Knowledge Growth in Teaching Mathematics/Science with Spreadsheets: Moving PCK to TPACK through Online Professional Development

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Abstract

Inservice teachers need ways to gain an integrated knowledge of content, pedagogy, and technologies that reflects new ways of teaching and learning in the 21st century. This interpretive study examined inservice K–8 teachers' growth in their pedagogical content knowledge (PCK) toward technology, pedagogy, and content knowledge (TPACK) in an online graduate course designed for integrating dynamic spreadsheets as teaching and learning tools in mathematics and science. With the lens of four TPACK components (Niess, 2005), the analysis describes teachers' development from recognizing *to* accepting, adapting, *and* exploring *TPACK levels. Implications and recommendations for the design of future professional development courses and continuing research are identified to support inservice teachers' knowledge growth for teaching with technologies. (Keywords: Teacher knowledge, spreadsheets, inservice teachers, elementary and middle school, online, professional development)*

More than 20 years ago, Shulman (1986, 1987) proposed the construct of pedagogical content knowledge (PCK) as knowledge teachers need for teaching. This construct recognized that teachers rely on more than content knowledge as they guide students in learning that content. PCK was proposed as an integrated knowledge structure of subject area, knowledge of students, pedagogical knowledge, and knowledge of the environmental context as teachers engaged in planning, teaching, and assessing activities. In response, many teacher educators reconstructed their teacher preparation programs based on research and understanding of the development of PCK (Niess, 2001).

At the time of the recognition of PCK, digital technologies were becoming more powerful and accessible as potential educational learning tools. The assumption was that these technologies were like other educational tools, and the PCK development in these programs provided adequate preparation for the knowledge of teaching with educational tools, including digital technologies. However, evidence abounded that teachers' PCK did not automatically translate to integrating knowledge about teaching and learning with these technologies (Pierson, 2001). Teacher educators were challenged to identify preparation for preservice and inservice teachers to extend their PCK to a more robust knowledge for teaching with technologies.

During the 1990s, spreadsheets emerged as potential tools for learning mathematics and science. Although the designers of spreadsheet programs had not focused on designing educational tools, spreadsheets contain features for modeling situations and analyzing change in various educational contexts. Linking key problem variables to tables and charts presented dynamic environments that afforded opportunities to engage in algebraic reasoning even in elementary grades. With access to multiple data collection devices (probeware to gather temperatures, light intensity, and motions), science classes could provide opportunities for students to engage in scientific inquiry to analyze actual data using spreadsheet capabilities. Spreadsheets, therefore, provide teachers with tools relying on science and mathematics concepts and processes for accurate analysis, thus challenging teachers to revise the mathematics and science curricula to utilize these capabilities. For example, how might the table and charting capabilities available in spreadsheets impact graphical learning in the mathematics curriculum?

Most teachers learned science and mathematics using paper and pencil, which limited the data for exploration and required time to calculate averages and create charts for every change in the variables. Yet teachers are confronted with learning about teaching and learning science and mathematics differently with newer technologies. They need educational opportunities to extend their PCK for teaching science and mathematics to a technology, pedagogy, and content knowledge (TPACK) (Niess, 2008; Thompson & Mishra, 2007) for integrating dynamic spreadsheets as teaching and learning tools.

Inservice teachers are limited in their access to professional development opportunities that they need to develop their TPACK. Online distance education provides a mechanism for meeting teachers' educational needs while actively teaching. As noted by Garrison, Anderson, and Archer (1999), research efforts are needed to understand how worthwhile educational experiences can be optimally designed and delivered through online environments. This interpretive study responded to the challenge of designing online educational experiences to extend elementary teachers' PCK to a more robust knowledge for teaching in the 21st century, TPACK.

Perspectives and Theoretical Framework

Grossman (1989, 1990, 1991) proposed four central components for PCK to focus its description and understanding:

1. An overarching conception of what it means to teach a particular subject
2. Knowledge of instructional strategies and representations for teaching particular topics
3. Knowledge of students' understandings, thinking, and learning in the subject
4. Knowledge of curriculum and curriculum materials with learning in the content areas

Examinations of teachers' PCK since then have revealed that teachers' beliefs about how to teach mathematics and science generally align with how they were taught these subjects (Kastberg & Leatham, 2005; Walen, Williams, & Garner, 2003; Yoder, 2000). As a result, teachers' knowledge of students' understandings, thinking, and learning in mathematics and science has maintained the importance of mastery of skills with paper-and-pencil learning prior to using modern digital technologies. Their curricular knowledge with technologies such as spreadsheets has been limited by lack of availability and access to software and curricular challenges (Harvey & Charnitski, 1998; Haspekian, 2005; NCTM, 2000).

