because teachers have not been prepared to integrate them as teaching and learning tools. Teachers need actual experiences in developing their own knowledge and skills of spreadsheets as tools for exploring and learning science/mathematics; they need support in identifying problems and scaffolding activities that can be integrated in their specific curricula; they need guidance and training in assessing technology-based learning among their students; and, they need support in creating spreadsheet experiences that expand avenues for their students to enhance their learning of science and mathematics.

Reality suggests that teachers must rely on summer workshops for intensive instruction directed toward developing their TPCK. Yet, an experience in a summer workshop does not result in teachers who either have TPCK or who do not. From prior professional development program research, Niess et al. (2006) identified and described five increasing ability TPCK levels for teaching with spreadsheets:

- *Recognition*: The teacher considers spreadsheets as tools for teaching and learning their content.
- *Accepting*: The teacher accepts the idea of teaching and learning their content with spreadsheets.
- *Adapting*: The teacher adapts experiences with learning about the technology within their curriculum for teaching and learning with spreadsheet.
- *Exploring*: The teacher actively investigates and explores the curriculum, trying new ideas for teaching and learning their curricula with spreadsheets.
- *Advancing*: The teacher advances the curriculum integrating learning with and about spreadsheets as learning tools where appropriate, evaluating their students' knowledge of mathematics within a spreadsheet context.

While the first two levels point toward teachers who are considering teaching with spreadsheets, the other three levels identify teachers who actually act upon their thoughts, testing and reflecting on their developing TPCK knowledge and skills about teaching science or mathematics with spreadsheets.

## A. Objectives

Professional development programs are challenged with the goal of preparing inservice teachers for teaching from an integrated knowledge structure of teaching science and mathematics with technology. This challenge involves guiding the development of teachers' knowledge and skills for teaching with technology – a knowledge that is described by the intersection of their knowledge of content with knowledge of technology and knowledge of teaching and learning; these teachers need programs that help them develop a 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, 2002; Mirsha & Koehler, 2006; Author, 2005; Pierson, 2001). The question becomes: How can inservice teacher preparation programs guide teachers' development of a TPCK that prepares them to establish a classroom environment where spreadsheets have the potential to significantly impact and improve learning in classrooms? In consideration of this question, this study created a professional development program focused on preparing science and mathematics teachers to scaffold student construction of knowledge and skills with dynamic spreadsheets integrated in their specific content curricula. More directly, this study was framed by these questions:

1. What features of the professional development program impact teachers' development beyond a *recognition* TPCK level with respect to integrating dynamic spreadsheets as tools for learning in their classrooms?
2. What are the effects of the professional development program on the development of teachers' planning to scaffold their students' learning with dynamic spreadsheets?
3. What is the impact of the professional development program on teachers' engagement of students in their own classrooms with dynamic spreadsheets as learning tools?

## B. Theoretical Perspective

Extending Grossman's four central components of PCK (Grossman, 1989, 1990) to incorporate technology (i.e., TPCK) (Niess, 2005) provides a framework for the design of the professional development experienced teachers need: Based on research both with preservice (Niess, 2005) and in-service (Niess et al., 2006) mathematics teachers, Niess further clarified these central components of TPCK as the knowledge and beliefs that a mathematics/science teacher demonstrates that is consistent with:

1. An overarching conception about the purposes for incorporating technology in teaching mathematics/science.
  - This conception is what the teacher knows and believes about the nature of mathematics, what is important for students to learn, and how technology supports learning mathematics/science. These foundations of the teacher's knowledge and beliefs about teaching mathematics/science with technology serve as a basis for their decisions about classroom instruction (objective,

- strategies, assignments, curriculum and text, and evaluation of student learning).
2. Knowledge of students' understandings, thinking, and learning in mathematics/science with technology.
    - In this area, the teacher relies on and operates from knowledge about how students learn mathematics/science with technologies and believes that technologies are useful in learning appropriate mathematics/science.
  3. Knowledge of curriculum and curricular materials that integrate technology in learning and teaching mathematics/science.
    - With respect to the curriculum, the teacher discusses and implements various technologies available for teaching particular topics and how the topics and ideas in a technology-enhanced environment with concern for how the activities are organized, scaffolded, structured, and assessed throughout the curriculum.
  4. Knowledge of instructional strategies and representations for teaching and learning mathematics/science with technologies.
    - With respect to teaching and learning, the teacher adapts mathematical/scientific representations with technologies in multiple ways to meet specific instructional goals and the needs of the breadth of learners in the class.

