



Professional Development for Elementary Teachers Using TPACK

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Abstract

Teacher preparation for the 21st century deserves a front-end approach to addressing the use of technology in the learning environment. To study the effect of instructing with technology, pedagogy, and content knowledge (TPACK), teachers were asked to apply pedagogical, mathematical, and cognitive fidelity to technology used in an instructional unit they were designing. Initial results indicated that teachers were conflicted by a conceptual approach to technology use. Through clarifying and defining pedagogy, mathematics, and cognitive fidelity within the TPACK framework, teachers became more aware of the misuse of instructional technology, what attributes of technology lead to conceptual development, and integration of meaningful technology into instructional units. TPACK, with fidelity carefully defined, creates a research-based model by adding the qualifying features needed to maximize the potential of technology in the classroom. The purpose of this study is to look at the knowledge structures of TPACK and examine them in designing instruction units.

The preparation of teachers in the educational uses of technology appears to be a key component in almost every improvement plan for education and educational reform efforts (Conference Board of Mathematical Sciences, 2001; International Society for Technology in Education, 2007; Mathematics Association of America, 1991; National Council for Accreditation of Teacher Education, 2002; National Council of Teachers of Mathematics, 2000; Partnership for 21st Century Skills, 2008). The research literature, in keeping with national and international recommendations, provides supporting evidence that technology can enhance students' understanding of mathematics concepts (Graham & Thomas, 2000) and improve their achievement (Bos, 2007; U.S. Department of Education, 2009; Wenglinsky, 2005). Furthermore, technology use has been found to improve classroom experiences for students (Doerr & Zangor, 2000; Guerrero, Walker & Dugdale, 2004).

Yet, the lack of a theoretical and conceptual framework to inform and guide research in the area of teaching with technology is a major weakness in the educational technology literature (Angeli, 2005; Angeli & Valanides, 2005; Koehler & Mishra, 2008; Margerum-Lays & Marx, 2003; Mishra & Koehler, 2006; Niess, 2005; Selfe, 1990; Willis & Mehlinger, 1996; Wilson, 2003; Zhao, 2003). As Selfe (1990) stated, “Until we share some theoretical vision of this topic [teaching with technology], we will never glimpse the larger picture that could give our everyday classroom efforts direction and meaning” (p. 119).

In recognizing the lack of a sound theoretical orientation to guide teachers in technology integration, researchers initiated research efforts for the purpose of developing theory and models to ground research in the area of teacher cognition about technology integration (Angeli, 2005; Angeli & Valanides, 2005; Margerum-Lays & Marx, 2003; Mishra & Koehler, 2006; Niess, 2005). Recently, considerable interest has emerged around the knowledge structures of technology, pedagogy, and content knowledge (TPACK; or technological pedagogical content knowledge in Mishra & Koehler, 2006) as a framework for teaching preservice and in-service teachers needed for effective technology integration. The TPACK framework describes how teachers' understandings of technology, pedagogy, and content can interact with one another to produce effective mathematics-based teaching with educational technologies.

The purpose of this study was to use the TPACK framework with practicing teachers as they developed instructional units using Web 2.0 instructional tools and mathematical objects to verify whether technology increased their knowledge and enabled them to assimilate technology into an instructional unit adhering to TPACK.

What does TPACK look like when determining websites for instructional units in the mathematics classroom? To focus on the use of technology, standards from the International Society for Technology in Education (2007) and Partnership for 21st Century Skills (2008) were used to gauge use of technology complementing TPACK structures.

The following sections include a literature review of TPACK, the teacher's role in curriculum development, and a discussion on fidelity of treatment. Fidelity of treatment requires a closer look at TPACK's components—pedagogical, mathematical (content), and technological—and cognitive fidelity is added for the purpose of conceptual knowledge development. Graduate in-service teachers were examined as they explored TPACK components as curriculum designers.

