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Preservice Teachers' Emerging TPACK in a Technology-Rich Methods Class

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There is a dearth of research on the mechanisms for preservice teachers' development of the pedagogical knowledge necessary for effective use of such technologies. We explored the emergent Technological Pedagogical and Content Knowledge (TPACK) (Niess 2005, 2006, 2007) of a group of secondary mathematics preservice teachers in a methods course as they designed and implemented technology-rich teaching materials in field settings. Participant surveys and collected assignments were analyzed through the lens of the TPACK framework. The data were also analyzed to examine the trajectory of the participants' beliefs about the appropriate role of advanced digital technologies in mathematics. The results indicate that the participants' understanding of technology shifted from viewing technology as a tool for reinforcement into viewing technology as a tool for developing student understanding. Collected data supports the notion that preservice teacher TPACK development is closely related to a shift in identity from *learners of mathematics* to *teachers of mathematics*. In a class where advanced digital technologies were used extensively as a catalyst for promoting inquiry-based learning, preservice teachers retained a great deal of skepticism about the appropriateness of using technology in concept development roles, despite their confidence that they can incorporate technology into their future teaching.

To me, it's [the use of calculators in mathematics instruction] more about where kids are at developmentally. The methods are influenced by this. When kids are younger and inexperienced, they need to be taught the basics using direct instruction like I was. Now that I know some things, I can use the calculator to learn more. But I have a good foundation in the basics FIRST.

In the above quote, a preservice teacher shares his views on the use of technology to teach mathematics. Based on his strong views on this issue, we might not expect him to use a great deal of advanced digital technologies in his classroom nor to employ discovery activities (using technology or otherwise). Many researchers have highlighted the important influence of teachers' beliefs and views on instructional decision-making and classroom practice (Ball, Lubienski, & Mewborn, 2001; Borko & Putnam, 1996; National Council of Teachers of Mathematics [NCTM], 1991; Richardson, 1996; Stipek, Givvin, Salmon, & MacGyvers, 2001; Thompson, 1984, 1992). Furthermore, Peressini, Borko, Romagnano, Knuth, and Willis-Yorker (2004) argue that none of the experiences (mathematics and teacher preparation courses, preservice field experiences, and employment) in learning to teach are independent of one another, which ensures a complicated collection of influences on a prospective teacher's learning trajectory.

A growing body of research indicates that digital technologies, including graphing and Computer Algebra System (CAS)-enabled calculators, can enhance young students' conceptual and procedural knowledge of mathematics (Dunham, 2000; Thompson & Senk, 2001). As teachers decide whether and how to use advanced digital technologies in their teaching, they need to consider the mathematical content that they will teach, the technology that they will use, and the pedagogical methods that they will employ. Moreover, they need to reflect on the critical relationships between these concepts: content, technology, and pedagogy. Drawing on a series of case studies, Zbiek (2002) suggests some direction for the development of a model of effective teaching using CAS. This model stresses the importance of many of the influences discussed by Peressini et al. (2004), including conceptions of school mathematics and how available curriculum materials intersect with

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technology. Zbiek concludes that such a model could be a useful analytic tool for describing and facilitating teachers' evolution in teaching with CAS. As will be discussed in more detail in the next section, Niess (2005, 2006, 2007) developed the Technological Pedagogical and Content Knowledge (TPACK) framework to provide such a tool for using advanced digital technologies in teaching in general. However, empirical studies of preservice teachers' emerging TPACK remain in short supply.

Theoretical Context

Shulman (1986) provided an analysis of teachers' knowledge as a complex structure including content knowledge, pedagogical knowledge, and pedagogical content knowledge (PCK). Ensuing research on teacher knowledge is grounded in his framework. With Mishra and Koehler's (2006; Koehler & Mishra, 2005) and Niess' (2005, 2006, 2007) conception of TPACK, the field has additionally gained "an analytic lens for studying the development of teacher knowledge about educational technology" (Mishra & Koehler, 2006, p. 1041).

TPACK involves the content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK) required to teach in technology-rich environments (see Figure 1). In our case, content knowledge is high school mathematics. Pedagogical knowledge includes learning theories and instructional methods. Technological knowledge includes the knowledge of how to operate technology-oriented tools (such as Geometer's Sketchpad or TI-Nspire) and the ability to adapt to ever-changing, novel technologies.