Recognizing the importance of a broader perspective on knowledge teachers need for teaching with technology, researchers focused on the integration of technology, content, and pedagogy in much the same way as Shulman described PCK. They defined TPACK as that body of knowledge that teachers need for teaching with and about technology in their assigned subject areas and grade levels. TPACK has been envisioned as the interconnection and intersection of content, pedagogy, and technology (Mishra & Koehler, 2006; Niess, 2005, 2008; Thompson & Mishra, 2007). To clarify the TPACK construct, Niess (2005) adapted Grossman's four components of PCK to incorporate technology.

Guiding teachers in the development requires attention to these four components of TPACK along with recognition of the challenges presented by new and innovative technologies for educational purposes. Rogers (1995) described a process that innovators make when incorporating such innovations as knowledge, persuasion, decision, implementation, and confirmation. Niess, Sadri, and Lee (2007) drew from Roger's work in framing a model to describe teachers' development of TPACK; their model emanated from three years of extensive observations of inservice science and mathematics teachers learning to use spreadsheets and how to integrate them as learning tools. Five levels describe teachers' development when learning to integrate technologies such as spreadsheets as teaching and learning tools. These levels provide a framework for assessing the impact of a technology-rich program on participants' knowledge and integration of technology in their own classrooms:

1. Recognizing (knowledge): Teachers are able to use spreadsheets and recognize the alignment of spreadsheet capabilities with subject-matter content. Teachers at this level rarely think about incorporating the spreadsheet as a mathematics and science tool and are unwilling to integrate spreadsheets for teaching and learning in their content and at their grade level.
2. Accepting (persuasion): Teachers form favorable or unfavorable attitudes toward teaching and learning content topics at their specific grade levels with spreadsheets. They may try activities they have experienced with their students in the process of forming their attitudes toward acceptance. Teachers at this level practice mathematics or science ideas with spreadsheets, but spreadsheets are not a consistent thought when they think about teaching mathematics or science.
3. Adapting (decision): Teachers engage in activities that lead to a choice to adopt or reject teaching and learning mathematics and science topics with spreadsheets. Teachers at this level try ideas for incorporating spreadsheets in teaching mathematics/science but typically engage students only in low-level cognitive activities (such as drill and practice) with the spreadsheets. They manage the classroom through the use of prepared worksheets to carefully guide students toward the intended ideas.
4. Exploring (implementation): Teachers actively integrate teaching and learning of content topics with spreadsheets where they rephrase and design activities to align with their curriculum. Teachers at this level investigate different ways for teaching the content and are willing to demonstrate new ways of thinking about mathematical/scientific concepts with spreadsheets as learning tools. These teachers allow students to explore spreadsheets and use them as problem-solving tools.
5. Advancing (confirmation): Teachers evaluate the results of the decision to integrate teaching and learning content with spreadsheets and make changes in the curriculum to take advantage of spreadsheet affordances. At this level, they willingly consider using spreadsheets in a variety of ways in building mathematics or science concepts and ideas. They encourage students' hands-on explorations and experimentation and incorporate spreadsheets in student assessment of the content.

The Study

This study explored the impact of an online course on teacher participants' developing knowledge for integrating dynamic spreadsheets in teaching at the elementary and middle school levels. The following questions framed the extension of PCK to TPACK. What is the impact of this online course about integrating dynamic spreadsheets as learning tools in science and mathematics on the teachers' TPACK? Specifically, what is the impact on teachers':

1. Overarching conceptions of what it means to teach the mathematics and science with spreadsheets
2. Knowledge of instructional strategies and representations for teaching particular mathematics and science topics with spreadsheets

3. Knowledge of students' understandings, thinking, and learning in mathematics and science with spreadsheets
4. Knowledge of curriculum and curriculum materials with learning mathematics and science with spreadsheets?

Context of the Study

The researchers conducted this study within the context of a Title IIB Mathematics Science Partnership (MSP) that developed a 3-year online master's degree program focused on the integration of technology with science and mathematics teaching and learning. The design of the program addressed teachers' development of TPACK as an extension of their PCK. Twelve K–8 teachers from a broad geographical region participated in a program framed around the four TPACK components (Niess, 2005). The third course in the program was titled Dynamic Spreadsheets as Learning Tools in Science and Mathematics. The participants ranged in experiences using spreadsheets, but none had participated in education for integrating spreadsheets in teaching, and none had incorporated spreadsheets in their teaching. They were engaged in an active process where they challenged their existing PCK understanding as they considered the integration of dynamic spreadsheets with content and pedagogy.