Literature Review

Recognizing the complex, ill-structured nature of teaching and technology, the “wicked problem” coined by Rittel and Webber (1973), researchers advocated the need to develop a new body of knowledge that included an extension of Shulman's (1987) pedagogical content knowledge (PCK) into the domain of teacher training. Mishra and Koehler (2006) offered their TPCK framework for teacher knowledge as a complex interaction among three bodies of knowledge: content, pedagogy, and technology. “They described how these bodies of knowledge interact, theoretically, and in practice, to produce the type of flexible knowledge needed to successfully integrate technology in the classroom” (Mishra & Koehler, 2006, p. 3).

Content knowledge is deep knowledge about actual subject matter that is to be learned. Pedagogical knowledge is multifaceted information about the processes and practices or

methods of teaching and learning and encompasses overall educational purposes, values, and aims. "Pedagogical knowledge," according to Koehler and Mishra (2008), "requires an understanding of cognitive, social and developmental theories of learning and how they apply to students in the classroom" (p. 14).

Grandgenett (2008) identified TPACK pedagogical strategies teachers need to strive to know as "where" their students are conceptually, "what" they need to do to achieve the next step in an instructional process, and "how" they generally want their students to proceed through careful sequences of classroom interactions and tasks (p. 158).

Technology knowledge is in continuous flux and requires a deep and essential understanding as well as a mastery of technology for information processing, communication, and problem solving. Technological content knowledge is seen as representing mathematics concepts through the use of technology in the most accurate and conceptual way possible. Some concepts are easier to represent than others, which creates a challenge.

One must understand how teaching and learning changes when particular technologies are used. Since pedagogical knowledge embraces various uses of technology for different purposes, seeking the appropriate technology for the learning goal suggests that the teacher maximizes the interactive potential of technology whenever possible. With the importance of the interchange between these constructs, TPCK has changed to TPACK, to emphasize the integration of technology, pedagogy, and content knowledge in the design of instruction for learning mathematics with technologies. (Niess, 2008; Thompson & Mishra, 2007).

Cognitive complexity must play a lead role when using the TPACK model in an educational setting. Persons who are high in cognitive complexity are able to analyze (i.e., differentiate) a situation into many constituent elements and then explore connections and potential relationships among the elements; they are multidimensional in their thinking. Complexity theory assumes that the more an event can be viewed from different perspectives and the parts considered in new relationships, the more sophisticated the response and successful the solution. "While less complex people can be taught a complex set of detailed distinctions for a specific context, high complexity people are very flexible in creating new distinctions in new situations" (Streufert & Swezey, 1986).

The more developed the cognitive complexity created by the use of technology, the greater the value of the construct. Cognitive complexity is possible when technology is used to make abstract concepts more concrete (Kaput, Hegedus, & Lesh, 2007). In education the purpose of improving cognitive complexity while using knowledge structures defined by TPACK is to recognize technology as a conceptual tool. When referring to the features of TPACK, for the purpose of this paper, cognitive complexity is included along with the knowledge structures pedagogy, mathematical content, and technology.

Teachers as Curriculum Designers

Koehler and Mishra (2008) argued that because of the complexity of developing and applying TPACK a greater emphasis should be placed on the idea of teachers as "curriculum designers." This study created opportunities for in-service teachers to explore the workings of TPACK by designing an instructional unit using pedagogical, mathematical, and cognitive fidelity with technology available on the Web. A group of experienced, practicing elementary teachers in a graduate class were divided into groups

and asked to design and develop digital-age learning environments. The assignment was to develop a problem- or project-based instructional unit suitable for the 21st-century learners using TPACK's knowledge structures.

A problem-based learning environment was developed by starting with a driving question that would function as a motivating entry point for an investigation or problem. The practicing teachers were divided into groups of four to five teachers. A class wiki on [PB Works](#) with folders for each assigned group was created, providing a collaborative learning environment for teachers to work on the project. Specific pages were made for activities used in the development of the instructional unit. A page was allocated for concept maps using [bubbl.us](#), another page for the calendar (formed using the PB Works dropdown menu), and a page for the table of contents for the lesson plans (also formed by the table of contents option in the dropdown menu). (**Editor's note:** URLs for all websites can be found in the [Resources](#) section at the end of this paper.)

The performance assessment was to be found on another page and included a rubric made with [Rubistar](#). An instructional video was created by narrating directions for using an interactive mathematics website using [Jing](#). [Delicious](#), a social bookmark service, was used to make the resource page.