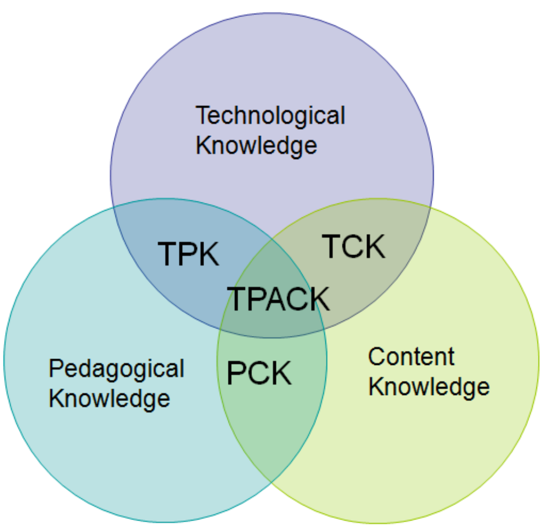


Figure 1. Re-creation of Mishra and Koehler's TPACK model.

Shulman's (1986) discussion of PCK focuses on the two-way relationship between content and pedagogy, for instance, how particular pedagogical methods might help (or hinder) students' learning of specific content. Niess's (2005, 2006, 2007) TPACK model extends this relationship to include relationships with other constructs, including technological content knowledge (TCK) and technological pedagogical knowledge (TPK). TCK is viewed as the intersection of the technology and the content wherein a wholly different perspective on content may arise. For example, technology can be used to explore the fact that a quadratic with integer coefficients is highly unlikely to be factorable, drawing attention to and questioning the traditional content of school mathematics. With respect to TCK, Mishra & Koehler (2006) say, "teachers need to know not just the subject matter they teach but also the manner in which the subject matter can be changed by the application of technology" (p.1028). On the other hand, "technological pedagogical knowledge (TPK) is knowledge of the existence, components, and capabilities of various technologies as they are used in teaching and learning settings, and conversely, knowing how teaching might change as the result of using particular technologies" (p. 1028).

Research Question

There is much to consider when studying pre- and inservice teachers' knowledge, views, beliefs, attitudes, and decisions about the use of technology in their classrooms. Whereas Niess (2006, 2007) discussed how teachers' beliefs and views about teaching mathematics with technology play a crucial role in the development of TPACK, our research question was: How does preservice teachers' TPACK emerge during their methods classes and field placement? Therefore, in a methods course intended specifically for preservice secondary mathematics teachers, we examined teachers' emerging TPACK (Niess 2005, 2006, 2007) as manifested in their use of advanced digital technologies in the design and implementation of technology-rich teaching materials in field placements. Moreover, through written responses regarding the use of the TI-Nspire (Texas Instruments, 2007) and other advanced digital technologies, we studied their views about the use of technology to teach mathematics.

Data Collection

We studied a group of 20 preservice teachers enrolled in a first-semester mathematics teaching methods course at a small Midwestern university. The sample is one of convenience (Lodico, Spaulding, & Voegtle, 2006). The participants were students in one of the researchers' classes, which was designed to introduce participants to inquiry-based learning with open-ended questioning. In past research, we have found that technologies such as the TI-Nspire calculator, virtual manipulatives, and dynamic geometry software (DGS) open up new possibilities for teachers to promote connections between representations, encourage students to explore dynamic mathematics environments, develop students' skills of inquiry, and support students' construction of knowledge (Özgün-Koca, Meagher, & Edwards, in press). Based on this result, the instructor placed considerable emphasis on the use of such technologies in the teaching and learning of mathematics, with particularly extensive use of the TI-Nspire. The TI-Nspire is a handheld device that incorporates functionalities such as graphing, manipulating algebraic expressions, and constructing geometric figures and analyzing data in a dynamic environment, while dynamically linking all of these representations.

Activities in the course focused primarily on pedagogical tasks (e.g. constructing lesson plans and grading rubrics, creating technology-oriented math activities) and content-related activities (solving mathematics problems, analyzing mathematical accuracy of student work). For example, participants completed problem sets designed to give them the opportunity to explore (and extend) content and pedagogical knowledge of secondary school mathematics. As part of their field experience, participants completed two reports in which they researched, developed, and implemented mathematics lessons. In addition, they submitted five secondary-level mathematics activities constructed and/or modified for use with the TI-Nspire. They were encouraged to use these materials in their field teaching whenever possible. Finally, participants conducted original research dealing with the teaching of a secondary mathematics problem (or set of related problems) using the TI-Nspire. The field experiences varied in the extent to which technology was used, from almost none in some classrooms to extensive and skilled implementation in others.