With this perspective, the professional development of science/mathematics teachers must guide the development of their knowledge and thinking in a manner that considers the knowledge required for scaffolding student learning of the content as they also learn about the technology. The professional development must challenge experienced teachers to reconsider their subject matter content and to develop their knowledge of the technology along with its impact on the comprehension of the subject itself as well as on teaching and learning the subject. But this attention must also 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) have argued that teachers' adaptation of new instructional practices is a process of assimilation and accommodation that results in changes in their thinking. This perspective suggests that the professional development programs must provide numerous experiences to engage the experienced teachers in investigating, thinking, planning, practicing and reflecting on their learning and teaching. Numerous studies have yielded consistent findings on differences in the thoughts and instructional practices of experienced versus novice teachers (Borko & Livingston, 1989; Leinhardt, 1989; Livingston & Borko, 1990; Westerman, 1992). With respect to the development of TPCK, even experienced science/mathematics teachers are novices with respect to integrating technology in teaching their subject matter. From a constructivist perspective, their actions largely grow from an understanding based on having been taught science/mathematics without the use of technology; they need a professional development program that provides experiences and instructional practices that encourage and allow their beliefs, knowledge and thinking to mature - a TPCK. In

essence then, professional development that aims at guiding experienced teachers in developing TPACK must include active learning - not only about the technology but also about teaching and learning science/mathematics with the technology. The program must provide the follow-up support to assist the teachers in implementing their instructional plans while dealing with school-based barriers to technology implementation, and in adapting their curriculum and instructional strategies to guide student learning of mathematics/science with technologies such as spreadsheets (Brzycki & Dudt, 2005; Feist, 2003).

### **C. Methodology**

This professional development program for the science and mathematics teachers was framed around preparing them to teach their content with the aid of dynamic spreadsheets as learning tools. The program began with a 30-instructional hour workshop over one week (3 graduate credits) that was followed by a field practicum (2 graduate credits) for followed the teachers to their teaching assignment. Six mathematics teachers (4 from grades 6-8, 1 high school, and 1 community college) and five science teachers (2 middle school and 3 high school) were supported through an NSF grant for their participation in the program. The program emphasized helping teachers develop their TPACK, along with guiding them in identifying and preparing to consistently integrate spreadsheet instruction in their teaching. Another related issue of interest in the design of the program had been the adoption of an instructional approach that scaffolded learning experiences about spreadsheets while also attending to both instructional and assessment strategies in their planning. The instruction began with activities for developing skills and abilities to design dynamics spreadsheets. Teachers were engaged in these interactive, hands-on activities based within learning science and mathematics concepts while also experiencing important instructional modeling of effective strategies for integrating spreadsheets as learning tools. Previous research (Niess, et al., 2006) in preparing teachers to teach with spreadsheets highlighted that a significant barrier affecting a teachers' capacities for integrating spreadsheets in the curriculum was the difficulty in identifying appropriate topics and content in their own curriculum. Therefore, the program engaged the teachers in collaborative investigations of their science or mathematic curriculum (with teams formed by content (science/mathematics) and further by grades levels (middle or high school/community college) with the expectation that they plan their content area curriculum to support students in building their knowledge and skills with spreadsheets concurrently with their science/mathematics knowledge and skills. The final expectation in the program was that each teacher would personalize the developed plans for the students they would be teaching during the subsequent school year. The second phase of the program involved following the teachers to their classrooms during the school year where they were expected to design and integrate dynamic spreadsheets in their curriculum. A minimum of two extended plans, videos or audios of instruction, pre- and post lesson interviews, and reflections of the teachers on their learning and teaching effects of integrating spreadsheets over the school year will provide a means to assess and document their developing TPACK for teaching with spreadsheets.

At the end of each stage of the program, teachers' TPCK was assessed to determine their level of TPCK (Recognizing, Accepting, Adapting, Exploring, Advancing). More importantly, the in depth case descriptions provided detail for more carefully delineating each level of TPCK.