The instructional unit incorporated Web 2.0 technology, [bubbl.us](#), [Rubistar](#), [Jing](#), [PB Works](#), and [Delicious](#) to create Web activities in which students could use Web 2.0 technology during the teachers' instructional units. Through creating opportunities to use technology in innovative, creative ways the practicing teachers attempted to create 21st-century learning environments using TPACK. To assure pedagogy, mathematical content, and cognitive complexity were used in keeping with high educational standards, treatment construct fidelity was examined. Thirty practicing elementary teachers from urban at-risk school districts were followed and observed using TPACK's knowledge structures and cognitive fidelity as they developed elementary mathematics units.

Treatment Fidelity

Fidelity of treatment in outcome research refers to confirmation that the manipulation of the independent variable occurred as planned (Moncher & Prinz, 1991, p. 247). The independent variables are pedagogy, mathematical content, cognitive complexity, and the use of technology. Verification of fidelity was needed to ensure that fair, powerful, and valid comparisons of replicable treatments would be made. As part of the process to assure a common language on the part of all participants and to establish a pattern for construct validity, teachers engaged in an activity to search the Web for sites that exemplified mathematical, pedagogical, technological, and cognitive fidelity in order to develop a collective catalogue of websites to use in developing lessons. Instead of merely locating sites on a certain subject or topic, they were challenged to find webpages that typified TPACK and had a high level of cognitive complexity.

Individually, teachers given the assignment to look for websites containing interactive activities that use mathematically accurate and pedagogically sound representations failed to take into consideration the value of the environment's cognitive potential. Cognitive complexity implies that mathematical objects are manipulated to discover rich mathematical patterns. The patterns were often difficult to find, and some of the teachers suggested sites with distracting moving objects and dazzling colors. Justifying their choice, they explained how entertaining and enjoyable these sites would be for their students; therefore, they would spend more time on the site. Yet the site's mathematical content was minimized by all the confusing action and bright colors.

Other teachers picked sites that involved fill-in-the-blank activities with interactive feedback. Though mathematically correct, the chosen activities were often reflective of the typical worksheet and reinforced rote memorization rather than building conceptual understanding. Teachers were usually surprised when they realized that technology is underutilized when used only to practice skills. After looking at a few sites from the [National Library of Virtual Manipulatives](#), teachers were able to see how conceptual understanding develops from observing how a pattern emerges through the use of multiple representations and by manipulating key mathematical objects.

Playing upon gaps in teachers' own understanding, the class discussion focused on the Web design principles of pedagogical, mathematical, and cognitive fidelity TPACK was discussed as providing the knowledge structures that afford the big picture or theoretical framework, but to be effective and focused, fidelity of treatment assures conceptual development and adds to cognitive complexity. A webpage with interactive mathematical objects, it was determined, must not only fit the driving question but be identified as having pedagogical, mathematical, and cognitive fidelity. Realizing that teachers needed to be faithful to the constructs meant further defining pedagogical, mathematical, and cognitive content fidelity.

A search of the literature revealed to the teachers that pedagogical fidelity refers to the art and science of teaching. Zbiek, Heid, Blume, and Dick (2008) further described the pedagogical fidelity of technology as “the extent to which teachers (as well as students) believe that a tool allows students to act mathematically in ways that correspond to the nature of mathematical learning that underlies a teacher's practice...” (p. 1187). To accomplish this purpose the mathematical manipulation of objects is logical and natural to the action performed. It follows that the pedagogy shown in the technology-driven activities stress active participation and have mathematical objects that are appropriate for the age and type of activity. Pedagogical fidelity takes features of pedagogy and applies them to the student's manipulation of mathematics objects. Pedagogical fidelity implies that mathematical manipulation is logical and doable, stresses active participatory learning, and strives for mathematics objects that are appropriate for the age level and activity.

According to Zbiek et al. (2007), in order to function effectively as a representation of a mathematical “object,” the technology-generated representation must be faithful to the underlying mathematical properties of that object. The actions taken and the resulting behavior should accurately reflect the expected mathematical characteristics and behavior. The degree to which this takes place reflects its mathematical fidelity. Mathematical fidelity maximizes the use and interpretation of patterns to develop conceptual understanding at a deep and lasting level. According to Grandgenett (2008), “For those who take the time to look more deeply, mathematics often represents a rich and dynamic excursion into trying to know and control our world through its patterns.”