At both the beginning and end of the course, the participants completed a mathematics technology attitudes survey (MTAS), which included questions rated on the Likert scale. Additionally, they participated in three short surveys administered electronically in weeks 4, 8, and 13 of the course. Each of these surveys consisted of a combination of Likert scale and open-ended items. Finally, participants completed an open-ended exit survey at the end of the course with questions that were more general than those asked in the earlier surveys. Likert scale questions from the MTAS and short surveys included:

1. Graphing calculators help me understand mathematics.
2. Graphing calculators are a useful support for discovering algebraic rules.
3. Students shouldn't use calculators until they have thoroughly mastered the required skills by-hand.
4. Graphing calculators help people who have difficulties with algebra to still be able to do mathematics.
5. I have been thinking and working a lot on the technology of the course we are designing.
6. Our group has been considering how course pedagogy and technology influence one another.

Some of the examples of open-ended questions were:

1. What kind of technology skills that you can use later in your profession are you learning? Describe how you intend to use those skills in your future teaching.
2. Discuss the extent to which you have been thinking and working with pedagogical issues in the student activities you have been designing in our class. While recently observing classroom instruction in a local high school, a mathematics teacher made the following comment to me: "Content and pedagogy influence one another, especially when I use technology with kids in my classroom." Discuss your thoughts regarding this statement.
3. Similarly, a student in the aforementioned classroom noted that "technology changes the way our teacher teaches mathematics and the way I learn mathematics." Discuss your thoughts regarding this statement
4. Lastly, the classroom teacher noted that "technology changes the mathematics content that I teach." Discuss your thoughts regarding this statement.

Data Analysis

Our analysis focused on the data collected through the five secondary-level mathematics activities, field experience reports, and surveys. The first level of analysis focused on survey responses. We used descriptive statistics for quantitative data and searched for emerging codes and themes in the qualitative data. The initial themes arising from the analysis were (i) a shift in thinking of technology as a reinforcement tool to thinking of technology as a tool for developing mathematical concepts, and (ii) a change in relationship to technology predicated on a shift of the participants' own identity from *learner of mathematics* to *teacher of mathematics*. Once these themes had been identified, we re-analyzed changes between pre- and post-survey data and found the themes to validly reflect key characteristics of the data. We analyzed the activities and field experience reports through this lens and found further evidence to support the conclusions.

We used the TPACK framework to guide the qualitative data analysis for the open-ended survey questions, the secondary-level mathematics activity write-ups, and the field experience reports. The first level of analysis involved coding the data for instantiations of the participants' attitudes towards, skill in using, and deployment of, TK, CK, and PCK. For instance, if a participant were to say that calculators should not be used until students master the skills by hand, or if a participant were to discuss how using technology in their activity write-ups affected instructional planning, then we would code this as TPK. While analyzing the activity write-ups, we focused on three key issues: implementation of technology, implementation of inquiry-based methods, and quality of problem solving. Our interest in the interactions among the various domains of the model fueled our second level of analysis. We developed codes for each of the possible interactions between TK, CK, and PCK. We then analyzed the data for important aspects of these interactions. For example, a participant's statement suggesting that the use of calculators means that certain topics should be de-emphasized would be coded as *how technological knowledge influences content knowledge*. We feel that the multiple data sources and use of different lenses in the analysis provided sufficient data and researcher triangulation to ensure trustworthiness of our findings in this study (Miles & Huberman, 1994).

Results and Discussion

Two major themes emerged from the data analysis. Firstly, the participants' understanding of technology showed perceptible shifts and mutations from thinking of technology as a reinforcement tool to a tool for developing mathematical concepts. Glimpses of this evolving relationship to technology, which we see as a positive development in their TPACK, are reflected in candidate comments throughout the semester. Secondly, we saw an interesting change in participants' relationship to technology as they shifted their identity from being a learner of mathematics to being a teacher of mathematics. This also represents a positive step in developing TPACK, specifically in TPK. The course was the first methods course for these teacher participants and, therefore, their first opportunity to give serious thought to the use of technology from a teacher's perspective.

Reinforce or Develop: The Use of Technology in Lesson Plan Development

The development, or lack thereof, of TPACK in teacher participants is reflected in the learning activities they design for students. Developing good tasks that incorporate technology presents a challenge for the preservice teachers since they have to mix CK of the topic they wish to address, TK of the technology they choose to use, and PK in designing an inquiry-based task for their students. Their intersection, TPACK, proved particularly interesting in this challenge. In the quotes below, we see two participants' reflections on how they started to think about technology as an instructional tool to build conceptual understanding:

> *I am using technology because we are required to do so. However, the second activity write-up used the TI-Nspire extensively because I thought it would be really neat to see if I could use it for my idea.*

> *At first, the activity seemed to me that we had to use and had to incorporate technology in our activity. Now is seems that technology is more of a tool to help us design a really good hands on, visual activity.*

TPACK was evident in the content-specific ways that preservice teachers took advantage of the functionalities and affordances of the technology to engage students in inquiry-based tasks. The examples discussed below illustrate that participants moved beyond a naïve use of the technology into a more sophisticated incorporation of technology into the mathematics of their tasks.