Throughout the course, the participants were expected to connect all the spreadsheet problems and units with the NETS for Students (NETS-S; ISTE, 2007). The course consisted of four units. The first unit focused on engaging participants in exploring spreadsheet capabilities within specific mathematics and science units and problems at the elementary and middle school levels. This unit challenged participants to consider how spreadsheets might be incorporated in learning the content. In this unit, they were asked to engage in online whole-group discussions in response to prompts such as: How are variables, algebraic reasoning, and dynamic spreadsheets linked? Why is it important to have the variables of the problem visible in a dynamic spreadsheet? The second unit emphasized themes and unit development integrating spreadsheets. The participants identified and discussed the spreadsheets skills in various themes and units as they explored them. The third unit added assessment considerations of students' outcomes when solving mathematics and science problems with spreadsheets. The participants' online, whole-group discussions were focused around identifying and defending objectives and potential rubrics to address the performances and solutions of specific problems. The fourth unit included curriculum planning and scaffolding student learning with spreadsheets. During this unit, the participants each designed their final electronic portfolio project. The online, whole-group discussions were focused around different ideas to consider as they shared their progress with the final portfolios to assist in developing their ideas about teaching mathematics/science with spreadsheets with middle or high school grade-level students. The final portfolio included three sections:

1. Collection of a minimum of 10 spreadsheet problems with accompanying supporting worksheets and scoring rubrics
2. Their plan of how to incorporate these problems in their curriculum and instruction
3. An in-depth reflection on integrating spreadsheets in their instruction along with consideration of student learning with spreadsheets

Data Sources and Analysis

This interpretive case study developed a rich description of participants' knowledge for integrating spreadsheets in teaching science and mathematics. Throughout the data collection, electronic case binders were built for each of the participants in the study. Each participant's binder contained all data in chronological order. The data included (a) one observation of the participant's instruction at the beginning of the program using the Reformed Teaching Observation Protocol (RTOP) (Sawada et al., 2000, 2002); (b) all assignments submitted in the course and the final portfolio that presented ideas, plans, and thinking about engaging students in learning with spreadsheets as algebraic reasoning and modeling tools in mathematics or science; (c) transcripts of the online course discussions organized and aligned with the course assignments; and (d) transcripts of the in-depth interview following the course using a protocol (see Appendix A, pp. 50–51) focused on the participant's understanding of spreadsheets as algebraic reasoning tools, as teaching and learning tools, and his or her TPACK at this point in the program, as delineated by the four research questions.

The researchers analyzed observation data to describe each participant's PCK and TPACK knowledge levels at the beginning of the program. TPACK level descriptions (Niess et al., 2007) provided the lens for identifying the entry-level TPACK knowledge of each participant.

The TPACK level identified for each participant was in alignment with pretest results of the TPACK self-efficacy survey (see Appendix B, p. 52, a project revision of an original survey validated by Riggs and Enochs [1993]). A paired t-test analysis of the pre- and posttests of TPACK self-efficacy provided secondary information about their beliefs and knowledge of integrating technology in science and mathematics before and after the course.

The researchers conducted an analysis of each data set in the case binders using a whole-to-part inductive approach (Erickson, 2006) beginning with a first pass of an entire specific data set in each binder (e.g., assignments, transcripts of interview) recording notes. Subsequent iterative reviews involved stopping, reviewing, and confirming parts that were significant to the four research questions.

The researchers considered each participant's knowledge prior to the spreadsheet course, during the course, and at the end of the course in the development of the individual cases. Qualitative analyses of the case binders were conducted to identify patterns in participants' discussions and plans for integrating dynamic spreadsheets. The cases provided a general description of each participant's growth in viewing the integration of dynamic spreadsheets as learning tools when considering their overarching conception of teaching mathematics and science with spreadsheets, knowledge of instructional strategies, knowledge of students' understandings, and knowledge of curriculum and curriculum materials. Comparisons of the initial description of participants' PCK with the data from the post interviews addressed the four research questions. In-depth descriptions presented teachers' development of TPACK. To increase the validity and reliability of the results, two researchers independently conducted the case-binder analyses and then collaborated to confirm the final determinations of each participant's development of TPACK.

Results

This graduate online course engaged the participants in learning about spreadsheets while examining teaching science and mathematics with spreadsheets. Twelve K–8 teachers in the MSP/master's program participated; four taught grades K–3 in self-contained classrooms, five taught grades 4–5 in self-contained classrooms, and three taught grades 6–8 in subject specific classrooms. Initially, the TPACK levels of all the participants were identified as *recognizing*, based on their acceptance through a competitive application process. Observations of teaching confirmed this level analysis, with virtually no presence or indication of technology integration in any classes. The observations confirmed that these teachers' PCK supported them in teaching at their specific grade levels. They described how the content is learned. They managed their classrooms in ways that engaged the students in learning the ideas. Ten of the teachers exhibited teacher-centered instructional strategies, and two used more student-centered strategies (Sawada et al., 2000, 2002). They identified that students with learning difficulties needed more time, practice, and one-on-one attention. The two teachers incorporating student-centered instructional strategies found student-centered strategies effective in keeping students engaged and interested. All demonstrated competence with the curriculum. Their application to the MSP/master's program confirmed their interest in improving teaching mathematics and science with technology.