Mathematical fidelity implies that the activity is believable, is concrete, and relates to how mathematics is a functional part of life. Multiple representations and manipulative mathematics objects add strength to an understanding of mathematical patterns. The Web opens numerous doors to greater meaningful application of mathematics if the websites are carefully examined for mathematical fidelity.

Dick (2008) referred to the degree to which the cognitive tool's actions explicitly reflect the user's cognitive action as cognitive fidelity. Cognitive fidelity uses mathematical objects to construct and deconstruct, test, and revise to understand the patterns and structure of concepts. Manipulating the patterns leads to greater flexibility and comprehension, as it encourages students to reflect on their own understanding and build

higher order thinking. The use of technology creates a mathematical experience that fosters creativity, deepens conceptual understanding, and develops connections to create memorable schema bonding all three interlinked fidelities. Together they are reflective of the interactive, communicative, and informational capacities of technology.

The following sections describe the methods and results of how the in-service teachers investigated and used TPACK in building instructional units. The final products are described in terms of the technology used and their impact on the pedagogical, mathematical, technological, and cognitive fidelity of the instruction unit. A peer evaluation of the final unit was conducted, and the results are provided to indicate a rating of final projects and that a variance did exist.

Method

This study examined qualitatively and quantitatively 30 elementary teachers from urban, high at-risk, K-5 schools who were enrolled in a graduate elementary number concepts course. The purpose of the study was to determine how learning about the integrated use of technology, pedagogy, mathematics content, and cognitive complexity would affect their knowledge structure base and help them in constructing instructional units that adhere to the International Society for Technology in Education (2007) and Partnership for 21st Century Skills (2008) suggested guidelines. The 30 teachers, 29 female and 1 male, had a mean teaching experience of 5 years and represented four school districts. All teachers enrolled in the course agreed to participate in the study.

The purpose of this study was to use the TPACK framework with practicing teachers, as they developed instructional units using Web 2.0 instructional tools and mathematical objects to verify whether technology increased their knowledge and enabled them to assimilate technology into an instructional unit adhering to TPACK. It considered what the use of TPACK looks like when determining websites for instructional units in the mathematics classroom.

Teachers were asked after examining websites with high and low fidelity according to criteria (see Table 1) to determine a website they could use in the development of their instructional unit that had pedagogical, mathematical, and cognitive fidelity and to justify their choices. All terms were defined prior to the assignment. Justifications were examined to determine teachers' understanding of the terminology when applied to a mathematical object on a webpage.

After completing this activity and determining a website that exemplified instruction suitable for conceptual learning in the classroom, the practicing teachers in groups of 4 or 5 developed an instruction unit. Lessons were designed to include one of their websites determined to have fidelity, including cognitive complexity. The class was divided into eight groups, and each group prepared its own instructional unit. On completion groups formally presented their units, discussing their integrated use of mathematical content, pedagogy, and technology. Members of the class were then asked to peer evaluate each group's presentation using a 1 to 5 scale; 1 indicated the statement made was not at all true, while 5 was very true. They were asked to rate the following statements:

- Unit draws upon the team's creativity and encourages students to be creative.
- Technology, pedagogy and content are blended. One does not stand out more than another. They support each other connecting curriculum content in a meaningful way.
- Instructional opportunities are problem driven.

- Unit is flexible enough to reach the needs of all students.
- Technology is used effectively.
- Students were encouraged to take intellectual chances.

The criteria used for students to evaluate instructional units, the six statements above, were derived from TPACK, the International Society for Technology in Education (2007) and Partnership for 21st Century Skills (2008). A paired *t*-test was used to evaluate the means to look for trends.