#### **D. Data Sources**

Multiple data sources were used to gather information throughout the program. Pre- and post-questionnaires and attitude inventories, daily journal prompts, assignments (resource cards, lesson plans for teaching students) were used to describe each teacher's developing TPCK during the summer program; observations and interviews of teachers prior to and after teaching with spreadsheets provided a view of their TPCK as they taught. An interview protocol was used to gather teachers' reflections both before and after teaching their plans. Interviews gathered data on their planning and preparation for the lessons, their goals and objectives for the lessons, details about their work during the lessons including classroom management of students with the technology, reflections on student learning in the lesson, the use of spreadsheets as a learning tool for students, the impact of the professional development in their planning and implementation of their plans.

#### **E. Results**

The teachers' development of TPCK was observed throughout the professional development program. All of the teachers demonstrated a strong pedagogical content knowledge (PCK) prior to the summer program in that they had clear conceptions for strategies for motivating and encouraging students to think and learn about the subject matter content. However, for all of the teachers, their TPCK was at best described as 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 operation, rather than an integration of spreadsheets with teaching and learning science/mathematics.

By the end of the summer session, the teachers were able to describe and discuss scaffolding ideas for developing spreadsheet skills in science/mathematics lessons. They recognized advantages of using spreadsheets for solving complicated problems, motivating students, and providing opportunities for students to extend problems to additional hypothetical situations. Their plans for teaching with spreadsheets were sketchy, much like novice planning despite their strength in PCK. While some of them clearly had strong content knowledge of spreadsheets, they were still developing their knowledge of teaching science/mathematics with spreadsheets. Of the 11 teachers in the program, 6 were assessed at the *exploring* TPCK level, 4 at the *accepting* TPCK level, and 1 at the *recognition* level.

The multiple teaching requirements in their own classrooms supported the teachers in improving their teaching with spreadsheets. Observations of their teaching during the school year along with the extensive interviews before and after teaching identified that

their TPACK level was affected by the school-based barriers of time, infrastructure, and culture. With their inexperience with teaching with spreadsheets, they were reluctant to gather and explore student ideas while working with spreadsheets with the students, because those ideas redirected the lessons to areas in which they were unsure; they preferred to give answers rather than guide student thinking. They demonstrated their novice abilities in working with spreadsheets as they failed to notice advancements in student thinking. In essence they demonstrated comfort with the subject matter and their own work with the spreadsheet but they preferred to direct the lessons when spreadsheets were integrated. As the teachers provided their students with more opportunities for learning science/mathematics with spreadsheets, they demonstrated a shift toward a more student-centered instruction that allowed student exploration and scaffolding of student learning with spreadsheets.

The TPACK levels for all teachers in the programs were identified using the five levels proposed through the research by Niess, et al. (2006). Individual, in-depth descriptions for all teachers were developed, identifying their content area knowledge, beliefs and dispositions, teaching preparation and implementations, their instructional strategies, their thinking before, during, and after teaching with spreadsheets, and their knowledge of student thinking and learning with specific technologies. The TPACK lens that Niess (2005) used in extending Grossman's central components of PCK was used for framing the extended descriptions developed through triangulation of the data and analyzed by TPACK level. These extended descriptions are provided only as examples to frame the levels rather than as check-off items for the particular levels.

#### *1. Recognizing*

- Recognizes mathematics/science ideas displayed with the technology.
- Views technology activities as focused on learning about the technology within a mathematics/science context as a tool that does the mathematics /science rather than teaching the mathematics/science.
- Knowledge and beliefs about learning and teaching mathematics/science describes mathematics/science as a subject learned through memorization of rules, algorithms and procedures without the use of technologies.
- Retains fundamental beliefs about how students learn mathematics/science.
- Motivation for exploring, experimenting and practicing integrating technologies in learning mathematics/science is challenged by beliefs about how students learn mathematics/science.
- Resists consideration of changes in the curriculum to integrate technology without further investigation about the technology.
- Instructional strategies for teaching mathematics/science based on teacher-directed lectures followed by individual student practice and repetition to solidify ideas.