After the course, the researchers identified the teachers' TPACK levels based on coursework and interviews. Eight of the teachers were identified at the *accepting* level, two at the *adapting* level, and two were moving into the *exploring* level. A significant positive increase in TPACK self-efficacy beliefs for all of the participants ($p = 0.002$) confirmed these shifts in TPACK levels.

Exploring *TPACK Level*

The two teachers demonstrating growth into the *exploring* TPACK level exhibited student-centered instructional practices prior to participation in the program. Both teachers did not report using technology any more or less than their peers in their personal lives or with students. Artifacts from coursework, interview transcripts, and TPACK survey results suggested that these two teachers quickly implemented and expanded upon ideas for integrating technology and spreadsheet use with students in their classrooms. Both teachers developed a vision of using spreadsheets in teaching at their grade levels. Their final portfolios clearly described resource ideas for their classes and student-centered instructional strategies for engaging students in learning with spreadsheets. Both described students' thinking and learning with spreadsheets.

Mr. Carlson, a first grade teacher, had not used spreadsheets previously. In the interview, when asked about using spreadsheets as a tool, he said:

> I didn't think there was an application for me, you know, as a teacher.… Personally, I was like, oh, I'm sure they do some neat things, but now that I can use them I can see how they can be used in the classroom setting.

With this perception, Mr. Carlson described how he had tried some of the ideas with his students in his first grade class in a charting activity for a make-believe town and collecting money each day in this town:

> The kids had fake stores, and they would make money, and we would count it up, and they would see how it would total up and how the money would change, and they would ask questions about who made the most money, and we'd make graphs. You know, I was doing all the running of the spreadsheet, but they were still seeing and asking questions and using it as a tool … even in this classroom, yeah, in first grade.… I was really excited to see them just asking questions.… They were totally making connections in totaling.

Mrs. Simon was the other teacher identified as moving into the *exploring* level. She was teaching fifth grade in a self-contained classroom with responsibility for all subjects. She used the framework of one of the spreadsheet activities from the online course with her students; however, she adjusted the activity to explore fractions, decimals, and percents. As she noted in her final portfolio:

> I'm probably one of the most enthusiastic students of the integration of spreadsheets as learning tools in science and mathematics instruction that you will ever meet. When I think about all the topics spreadsheets help students convey their understanding with, the possibilities are endless.

Mrs. Simon found value in spreadsheets for modeling science and mathematics problems in interdisciplinary units as a way to provide students with opportunities to ask "what-ifs." She explained:

> For instance, what if you were testing the pendulum on a clock

> and you wanted to see if a heavier weight made a difference? You could set up a spreadsheet to show the change of weights and what that did to the data collected.… You could then go on and change another variable to see if that changes the outcome. By building dynamic spreadsheets, students are able to show their algebraic reasoning and collect data all at the same time.

In her interview, Mrs. Simon expressed a wide variety of issues in thinking about integrating spreadsheets as learning tools:

> Does the use of spreadsheets enhance the learning of the topic? Does the topic enhance the learning of spreadsheets? Do the students know how to use the tools required in a spreadsheet? Does the question students are trying to answer lead to "what-if" questions? Can the information be graphed? Will the student become more confident and engaged by using technology?

These questions suggest that Mrs. Simon had developed a deeply nuanced appreciation of the potential for learning that spreadsheets can provide.

Adapting *TPACK Level*

The major differences between the two teachers at the *adapting* level and their counterparts at the *exploring* level seemed to be their primary instructional styles and the spreadsheet applications they completed with their students. The teachers at the adapting level used primarily teacher-directed strategies with small group activities. As Mrs. Hanover, an eighth grade mathematics teacher, indicated, "I think I'd introduce it first and try to lead them through it and … show them how." These teachers used activities from the course adapted for their students to meet their grade-level and curricular needs.

Mrs. Blair taught mathematics in grades 6–8. Although she used an activity from the course, she identified several mathematical topics where spreadsheets could support students in learning:

> There's a lot of different concepts I can integrate spreadsheets with. I can take away paper and pencil and instead, they can use spreadsheets … linear relationships … measures of center.

Mrs. Hanover implemented a linear relationships activity from the online course:

> When I'd look at the book, I'm like, 'Why … do I want to be able to create this on a spreadsheet?' It didn't give me the next step … or show me how it was applicable to … the problems that we were just doing out … longhand.

As she considered possible topics for using spreadsheets, she indicated her reliance on the experiences she had gained in the course:

> A lot of the problems that I've done, I didn't realize … you could involve spreadsheets in. Like, we've covered applications, just like probabilities, and percents, and all these different things in class … all this stuff, this linear relationship, I could've done … with this too and I could've shown them that. And then when the kids had to create the graph to show which plane was the fastest, we could've used a spreadsheet for that! And we didn't even realize that.