When developing activities and creating lesson plans using technology, preservice teachers often incorporated technology into lessons through a superficial use of the available tools rather than taking advantage of those capabilities that were specific to the technology at hand (e.g. drawing shapes within a DGS environment while ignoring dynamic construction capabilities of the software, calculating simple results or using graphing functions while ignoring linkages between different representations), thus showing some lack of TK. This also showed an underdeveloped sense of TPK since the technology was not being used in a sophisticated way to help provide inquiry-based experiences for the students to develop understanding. In many of the participants' lessons, technology use was not tied to acquisition of the mathematics content—technology and content were envisaged as separate constructs rather than as intertwined entities. Therefore, although we found little evidence of TPK, there was an increasing trend throughout the study. For example, early work samples of student-generated activities revealed naïve understandings of various TI-Nspire tools and had low cognitive demand (see Figure 2). The activity in Figure 2 does not use the dynamic capabilities of TI-Nspire, focusing strictly on its drawing and measurement capabilities. Utilized in this manner, the technology contributed few, if any, advantages over use of traditional paper and pencil.

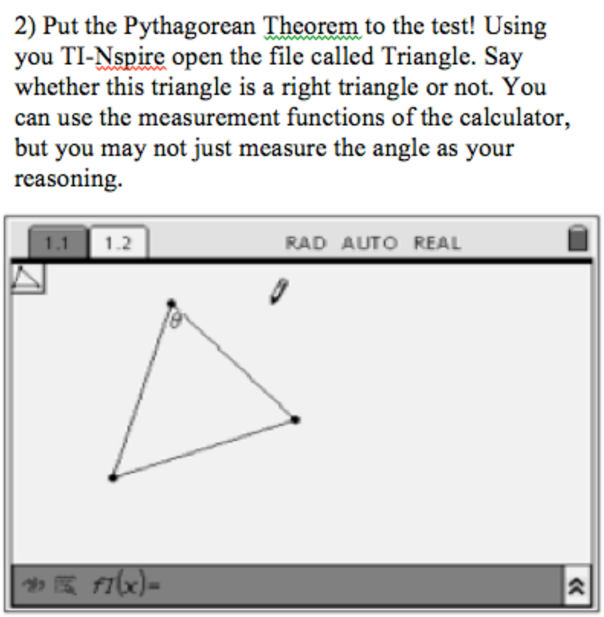
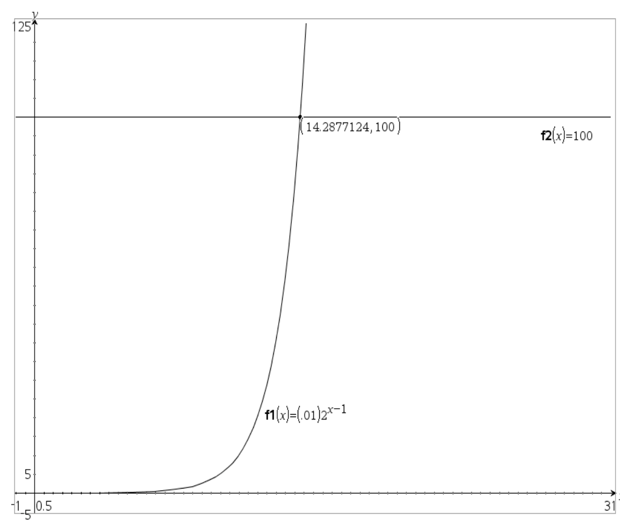


Figure 2. An example of a student-generated activity of low cognitive demand.

In this activity, asking the student to "say whether this triangle is a right triangle or not" implies that the angle theta remains fixed. Although it is not clear from the prompt alone, the participant intended the student to use the converse of the Pythagorean Theorem to answer the question, determining the length of each side of the triangle and verifying that the square of the side opposite theta was strictly less than the sum of the squares of the other two side lengths. While theta is clearly an acute angle when viewed statically (as is the case on the printed page), when vertices of the triangle are dragged, theta may also assume values larger than 90 degrees. Hence, viewed dynamically, it is impossible to determine if the triangle is right or not. Therefore, in addition to being a very low-level identification task (identify the type of angle denoted by theta), the prompt makes no sense in a dynamic context.