#### **Teacher comment:**

*The idea of organizing the information to help them solve math problems is a key to helping students learn math. Another feature that is difficult to learn in its intricacies but easy to start with is graphing. The graphical representation of spreadsheet data is very helpful especially for the visual*

*learners in the class... I can see a student using spreadsheet skills to help them solve a mathematical problem if they already understand the underlying mathematical concepts. But I can see only limited, observational understanding being developed through their use.*

*Spreadsheets will allow me to teach concepts using much larger data sets than doing analysis by hand. This allows for better results from experiments and more possibility of problems relating to 'the real world*

## 2. *Accepting*

- Accepts the idea that some technologies can be useful tools for teaching and learning mathematics/science.
- Concerns about:
  - Students' attention to and learning appropriate mathematics/science being diverted to a focus on the technology in the activities
  - Students' thinking in mathematics/science when the technology is used as a tool for exploring the mathematics/science
  - Technology classroom access and management
  - The need to teach about the technology as taking away time for teaching mathematics/science
- Mimics mathematics/science curricular ideas for incorporating the technologies that were experienced in the professional development.
- More apt to accept the technology as a teaching tool than a learning tool.
- Expresses desire but demonstrates difficulty in identifying topics in own curriculum for including technology as a tool.
- Tightly manages and orchestrates instruction with technology with the focus on technology in first lesson and the focus on mathematics/science in subsequent lessons after students have sufficient knowledge and skill with the technology.

### **Teacher comment:**

*My overall impression of using the spreadsheets in lessons and trying to integrate them with the mathematical concepts is that the students have a very difficult time learning the mathematical concepts when they are attempting to learn about using spreadsheets at the same time. The mechanics of producing the spreadsheets overshadows the mathematical concepts for many of the students. The only ones which seemed successful mastering both were the students that were fairly competent with spreadsheets prior to using them in my class.*

*I think students can use the graphing abilities of Excel to solve science problems quite easily. It is relatively easy to learn how to turn raw data from the spreadsheet into graphs. This seems to result in students feeling successful and engaging them better than graphing on paper*

## 3. *Adapting*

- Recognizes some benefits of incorporating technology as a tool for teaching and learning the mathematics/science curriculum.
- Discusses desire to explore, experiment and practice integrating technologies as mathematics/science learning and teaching tools.
- Considers the technology as a tool to enhance a mathematics/science lesson, primarily as a means of providing students with a new way to approach the mathematics/science.
- Thinks of the technology as enhancing mathematics/science ideas that students have previously learned prior to using the technology.
- Expresses questions about student thinking with the technology as a tool in learning mathematics/science.
- Mimics the professional development activities with the technologies but does attempt to adapt lessons for his/her mathematics/science classes.
- Actions for implementing technologies in teaching mathematics/science are restricted by the challenges/barriers for teaching/learning with technologies.
- Instructional strategies with technologies are primarily deductive, teacher-directed in order to maintain control of the how the activity progresses.

**Teachers' comments:**

*Overall, I thought the experience of using Excel for teaching math concepts was worthwhile, both for myself as a teacher and for the students. They were able to see the math concepts we were working on applied in a real problem-solving environment, they felt successful when they applied those concepts in a spreadsheet and got a physical result (immediate feedback), and I was able to monitor their progress at a glance, which is not always obvious when they are working with pencil and paper.*

*The number one barrier I envision would be my own limited abilities in using spreadsheets. While I am teaching the students to use spreadsheets, I will also be learning as I go. Over time as I become more familiar with the programs this won't be as much of a problem.*

*4. Exploring*

- Motivated to explore, experiment and practice integrating technologies as mathematics/science learning and teaching tools.
- Accepts technologies as tools for learning and teaching specific topics in the mathematics/science curriculum.
- Plans, implements, and reflects on teaching and learning in the implementations with concern for guiding students in understanding mathematics/science using the technology as a tool.
- Recognizes challenges for teaching mathematics/science with technologies but willingly explores strategies and ideas for minimizing the impact of the challenges.
- Explores ideas for placing technology in a more integral role for the development of the mathematics/science that students are learning.

- Tentative willingness to engage students in explorations of mathematics/science with the technology tool where the teacher is in role of guide rather than director of the exploration.
- Explores various instructional strategies (including both deductive and inductive strategies) with technologies to engage students in thinking about the mathematics/science.
- Manages technology-enhanced activities towards directing student engagement in learning the mathematics/science.
- Continues to learn and explore ideas for teaching and learning mathematics/science emphasizing the one technology (such as spreadsheets).