Table 1
Relationship of Unit Evaluation Statement to Sources

Unit Evaluation Statement	International Society for Technology in Education (2007)	The Partnership for the 21st Century (2008)	TPACK
Unit draws upon the team's creativity and encourages students to be creative.	1. Facilitate and Inspire Student Learning and Creativity	Creativity and Innovation	Pedagogy, Cognitive
Technology, pedagogy and content are blended.	3. Model Digital-Age Work and Learning	Apply Technology Effectively	TPACK
Instructional opportunities are problem driven.	2. Design and Develop Digital-Age Learning Experiences and Assessments	Think Critically and Problem Solve	Pedagogy, Cognitive
Unit is flexible enough to reach the needs of all students.	4. Promote and Model Digital Citizenship and Responsibility	Flexibility and Adaptability	TPACK
Technology is used effectively.	4. Promote and Model Digital Citizenship and Responsibility	Apply Technology	Technology Mathematical
Students were encouraged to take intellectual chances.	1. Facilitate and Inspire Student Learning and Creativity	Creativity and Innovation	Pedagogy/ Cognitive

Results

Justification for Fidelity

Matching the definitions to similar patterns in the applied use of pedagogy, mathematical knowledge, and cognitive complexity revealed interesting findings. In developing their instructional units, teachers were to find one interactive cognitive website that had high mathematical and pedagogical fidelity and incorporate it into their unit. Once they found such a site, teachers wrote justifications on why they felt the site met the high standards for mathematical, pedagogical, and cognitive fidelity.

Their rationalizations were revealing, and many appeared to encounter frustration. One young woman reported that she thought finding an interactive activity with high fidelity was impossible. She felt that multiple sites would be necessary. Some indicated indirectly that the Internet is informational rather than interactive and saw the Internet as a platform for finding other lesson plans rather than a forum for interactive manipulatives that can be used to generate greater conceptual understanding.

In their assigned groups they critiqued many sites. Yet, through their struggles each group arrived at one site that displayed pedagogical, mathematical, and cognitive fidelity, one that exemplified TPACK's effect on cognitive power and fit the intent of their unit. This process was far from linear or simplistic. After struggling to find meaningful interactive mathematical objects suitable for their units and making a second attempt at verbalizing their justifications for the use of their chosen site, they developed well-reasoned justifications. The [appendix](#) provides examples their final thoughts after looking at three mathematical interactive websites.

There is a danger in isolating the different knowledge structures in TPACK. Mishra and Koehler (2006, p. 1029) indicated that taking the knowledge structures apart would destroy the strength of the interconnectedness of the unified model and, thereby, misrepresent the TPACK model. By determining treatment of fidelity the attempt is a matter of quality, representing their embodiment with as much accuracy as possible to preserve the integrity of the model, rather than replace it or minimize it. Each component of TPACK is intrinsically linked to the other by purpose of concept development through the use of technology, and the bonds are intertwined. By going through the process of rationalizing the different fidelities, however, teachers become better and somewhat intuitive when recognizing a site's overall fidelity to TPACK.

Web 2.0

Web 2.0 technologies became feature tools for making the wiki useful and were used in ways that enhanced mathematical, pedagogical, and cognitive fidelity. The Web 2.0 tools enabled collaboration, flexible navigation, and teacher input and made accessibility to the mathematical content easier. Teachers were able to produce products that reflected mathematical understanding. The Web 2.0 tools the teachers were to use to make their unit plans also served as catalysts for enacting their units in their classrooms. Many teachers went beyond the use of tools planned by the instructor to include other Web 2.0 tools that met the needs of elementary-age students to help them collaborate, navigate, give input, enhance mathematical content, and produce personalized products.

Web 2.0 tools planned by the instructor for building the basic components of the unit included a wiki. A wiki is an online collaborative tool used to post websites, calendars, rubrics, videos, text documents, and pictures. Below each entry on a wiki page was a place to enter comments. This space was where the instructor could ask for clarifications, and team members would respond. Much as in a discussion group, the administrator was able to monitor and offer appropriate questions, and team members could collaborate online. Communication is one use of digital technologies that a wiki encourages, enabling teachers to share documents and ask questions in one common place. The wiki as a tool to communicate and collaborate gave pedagogical fidelity to the developing units. The two wikis (<http://mathmasterminds.pbworks.com> and <http://mathmastermindgeometry.pbworks.com>) index the various instructional units.