Below we can see a participant's first activity (see Figure 3) in which he used a real-world problem and both the tabular and graphing capabilities of the technology to find a point of intersection of two graphs. Here the use of technology was helpful, but not essential; the problem could have been solved just as easily with pencil and paper.

Figure 3. Participant 3's Activity, highlighting weak



use of technology

However, when we analyzed the second activity that he created later in the semester (see Figure 4), we saw that he constructed the cross-sections of various polyhedra using CABRI 3D to determine that cross-sections of a cone can form an ellipse, a circle, and parabola, and that cross-sections of a regular tetrahedron can form a scalene triangle, an isosceles triangle, an equilateral triangle, an isosceles trapezoid, and a quadrilateral. Without the technology, such constructions are impractical and not readily available to teachers or students. In this second example, the software is arguably an instructional necessity, indicating a more mature utilization of technology.

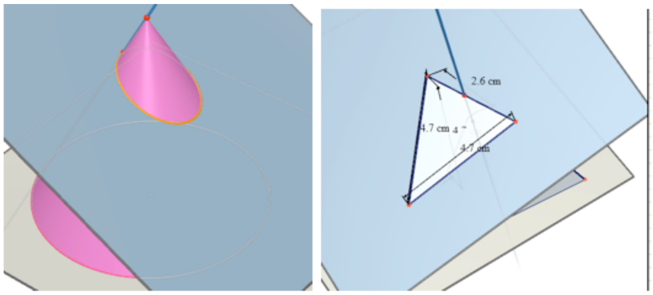


Figure 4. Participant 3's Second Activity with Effective Use of Technology

While there was a general improvement in the quality of the activities and lesson plans written by participants as the semester progressed, the activities written by those students with field placements in technology-rich environments showed more sophistication, not just in the use of technology, but also in terms of implementing inquiry-based and open-ended instructional approaches. Not only did both their technological and pedagogical knowledge develop, but the intersection of these two constructs, their TPK, also developed during those experiences. When participants did not have a rich technology experience in the field, they typically indicated that technology was not an instructional must:

> *I didn't really see any technology in schools when I had field, and I'm not convinced that kids need it. They need the basics first in order to actually UNDERSTAND what the calculator is doing. This is like reading. Kids need to know letters of the alphabet first before they can read.*

Change in Identity: Technology for Them and Technology for Their Students

On the pre-and post-surveys, a large percentage of participants agreed or strongly agreed that graphing calculators helped them better understand mathematics. In addition, a clear majority of the subjects agreed or strongly agreed that graphing calculators increased their desire to do mathematics (73% in the pre-survey and 65% in the post-survey). Based on these observations, it seems that the participants had a well-established understanding of how they themselves can use advanced technologies in doing mathematics. On the other hand, when it came to the issue of teaching with calculators, the participants had mixed views. In the pre-survey, 82% agreed that calculators help people who have difficulties with algebra to still be able to do mathematics. However, this percentage decreased to 70 in the post-survey. We, therefore, conclude that their perspective changed somewhat when putting themselves in the position of teachers of mathematics. This could be an indication that the participants, based on their experiences in their field placements, remained attached to the idea that students' can be overly dependent on calculators and that calculators can interfere with students' learning of basic concepts.

In addition, during the fourth week, two of the preservice teachers discussed their concern that they were learning about technology to which they were unlikely to have access as classroom teachers. Again, this shows that they had started to reflect on the issues as prospective teachers. That week the preservice teachers also discussed SMART$_{TM}$ Boards (n=8), websites (n=4), and Geometer's Sketchpad (n=1) as possible tools to use in their future teaching. However, by the eighth week, after some field experience, no one discussed TI-Nspire calculators, although many discussed the limited access that they had to advanced technologies in actual school settings: "After going out in the field, I believe more than I did before that the technology I am learning to base my lessons off of, though, is far too advanced." After their field experiences, many participants reported that they found internet-based resources, such as interactive web applets,more practical—both in terms of their accessibility in classroom situations (e.g. most classrooms were equipped with one demonstration computer with internet access) and their low cost (unlike the TI-Nspire, most applets were freely available).

The TPACK Model and Advanced Digital Technologies

In this section, we discuss how the TPACK model helped us to reach the two main conclusions discussed above.