**Teachers' comments:**

*I was somewhat anxious to introduce spreadsheets into my curriculum. It was a new concept for me and I wasn't sure how my students would adapt to it. I was also unsure as to how the marriage of spreadsheets and mathematics would look in my classroom. After the first lesson with my students, I knew I had nothing to worry about. Although none of them had ever used spreadsheets before, most had used the computer before and were very fluent with this technology. By keeping the math skills at a minimum in the beginning, students were able to focus more intently on learning the skills necessary for spreadsheets which later translated into being able to integrate more difficult math concepts with Excel.*

*Even students who had made it very clear that they did not especially enjoy math, found themselves very involved in their learning when spreadsheets were integrated. A second success was seen, as we were able to look more closely at certain topics that required graphing. By being able to quickly change variables that had an immediate effect on the graph, gave students a first-hand look at how each of the parts of the equations play a role. If students had to graph by hand, there would not have been nearly the amount of time and attention given to the changes of variables.*

*Guiding students to learn spreadsheets throughout the year is a challenge given limited computer availability. I think the key in my particular case to not require too much, too fast. My plan to take much smaller steps and provide more scaffolding so as not to turn the students off initially*

**5. Advancing**

- Sustained motivation and carry through in exploring, experimenting and practicing integrating technologies as mathematics/science learning and teaching tools.
- Active, consistent acceptance of technologies as tools for learning and teaching mathematics/science in ways that accurately translate mathematical concepts and processes into forms understandable by students.

- Plans, implements, and reflects on teaching and learning in the implementations with concern and personal conviction for student thinking and understanding of the mathematics/science to be enhanced through integration of the various technologies.
- Recognizes challenges in teaching with technology and resolves the challenges through extended planning and preparation for maximizing the use of available resources and tools.
- Technology-integration is integral (rather than in addition) to development of the mathematics/science students are learning.
- Engages students in high-level thinking activities (such as project-based and problem solving and decision making activities) for learning mathematics/science using the technology as a learning tool.
- Adapts from a breadth of instructional strategies (including both deductive and inductive strategies) with technologies to engage students in thinking about the mathematics/science.
- Manages technology-enhanced activities in ways that maintains student engagement in learning the mathematics/science.
- Continues to learn and explore ideas for teaching and learning mathematics/science with multiple technologies.

**Teachers' comments:**

*I think that many students will feel like they are getting out of doing math by making the computer do it! Little do they know that they actually have to do much higher-level math and higher-level thinking and letting the computer do the basic arithmetic. Also anytime students get to interact with technology, they are engaged. Spreadsheets make students responsible for their learning while keeping them accountable. It's a relatively easy way to engage students in mathematics learning.*

*Another thing that I think worked out well was you know, the tendency for us to give students answers and I've been really trying to watch myself on that, knowing that if I just give answers to somebody, I haven't really had them learn, I've only helped them memorize. So, I had to restrain myself a few times today just giving people the formulas and stuff like that.*

**F. Significance of the Study**

This study focused on the integration of learning science/mathematics with learning about spreadsheets. While textbooks provide some specific ideas for teaching with spreadsheets, the ideas primarily are in sidebars and do not identify the spreadsheet skills along with the particular subject matter content so that teachers are guided in designing the development of lessons to explore both the content and spreadsheets. Since teachers have learned their subject primarily without the use of explorations with dynamic spreadsheets, the professional development focused on identification and exploration of

problems in their specific curricula to provide experiences necessary for developing their TPCK beyond a *recognition* level. The summer program emphasized the notion of scaffolding, using that same strategy to develop the teachers' spreadsheet knowledge while they considered integrating spreadsheets with learning science/mathematics. Of particular note was the teachers' reluctance to allow student exploration with the spreadsheets during their classroom experiences. This reluctance is an indicator of limited experiences in working in classroom situations. Establishing a school culture of mentoring from experienced and successful teachers for the less experienced teachers holds promise in many of the same way mentoring has been demonstrated to help beginning teachers (Zeichner & Tabachnick, 1985). This study identified important professional development program format accompanied by school-based support recommendations to encourage the ongoing development of inservice teachers' TPCK as they plan, teach and assess students' development of scientific/ mathematical ideas incorporating dynamic spreadsheets as learning tools. However, this research also focused on the development of a more in depth understanding of the nature of TPCK as the knowledge mathematics and science teachers need for teaching with spreadsheets.

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