With the essential elements of the instructional unit (background information, concept map, calendar, lesson plans, assessments, and resources) in predesignated pages for the unit, teachers were persuaded to be creative and use technology to enrich their

instructional unit as would best enhance the pedagogy, mathematical content, and cognitive complexity. The website carefully chosen with high mathematical, pedagogical, and mathematical fidelity for the unit was turned into an instructional video using Jing, a screen capturing tool (see <http://mathmasterminds.pbworks.com/f/graphing+website+presentation.swf>). The teacher recorded directions and demonstrated using the interactive features of the website, as the tool captured the audio and webpage motion in the form of a video. The technology tool helps clarify directions and procedures for the student, providing on-demand instructions, thereby improving pedagogical fidelity.

Some groups also included YouTube videos (see Video 1 below and on the [PB Works wiki](#)) that could be used in presenting content in lessons in their instructional units. The videos were carefully chosen to fulfill an instructional purpose and reinforce the mathematical and pedagogical fidelity. [Glogster](#) is a poster making tool that supports photos, links to videos, and music. Glogster was used by a group of teachers as the framework for a child friendly table of contents that connected to many instructional websites (see <http://mathmastermindgeometry.pbworks.com/w/page/24462033/4-Technology-Integration>). The hotspots led to new websites that developed the concept of symmetry. Through active involvement of the students and giving them choices, the teacher showed high instructional pedagogical fidelity. Glogster is student friendly and personalizable, making it an excellent tool for encouraging engagement.

Video 1. Tessellation in Quilts. This video can also be found on the PB Works wiki (<http://mathmastermindgeometry.pbworks.com/w/page/23033396/GM-Background%20Information>)

A visual vocabulary map included in one lesson had the teacher's students making [wordles](#) out of vocabulary words (see <http://mathmasterminds.pbworks.com/w/page/4063173/Garden-Club-Background-Information>). The visual affect of combining words and then seeing the relationship between commonly related terms strengthens pedagogical fidelity. On one website [Blabberize](#) was used to teach vocabulary, [Voicethread](#) to narrate the choice of different seeds for the garden they were building, and [Animoto](#) to animate the different pictures taken when the students planted the seeds (see all three by scrolling down at <http://mathmasterminds.pbworks.com/w/page/4862992/13-Greens-'n-Things-Technology-Integration>). The technology tools were used for developing vocabulary and providing examples, and the photos reinforced the process of seed growth.

Teachers shared pictures taken by students with flip cameras as they worked on their unit (see <http://mathmastermindgeometry.pbworks.com/w/page/24462018/3-Photo-Gallery>). The visual images illustrated unit content and suggested its possible use. One group included an instructional [Voki](#) speaking avatar that introduced and gave closure to their unit (see <http://mathmasterminds.pbworks.com/w/page/4841690/2-Breakfast-Club-Concept-Map>). It was the making of the Voki, taking on another identity and composing the opening and closing, that empowered the Voki's pedagogical fidelity. As a tool for students the Voki motivates students to participate, nourishes creativity, personalizes relationship between teacher and student, and encourages language development and communication. Interactive resources on the websites provided additional ideas on how to present the content and encouraged students to be actively involved (see <http://mathmastermindgeometry.pbworks.com/w/page/24863139/TG-Interactive->

[Websites](#)). Teachers' games, video, and books bookmarked using Delicious are found on a resources page (see <http://mathmastermindgeometry.pbworks.com/w/page/24038422/Mathews-Mathematicians-Resources>).

Much of the upsurge of Web 2.0 technology on each group's wiki can be traced back to one teacher who served as her school's technology specialist. Her use of technology ignited a ripple effect because of the community of learners created by the wiki and its group discussion capabilities; no one wanted to be left behind. If this class of teachers is any indication, the climate is right for TPACK and the development of a research platform for examining some of the many learning opportunities provided. In the selection of Web 2.0 resources some were tools to communicate and collaborate and others were for inquiry. Most reflected the knowledge structures of TPACK through student actions.