Teachers at the *adapting* level exhibited a more cautious outlook on trying ideas with their students. As Mrs. Blair indicated in her interview:

> I'd want it to not use the technology just for the technology's sake. But that it seamlessly makes them see that in the curriculum. So if we're doing work on our linear relationships and it makes sense to use Excel in problems.… So that it can be technology as a tool to teach whatever concepts I'm teaching, not that it's in addition to teaching the concept.

Mrs. Blair seemed to understand that she could use spreadsheets as a tool for teaching, although she had not yet attempted such use in her own classroom, beyond what she herself had used in the spreadsheet course.

Accepting *TPACK Level*

The teachers at the *accepting* level were more concerned about access to the technology and convincing administrators of the value of integrating spreadsheets in learning. These teachers retained commitment to their observed teacher-directed instructional styles with the idea that students needed this direction with spreadsheets. Their conception was to use spreadsheets for motivation to study specific topics or confirmation of topics already learned. Mrs. Sanderson (a seventh grade science teacher) said, "I would integrate the spreadsheets into science just a couple days out of that unit … kind of re-teach things and add them as we did before." Mrs. Harris (a third grade teacher) indicated:

> If students are using spreadsheets to solve a problem or a similar set of problems that they have solved before, then students will be up for the challenge of designing their very own spreadsheet. I'd have to make sure that they had all the basics down first.

Mrs. Baines (a fifth grade teacher) described using spreadsheets to "reinforce if not enhance" the ideas the students had already learned.

On the whole, teachers at the *accepting* level saw technology in general and spreadsheets in particular as elements of curriculum that are outside of the learning process. They viewed the use of technology as a reward or a treat for adequate performance in a lesson or activity that was more in alignment with their established classroom activities. To these teachers, spreadsheet activities were viewed more as electronic worksheets, where students practiced skills learned with paper and pencil, as opposed to activities where students used spreadsheets as reasoning and learning tools to develop in-depth understanding of underlying concepts. This view of the value of spreadsheets in the classroom was in alignment with their teacher-centered classroom pedagogy, where relinquishing appropriate control of the technology to the students, thus refocusing from teacher to student, was outside of their comfort zone.

Discussion

A cross-case analysis revealed that all 12 teachers valued opportunities to experiment with spreadsheets, during which they learned about the spreadsheets and how they could use spreadsheets to support connections with mathematics and science topics. They indicated that their experiences were fundamental to considering whether spreadsheets were useful in learning science and mathematics. The researchers identified similarities and differences among the teachers at the different TPACK levels through the analysis of the course work and final interviews with respect to the four TPACK components.

Teachers at different TPACK levels held different overarching conceptions about teaching mathematics and science with spreadsheets. At the *accepting* level, teachers held that the content was to be learned first through the traditional methods before adding spreadsheet activities as a fun, related activity. These teachers displayed instrumental (Skemp, 1987) understandings of the content and viewed spreadsheets as interfering with the more rule-bound, procedural, instructional directions they used with their students; as a result, they viewed spreadsheets as more motivational and confirming of ideas. Teachers at the *exploring* level valued spreadsheets for developing conceptual understandings. These teachers appeared to value the development of a more representational (Skemp, 1987) understanding that emphasized the importance of conceptual understandings over a focus on procedural approaches to solving problems.

Teachers displayed differences in their knowledge of instructional strategies and representations for teaching topics with spreadsheets. At the *accepting* level, they relied on teacher-centered strategies and envisioned spreadsheets as motivational tools rather than instructional and cognitive tools. Teachers at the higher TPACK levels used more student-centered strategies, such as organizing students in collaborative groupings to explore problems while helping each other gain spreadsheet skills. These teachers recognized the importance of providing initial instruction about spreadsheets but valued smaller groups in designing spreadsheets solutions to problems.

Teachers held differing views on students' understandings, thinking, and learning with spreadsheets. Teachers at the *adapting* and *exploring* levels had actually tried activities with their students and identified how those experiences provided students with stronger conceptual understandings.

The teachers demonstrated different knowledge of the curriculum and curriculum materials in learning with spreadsheets. Those teachers at levels higher than *accepting* identified problem-solving ideas for integrating spreadsheets as learning tools (as demonstrated in their lesson portfolios). The *accepting* teachers struggled to envision how spreadsheets could be used prior to middle grades. Teachers at the *exploring* level found value in creating dynamic ideas where students at lower grades might enter data, view the graphical representation, and make conjectures about the patterns they observed.