Technological knowledge. Participants mentioned a variety of technologies when discussing which of the technological skills they were learning would be useful in their future teaching. In the fourth week, eight preservice teachers mentioned that they liked TI-Nspire calculators. Some mentioned the technological skills that they were learning, such as how to operate the TI-Nspire:

> *I've not had a lot of practice in using calculators besides the TI-84 and with that only the basic functions. The technological advanced TI-Nspire on the other hand, as I'm learning, is very user friendly, with menus you can go to find out more about what is available.*

On the other hand, some preservice teachers had technical difficulties learning how to use some of the technology: "I found the TI-Nspire to be too complicated and not worth the hassle figuring it all out. I spent more time trying to figure out how to use it than I did learning about math." Another mentioned that, "one of the issues I've struggled with is the extent [to which] we would use technology. A number of cases in using technology have required extensive knowledge/experience with the technology." Clearly a lack of TK for a particular technology could be an important factor in preservice teachers' consideration of whether to use that technology in their future classrooms.

Content and pedagogical content knowledge. The CK required by these teachers is, minimally, the high school mathematics content they will teach. Participants in the methods course mostly agreed that both their university class and field placement required them to work extensively with high school mathematics content as they designed teaching activities. Even though many said that they were not learning about mathematics content as they designed activities, quite a few mentioned they were "remembering" and that the activities were "refreshing us" on the high school mathematics while looking at content from a teacher's perspective:

> *So far, we have covered many of the content areas including algebra and geometry. These were important for my growth because I was unaware of the severity of my 'rustiness' when it came to basic algebraic and geometric principles.*

> *Quite a few of the activities we have done in class have made use of mathematics that I have not used since high school. These activities have reminded me how to do a number of problems. Overall, the course is requiring me to look at mathematics from a teachers' perspective and not a students' view of question and answer.*

Moreover, one preservice teacher mentioned that he or she was focusing on the "why" question more:

> *I feel as though I am not learning new mathematics content, but instead, I am thinking of what I already know in a different light. The class has caused me to think more about the why than the how, and to me, that is, the most important element of being a mathematics teacher.*

We see here the participants' transition from thinking of themselves as learners of mathematics to thinking of themselves as teachers of mathematics. The participants' CK provided a basis for the development of their PCK. Another participant mentioned that:

> *Both the problem sets and our activities have required us to investigate mathematics content. The Folded Paper problem is a perfect example. This problem could be solved with a table, via a graph or using calculus. Exploring each of these is valuable in understanding the content of the math and understanding multiple representations.*

Preservice teachers started thinking about pedagogical issues together with content. Moreover, another preservice teacher discussed how designing lesson plans helped him learn, not only about the content, but also about incorporating technology:

> *I have been trying to figure out how to make lessons based on certain content. This class has been helping me to identify how to design lessons based on content which is something I had no experience with. I now have a better understanding of how to incorporate things like technology into the lesson as well.*

Pedagogical knowledge. PK includes teaching strategies appropriate for student learning. When preservice teachers were asked to discuss pedagogical issues as they designed activities during the fourth week, only two mentioned the use of technology. Specifically, one mentioned TI-Nspire and one mentioned websites. Other than that, participants focused their discussion primarily on the use of manipulatives, inquiry, problem solving, differentiation, and other pedagogical issues.

> *The class has made me realize the importance of manipulatives and hands-on activities in the classroom. These types of activities help students to become active learners, and thus, cause them to retain more of the material.*

In the quote above, the candidate did not make an explicit connection between the use of technology and the use of manipulatives in an active/hands-on learning style.

> *I feel in my activity write-ups, I am constantly considering pedagogical issues. The one main issue is using an inquiry method for problem solving. I try to have my students explore a topic, such as finding the length of the diagonal of a square through investigation rather than lecture.*

Once again, the candidate does not explicitly link the use of digital technologies to the use of an inquiry-based pedagogical approach.

The interactions among pedagogy, content and technology. In a survey given in the thirteenth week, three open-ended questions asked the participants to discuss the relationships between content and pedagogy, content and technology, and technology and pedagogy. Figure 5 illustrates the interactions between content, technology, and pedagogy reflected in the data. The direction and thickness of the arrows represent the relationships articulated by the preservice teachers. If many preservice teachers articulated a relationship, the arrow representing that relationship is bolded. Dashed arrows signify relationships that were not mentioned or are non-existent.