Another lesson learned from observing the instructional units was how empowering technology can be for the student. TPACK curriculum has the potential for deepening personal knowledge, extending mathematical understanding, and initiating content driven conversations through student use of cognitive tools. These results were seen in the use of Glogster, Vokis, Voicethread, and Blabberize where students communicated mathematical ideas. At the click of a mouse videos explained terms, gave directions, showed directions, or illustrated process-strengthened mathematical understanding through effective student-oriented pedagogy and, thereby, promoted cognitive complexity.

Peer Evaluation of Problem-Based Unit Results

On completion of their instructional units, the teachers in their groups orally presented the unit, making sure they talked about the unit's pedagogical content, mathematical content, technology integration, and cognitive connections. Using a 5-point scale they evaluated each presentation using the questions found on Table 1, derived from the International Society for Technology in Education, the Partnership for the 21st Century, and the TRACK guidelines (see appendix). The results were then assessed and analyzed using a *t*-test (Table 2).

Table 2
Presentation Rubric Results

Statements	<i>M</i>	<i>SD</i>	<i>t</i> (30)
Unit draws upon the team's creativity and encourages students to be creative.	4.69	.25	53.57***
Technology, pedagogy, and content are blended.	4.56	.38	34.16***
Instruction opportunities problem driven.	4.55	.37	35.12***
Unit flexible enough to meet all student needs.	4.60	.35	37.56***
Technology is used effectively.	4.49	.29	44.53***
Students encouraged to take intellectual risks	4.53	.35	36.20***
*** $p < .001$			

Results of the statistical analysis of the data from the evaluations indicated that the overall mean was 4.6 out of a possible 5, showing all characteristics to be true to very true for the class. What is interesting but not statistically significant is that the statement, "Technology is used effectively," received the lowest average score, but 4.49 is still *true* and close to *very true*. As an area of growth it is understandable that many would still feel technology could be used to enhance instructional goals better. The overall average and each statement's average would have been higher if not for one group. This group had the lowest scores, with a total mean score of 3.8 that was statistically significantly lower than the other groups' scores.

The lowest scores came from a group of teachers within the same district that had limited technology opportunities due to lack of computers in the classroom and on the campus. They felt fortunate to have recently received some older, well-used computers for school purposes even though the computers lacked Web-friendly capacities. None of the four teachers in the group were comfortable loading pictures or documents. They felt that any effort they put into the project would not be carried through in their classrooms and, therefore, they were not motivated to explore the capabilities of technologies. They were especially discouraged after seeing other campuses receive more technology resources. Lack of resources is still a very real issue.

Implications

Teacher's knowledge of mathematical, pedagogical, and technological fidelity used to develop cognitive complexity, in keeping with the TPACK framework, was not a natural or culturally engendered process as appears in the business world or in the personal lives of students. It takes a deliberate, conscious, and analytical effort on the part of teachers to develop the knowledge sets to develop meaningful curriculum optimizing technology with mathematical, pedagogical, and cognitive fidelity. The attitude still exists that there is no real need for technology and that what worked in the past in education works today. Therein lies the problem. Society has changed and schools have not. What has been learned from studying the 30 practicing teachers is that change is occurring, but the change must be based on sound principles to be meaningful. Teachers need to use technology that will lead to conceptual understanding through instructional strategies that focus on knowledge structures of pedagogical, mathematical, and cognitive fidelity.

Also noticed in the preparation of this study was lack of clarity in the TPACK construct that connects it to teacher practice as shown by instructional units. The units applied mathematical content, student-driven pedagogy, and interactive technology. Just as the teachers had trouble determining the cognitive strength of the tool, however, a weakness appears in the construct. Identifying the parts, as noted by Mishra and Koehler (2006), does not embody the cognitive nature intended in the TPACK structure. It may be easy to identify a teacher who integrates the knowledge structures efficiently and effectively, but identifying why and how this works for one teacher and not for another following the same construct is unclear. Cognitive awareness, attentiveness to what actions on mathematical objects produce cognitive schema, and their pedagogical, mathematical, and technological connections need to be taught and emphasized either as another strand or a noteworthy part of pedagogical recognition. A definition of TPACK's knowledge structures in an applied and workable fashion is still evolving.