Implications and Recommendations

As Koehler and Mishra (2008) described, TPACK is an "emergent form of knowledge that goes beyond all three components (content, pedagogy, and technology) … [to an] understanding that merges from an *interaction* of content, pedagogy, and technology" (p. 17). The results of this study contribute to the recognition of TPACK as emerging from inservice teachers' PCK as the teachers were confronted with the curricular and pedagogical complexities in teaching mathematics and science when integrating spreadsheets as learning tools. The online course resulted in changes in the teachers' TPACK levels by the end of the course, suggesting changes in their PCK because, as Harris (2008) noted, TPACK is "interdependent" with PCK (p. 255). Because they had no previous experience learning mathematics and science with spreadsheets, the teachers needed to learn about spreadsheets as algebraic reasoning tools and explore the nature of the design of dynamic spreadsheets for problem solving, simulation, and modeling. The content-specific emphasis of the course engaged teachers in activities requiring them to seriously think about learning mathematics and science with dynamic spreadsheets. This conclusion is also supported by the Harris and Hofer (2009) study describing the importance of the curriculum content as the primary focus of the instruction, whereas the "digital tools and resources to support different types of learning" are secondary when guiding the teachers in integrating appropriate technologies as learning tools (p. 24).

Although all the teachers seemed to be excited about learning mathematics and science ideas with the spreadsheets, their prior beliefs about how those topics should be taught and learned limited their vision of integrating spreadsheets. The course consistently challenged them to consider the impact that spreadsheets had on what students learned about the topics involved. Throughout the course, the teachers were challenged to think about technology-enabled learning strategies as they learned about the technology (spreadsheets) in the mathematics and science context. These pedagogical experiences were reflected in their assignments as they considered the design, implementation, and assessment of instruction with spreadsheets. In essence, using the four components of TPACK to frame a professional development course involving integrating technologies shows promise for moving inservice teachers' PCK to TPACK.

Upon course completion, only four of the teachers actually explored instructional ideas with their current students. These four teachers demonstrated higher TPACK levels, suggesting the importance of providing opportunities for teachers to implement plans in their classrooms. Teachers need to examine students' thinking, learning, and understanding of topics learned with the specific technologies. Thus, professional development opportunities might be framed such that teachers are expected to implement their ideas for integrating the technologies. This MSP/master's program required such a process to follow this spreadsheet course.

This additional course was focused on instructional strategies for teaching mathematics and science with technologies. The teachers were required to gather a "scoop" (Borko, Stecher, & Kuffner, 2007) of their instruction over a short period of time for analysis as a way of providing evidence of their productivity in guiding learning in technology-enhanced learning environments. The participants engaged in collaborative and cooperative group tasks for investigating reformed-based instructional strategies involving the integration of technologies while they were in the process of gathering their data for the portfolio. Weekly interactions with the course instructor provided mentoring in the development of the ideas for teaching with technologies. Research results from that additional course revealed that the teachers' instruction shifted to student-centered instruction using small groups and cooperative groups to engage student in higher-level thinking and active participation in learning mathematics/science (Niess, 2010). Although this additional study focused on the teachers' work in gathering and developing the electronic portfolio of evidence of their instruction with technologies, future research might consider how mentoring and observation of this instruction can be implemented through online coursework.

An interesting result in this spreadsheet course study was that the four teachers identified as moving to the *adapting* and *exploring* TPACK levels exhibited preferences for student-centered instructional practices. The two teachers reaching the higher level (*exploring*) exhibited these tendencies prior to the course, whereas the two at the *adapting* level provided evidence of shifting to more student-centered instruction as they considered teaching with spreadsheets. The teachers at the *accepting* level expressed the need to control the classroom when integrating spreadsheets and thought of spreadsheets primarily for motivation and confirmation of ideas. The more student-centered teachers indicated an understanding of using spreadsheets for exploring and learning the content. Perhaps this difference is related to their emerging confidence with spreadsheets as learning tools and recognition that learning with spreadsheets shifted responsibility to the students for active engagement. The student-centered teachers indicated that students were capable of learning about spreadsheets through exploration, whereas the teacher-centered teachers expressed the importance of guiding elementary students in all work with the spreadsheets. As noted in the NETS for Teachers (ISTE, 2008), teachers must "transform learning environments" where an "emerging learning landscape" includes "student-centered, performance-focused learning" (p. 4). Future research needs to explore this shift from teacher-centered to student-centered instruction.