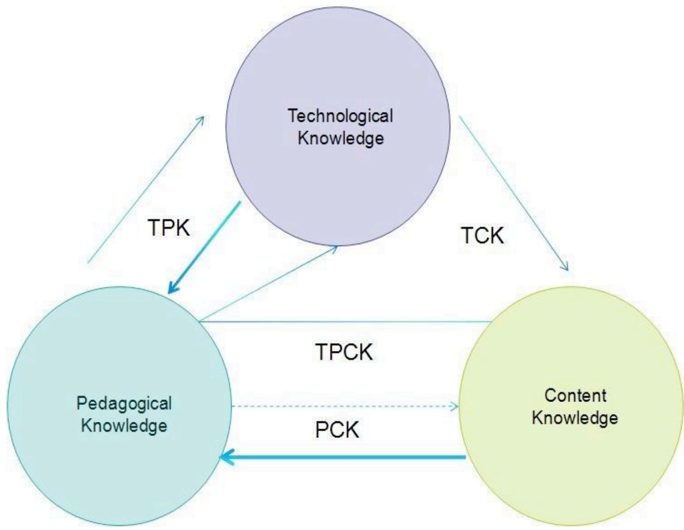


Figure 5. Interactions between the content, the technology and the pedagogy.

Many preservice teachers mentioned that they could see the influence of content on pedagogy. For instance, they acknowledged that the complexity of the high school content affects the teaching method to be employed:

> *I totally think that content influences how topics are taught. I'm not sure if pedagogy should influence content.*
>
> *The methods you use depend on the kids you teach and the topics you are teaching.*
>
> *The content you teach is related to the way you teach it. When I taught kids about area and perimeter in the field, we used plastic tiles to study the topics in a hands-on manner. But we didn't use hands-on materials when we studied cross multiplying. There just wasn't a good way to do this hands-on.*

Even though a few said that they were not sure if pedagogy should influence the content, the examples that they gave showed that they were considering the pedagogy to content direction in Figure 5. One mentioned, "in my field placement, I saw how dynamic geometry software influences what content is taught and how it is taught."

Even though no one mentioned how the content influenced the technology directly, several preservice teachers mentioned "appropriate uses" of technology when discussing the relationship between content and pedagogy. In these cases, they were not focusing on technological skills, but on the use of technology as one of many possible teaching strategies:

> *Some things that we taught kids were naturally studied with the Nspire. For instance graphing functions was a natural with the "Graphs and Geometry" application.*
>
> *The math you are teaching totally influences the way you teach it. Some topics are well suited for use with technology. Like when you are learning about transformations, then Sketchpad is a natural tool to use. When you're studying graphs, then calculators are a natural learning tool. Other topics, such as trigonometric proofs and identities, aren't as obviously hands-on. I feel more limited teaching these topics using methods other than lecture.*

Thus, in Figure 5, we connected content and technology through pedagogy with one arrow.

When discussing the influences of technology on content, participants focused on the capabilities of technology. Due to the capabilities of advanced technologies, the content (curriculum) might have been affected or some contents might have become more accessible:

> I have been using more technology now with the problems than I ever thought I would. I remember from problem set two that using technology made doing the problem much easier to do.
>
> Technology does change the content. There are things that I studied in school that don't seem relevant in algebra class anymore. For instance, factoring. We did an assignment on the Nspire that showed that 99% (or more) of quadratics aren't factorable. So why do we spend all of this time factoring?
>
> I think technology changes the content sometimes, but I don't think it should. I think math should influence the technology, not the other way around.

In regard to the relationship between technology and pedagogy, some preservice teachers discussed technology as a pedagogical tool as opposed to focusing on needed technical skills. Therefore technology was embedded in pedagogy. They noted how the use of technology might impact how a task develops, which in turn could influence student learning. In these instances, the participants are thinking through how technology is deployed rather than, as discussed earlier, which topics might naturally lend themselves to technology use:

> *Technology can make it easier to test conjectures. For instance, with sketchpad, we can test countless conjectures much more quickly than possible when using pencil and paper. When we observe behaviors in sketchpad (or with the TI-Nspire), students are more motivated to ask "does this always happen?"*

> *I have been able to incorporate things such as the TI Nspire and GSP into my activity write-ups, and I think that incorporating these types of technology into lessons helps to make them (the activities) more multifaceted and thus easier for a larger percentage of the students in a classroom to understand.*

Not all preservice teachers thought that technology influenced students' learning. In particular, one candidate noted:

> *Technology doesn't change the way kids learn math. They have to learn it the way I learned it, by repetition and practice. It's like learning how to read. You have to do some memorizing and repetition before you can get to the good stuff.*

Other preservice teachers noted the importance of first using paper and pencil experiences in students' learning. In these cases, it appeared that their beliefs about how learning occurs affected the extent to which they would use technology in their teaching. During the eighth week, after having some field experiences, one preservice teacher felt that students were dependent on calculators for computation: "The main issue that I dealt with in my classroom (i.e. methods field experience) was the severe dependency on calculators that students seemed to have." In the exit survey, approximately 70% of the preservice teachers agreed that they would specifically like to use the Nspire when they become a full-time teacher. However, in the fourth week, on a more general question about the place of technology in the mathematics classroom, approximately 68% of the preservice teachers agreed that students should not use calculators until they have thoroughly mastered the required skills by hand. This percentage decreased to 44% at the end of the study. We should point out that only 9 participants completed the survey in the thirteenth week, as opposed to the 20 that completed the survey in the fourth-week survey.