The interaction of the science and mathematics content with spreadsheets framed this study. Not only do different content areas warrant separate and careful investigation, different technologies integrated with different topics also warrant careful consideration. How much of the learning gained for teaching with spreadsheets is transferable to technologies that are significantly different in capabilities and connections with science and mathematics? What about the instructional and curricular implications for significantly different technological capabilities? What is the impact of different technologies on teachers' emerging TPACK? The research supporting teachers' TPACK development must be expanded to professional development that considers the knowledge for teaching with technology in a more integrative manner. Mishra and Koehler (2006) warned that:

> … separating the three components (content, pedagogy, and technology) … is an analytic act and one that is difficult to tease out in practice. In actuality, these components exist in a state of dynamic equilibrium.… Viewing any of these components in isolation from the others represents a real disservice to good teaching. (p. 1029)

The TPACK levels themselves present another concern. As teachers are confronted with different content classes, different technologies, varying availability of technologies, different students, and other contexts within which they implement technologies, their TPACK levels are affected (Niess et al., 2007). These differences may affect some, one, or all of the four components. As with PCK, teachers must continue to develop and strengthen their TPACK. Teachers need ongoing opportunities to enhance their TPACK, rather than simply learning about the technologies. They need programs to learn content with the technology as well as the pedagogy of teaching that content with the technology. With newer technologies, they need programs that engage them in envisioning the use of those technologies for learning the content and that challenge the curricula, given the power of the technologies. As this study demonstrated, online programs have potential for providing opportunities and access for teachers to expand their knowledge for teaching their content with multiple technologies and thus extend teachers' PCK to TPACK, a more robust knowledge for teaching in the 21st century.

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Appendix A

Interview Protocol

1. Teachers' understanding of spreadsheets as algebraic reasoning tools (based on their work in the Dynamic Spreadsheets course)

- When you hear the word "spreadsheet," what comes to your mind?
  - ☐ Encourage them to describe what a spreadsheet is rather than to focus on the course.
  - ☐ If they talk about algebraic reasoning, probe their understanding of what that means. If they don't talk about algebraic reasoning, ask them why spreadsheets are typically viewed as algebraic reasoning tools.
  - ☐ How is using a spreadsheet different from using a calculator? How is it similar to using a calculator?
  - ☐ Ask how they think they have come to this understanding of spreadsheets. How has your thinking changed as a result of the Dynamic Spreadsheets course? Have them talk about how they thought about spreadsheets before the course and if that has changed during the course.
- What is your current view and understanding about integrating spreadsheets as learning tools in science and mathematics? If they focus on mathematics, also extend them to science and vice-versa. Probe them to see how their view has shifted as a result of their work in the Dynamic Spreadsheets course.
- What changes do you see in students' mathematical/scientific thinking when they use spreadsheets in solving problems as opposed to when they do not use spreadsheets for solving problems? What specific math/sciences topics lend themselves to spreadsheets as learning tools?
- How can spreadsheets be integrated in science and mathematics courses? Explore their thinking about: specific effects on the curriculum, specific effects on instruction. Extend their thinking about specific uses of spreadsheets as useful in integrating science and mathematics.
- From you perspective, when and how should spreadsheets be introduced as learning tools in schools? Probe their ideas of scaffolding students' learning about spreadsheets as they learn specific ideas in math/science.
- What do you see as barriers for integrating spreadsheets in science and mathematics courses?
  - ☐ Try to get them to think more broadly than their own specific teaching level and course. They can start there and then broaden: If they focus on math, encourage them to think about science too.
  - ☐ What strategies can teachers use to overcome these barriers?

2. Teacher's development of TPACK over the first year of the program.

- With which digital technologies are you a consistent user? How do you use these technologies?
  - ☐ Encourage them to talk about their personal uses as well as professional uses.
  - ☐ Ask if they consider themselves as technology literate with these technologies. Probe them to see if they think they are a novice with digital technologies or if they have strong content and process working knowledge of these digital technologies (for their use personally).
  - ☐ How have your knowledge and skills with these and other technologies changed through your work in this program?
  - ☐ What technologies do you still want to learn more about? Why and for what purposes?
- When you think about teaching and learning math/science, what is your conception of how digital technologies are useful? This question is attempting to assess their overarching conception (knowledge and beliefs) about the purposes for incorporating technology in teaching subject matter topics.

- ☐ Which, if any, technologies do you feel support learning in math/science?
- ☐ When and how should these technologies be used in learning the topics?
- ☐ Pick a topic and a technology and discuss when and how students should be engaged with the technology. (Try to get an idea of their thinking as to whether the technology is useful in building initial understanding of the topic, in confirming the idea, in extending the idea.)
- ☐ How has your conception of incorporating technology in teaching specific topics in science/math changed through your work in this program? Challenge them to think about both math and science.

- Pick a science/math topic where you think a specific technology might be integrated as a learning tool. (This question is attempting to assess their knowledge about students' understandings, thinking, and learning in subject-matter topics with specific technologies.)
  - ☐ What are students' understandings and thinking about this topic?
  - ☐ How is the specific technology useful in guiding students' thinking about this topic?
  - ☐ How has your knowledge about students' understandings, thinking, and learning in subject matter topics with specific technologies changed through your work in this program? Challenge them to think about both math and science.
- Pick a major unit/idea in the math/science curriculum that you think incorporating technology would help students in learning the ideas in the unit.
  - ☐ What technology (or technologies) would be useful in this unit?
  - ☐ Describe the goals for learning when technology is integrated in the math/science curriculum. Probe to see if they focus on the subject matter or the subject matter within a technology context or something else.
  - ☐ Probe to see if their goals reflect ideas in the NETS for Students standards, since they have been focused on thinking that way during the Dynamic Spreadsheets course (see attached). Don't mention the standards, but perhaps use some of the phrases.
  - ☐ Explain how the concepts/processes are enhanced through the use of the technology.
  - ☐ How would you structure the integration of the technology in this unit? Explain why you would do it this way?
  - ☐ How would you assess students' understandings in this unit? (Try to get at their thinking about incorporating the technology in assessing students' understanding and thinking in this unit.)
  - ☐ How has your knowledge about integrating technologies in math/science curricular areas changed through your work in this program? Challenge them to think about both math and science.

- Thinking about instructional strategies, talk about instructional strategies that are useful when teaching with specific technologies. Pick a specific topic and describe the instructional strategies you would use when integrating the technology as students are learning the topic. (This question is attempting to assess their knowledge of instructional strategies and representations for teaching and learning subject matter topics with technologies.)
  - ☐ When the technology is a new one to the students, what strategies do you use to guide them in learning about the technology? Probe to see if they do the work in learning about the technology as they are learning the specific topic or if they focus on learning about the technology and later as the math/science context.
  - ☐ How, why, and when do your strategies change for different types of learners? How, why and when are they the same regardless of learner differences?
  - ☐ Describe useful strategies when students are sharing a technology in learning about a math/science topic.
  - ☐ Discuss useful strategies that assure equal access to the technology for all students.
  - ☐ How has your knowledge about instructional strategies useful when integrating technologies in math/science curricular areas changed through your work in this program? Challenge them to think about both math and science.

Appendix B

TPACK Survey: Computer-Based Technologies and Teaching and Learning Science/Mathematics (adapted from survey by Riggs & Enochs [1993])

Items not shaded: Self-Efficacy (beliefs in one's ability)
Items shaded: Outcome Expectancy (outcomes person believes are possible given effective behavior)

SA = Strongly Agree
A = Agree
UN = Uncertain
D = Disagree
SD = Strongly Disagree

1	I know how to use computer-based technologies.	SA	A	UN	D	SD
2	I am always finding better ways to use computer-based technologies.	SA	A	UN	D	SD
3	If I got better in using computer-based technologies, it would help me be a better science/mathematics teacher.	SA	A	UN	D	SD
4	I am not very good at using computer-based technologies.	SA	A	UN	D	SD
5	When students' attitude toward science/mathematics improves, it is often due to their having learned with computer-based technologies.	SA	A	UN	D	SD
6	Even when I try hard, I do not use computer-based technologies as well as other teachers do.	SA	A	UN	D	SD
7	I generally use computer-based technologies poorly.	SA	A	UN	D	SD
8	Learning how to use computer-based technologies well would help my students in learning science/mathematics.	SA	A	UN	D	SD
9	I understand what computer-based technologies can do well enough to use them correctly.	SA	A	UN	D	SD
10	My students' success in science/mathematics is related to how well they can use computer-based technologies.	SA	A	UN	D	SD
11	I know how to use computer-based technologies as well as most teachers.	SA	A	UN	D	SD
12	Learning how to use computer-based technologies can help me in teaching science/mathematics.	SA	A	UN	D	SD
13	I find it difficult to use computer-based technologies.	SA	A	UN	D	SD
14	Learning how to use computer-based technologies will not help me in my job as a science/mathematics teacher.	SA	A	UN	D	SD
15	It is not worth my student's time to use computer-based technologies when learning science/mathematics.	SA	A	UN	D	SD
16	I will probably never incorporate computer-based technologies in my science/mathematics instruction.	SA	A	UN	D	SD
17	Given a choice, I would not invite the principal to evaluate my computer-based instruction in my science/mathematics classes.	SA	A	UN	D	SD
18	It is really not necessary to use computer-based technologies in learning science/mathematics.	SA	A	UN	D	SD
19	When students in my science/mathematics classes have difficulty with computer-based technologies, I am usually able to help them.	SA	A	UN	D	SD
20	Computer-based technologies can be helpful in learning science/mathematics.	SA	A	UN	D	SD
21	My students' success in science/mathematics is related to use of computer-based technologies.	SA	A	UN	D	SD
22	I feel comfortable when I use computer-based technologies.	SA	A	UN	D	SD
23	Most good science/mathematic-related jobs do not require skills with computer-based technologies.	SA	A	UN	D	SD
24	Students do not know how to use computer-based technologies well for learning science/mathematics.	SA	A	UN	D	SD
25	Whenever I can, I would avoid using computer-based technologies in my science/math classroom.	SA	A	UN	D	SD
26	Success in learning science/mathematics has nothing to do with being able to use computer-based technologies.	SA	A	UN	D	SD