One of the preservice teachers' main messages was that content should be a teacher's first priority. As one preservice teacher put it:

> *Good teachers think about content first and ways to better deliver content to students. Putting pedagogy first (and even WORSE, putting technology first) is irresponsible. We should always be thinking about WHAT we [want] our kids to know MATHEMATICALLY . . . then figure out how (or if) technology or various teaching methods support THAT . . . not the other way around.*

Eventually, they started to look at the content from a teacher's perspective, thinking about issues related to teaching and learning Later, technology came into play as a pedagogical tool with novel capabilities that paper and pencil (or chalk and blackboard) cannot provide.

At the end of the course, participants thought themselves better prepared to use technology in their teaching. At the beginning of the course, only 40% of them considered themselves at least fairly prepared to have students use technology to explore new concepts. This percentage increased to 84% at the end of the course. Similarly, 64% of them felt fairly or very well prepared to have students use appropriate educational technology to learn mathematics at the beginning of the year. This percentage also increased to 84% in the exit survey.

Conclusions

This study sought to examine teachers' emerging TPACK as manifested in their use of advanced technologies in the design and implementation of technology-rich activities in their student teaching. We did this through an examination of their views on the use of advanced technologies, such as the TI-Nspire. Our major conclusions are that (1) preservice teachers' development of TPACK is related to their shift in identity from being learners of mathematics to teachers of mathematics; and that, even in a class where advanced digital technologies are used extensively as a catalyst for promoting inquiry-based learning, (2) preservice teachers retain a great deal of skepticism about the role of technology in mathematics education even though they felt much better prepared to incorporate technology into their teaching.

We have shown above that, often, a preservice teacher's first use of advanced technologies is naïve and incorporates technology superficially. We believe this results from a combined intial lack of PCK and TK. These two deficits, in tandem, make it hard to design tasks that allow students to explore mathematical concepts. The data show that, initially, preservice teachers' mathematical focus is on content and their own ability to solve problems. By and large, preservice teachers have been successful in doing mathematics in traditional environments. As they make the shift to being mathematics teachers, they begin to develop pedagogical knowledge and become interested in hands-on activities and inquiry-based learning. However, for many, there may remain a feeling that advanced technologies "do too much." The data shows that they do not see advanced technologies as part of an inquiry-based approach.

Preservice teachers can certainly develop their technological, pedagogical, and content knowledge separately, but integrating these types of knowledge through the development of their TPK, TCK and TPACK gives them a more holistic view of their teaching and helps them transition from learners of mathematics to teachers of mathematics. Our data show that close attention must be paid to the relationship between the university classroom and the field placement; ideally, every preservice teacher would see that what they learn in the university classroom has an impact on their work in the field. Field placements are where preservice teachers face the reality of a classroom and experience first-hand that how they design tasks affects student learning.

Our conclusions suggest several directions for further research. Perhaps the most obvious of these is the need for further investigation of what happens when participants complete their preservice training and become full time teachers: What are the crucial influences on the development of TPACK? Our past research (Özgün-Koca, Meagher, & Edwards, in press) suggests that experiencing success in the classroom and reflection, through journal writing or interviews, are vital elements in continuing the development of TPACK. Other potential influences to consider include access to technology, availability of materials to support inquiry-based instruction, and the existence of a supportive professional environment.

Another area for further research is studying the effect, on preservice teachers' attitudes and practices, of seeing exemplary inquiry-based instruction in a technology-rich environment. There is not enough data in this study to support strong claims, but our data does suggest that students found it difficult to appreciate the possibilities of advanced technologies in instruction without experiencing exemplary use in an authentic classroom situation. Such experience is highly dependent on field placement, although use of remote video technology could be employed to make an exemplary experience available to an entire class.

Using advanced technologies in methods classes puts preservice teachers in the position of being learners. This allows them to pay explicit attention to developing their TCK, which in turn encourages them to reflect on their PCK and CK. Thinking about, and engaging with, advanced technologies gives preservice teachers a vantage point from which to examine their beliefs about, and attitudes towards, what it means for their students to be successful.

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