What does this mean for the practicing teacher? If mathematical and technology knowledge are to be used in ways that are cognitively strong, they must be used in developing schema that pull from the best pedagogy possible. Patterns need to be manipulated. Another keystone is communicating mathematical ideas aided by technology. Varied representations, illustrations, graphs, verbalization, and drawings

need to be correlated, meaningful, and interactive. A thorough knowledge of pedagogy is good; applying it is critical. Most impressive about the products produced by the teachers in the study was the many varied ways they represented concepts using integration of literature, science, and social studies. The more mathematical connections that were made, the stronger the cognitive structure became.

This study could benefit from carryover into the classroom to see how teachers' actions affect students' conceptual understanding after using technology appropriately. Since the results represent the first step in a 2-year study, the researcher will be able to see if TPACK with cognitive fidelity will impact the teachers' choices and actions in the classroom and study students' performance on state-mandated mathematics tests.

Conclusion

What does the use of TPACK look like when teachers are asked to determine websites for instructional units in the mathematics classroom? The instructional units produced by the teachers involved in this study portray a clear picture of student involvement. The pedagogy was demonstrated in the use of Web 2.0 that enabled elementary students to communicate mathematically. Many of the tools made the mathematical objects embedded on different sites more accessible. Most of the Web 2.0 tools were pedagogically sound and enabled more time to be spent on the mathematics, communicating and operating mathematical objects. Transitions were student friendly, inviting, and personalized through the use of Glogster, Voki, and Blabberize. Jing helped to create student-friendly directions for learners to follow. Voicethreads, Voki, and Blabberize assisted students in organizing and communicating their thinking.

Websites carefully chosen for their cognitive complexity and mathematical content enhanced learning opportunities. Wordles stressed the importance of mathematical vocabulary. The project-based setting with driving questions provided the background for all the Web 2.0 tools to be used to think critically and problem solve. YouTube and Discovery Education (formerly United Streaming) served as sources for information for answering the driving question. The wiki served not only as a collaborative site for the teachers but teachers created wikis for their students and parents, where posted student products could be seen only by class members and their families. The uses of pedagogical, mathematical, and cognitive fidelity are viable and discernable components that in the true intent of TPACK embrace a unified framework for the instructional units.

The results of this study suggest that experienced teachers can see the importance of knowledge about pedagogical and mathematical content through their interactions with technology and that they also can find value in the creative and problem-solving capacity of technology. Teachers realized that the instructional choices they make are not easy, and inequities in technology exist in schools that may limit their ability to commit to TPACK. They all concurred, however, that TPACK provides a theoretical foundation for the 21st-century teacher. The transition from a casual relationship with technology to a more connected bond built on an understanding of appropriate student-oriented pedagogy, conceptualized mathematical content, and cognitive complexity can lead to more teachable moments with technology as the manipulated medium and arm of instruction rather than as a glitzy add-on.

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Resources

Animoto - <http://animoto.com/>

bubbl.us - <https://bubbl.us>

Blabberize - <http://blabberize.com/>

delicious - <http://www.delicious.com/>

Glogster - <http://www.glogster.com/>

GM-Background Information -

<http://mathmastermindgeometry.pbworks.com/w/page/23033396/GM-Background%20Information>

IXL Kindergarten Practice: Count to 10 -

<http://www.ixl.com/math/practice/kindergarten-count-to-10>

Jing - <http://www.techsmith.com/jing/>

Learning with NCES Kids' Zone: Create a Graph -

<http://nces.ed.gov/nceskids/createagraph/>

Math Warehouse: Online Bar Graph Maker -

<http://chartmaker.mathwarehouse.com/online-bar-graph-maker/>

National Library of Virtual Manipulatives - http://nlvm.usu.edu/en/nav/topic_t_1.html

PB Works - <http://pbworks.com>

Rubistar - <http://rubistar.4teachers.org/>

Discovery Education (formerlyUnited Streaming) - <http://unitedstreaming.com>

VoiceThread - <http://voicethread.com/>

Voki - <http://voki.com>

Wordle - <http://www.wordle.net/>

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**Appendix
Justification for Website**

Fidelity	<u>IXL Kindergarten Practice: Count to 10</u>	<u>Learning with NCES Kids' Zone: Create a Graph</u>	<u>Math Warehouse: Online Bar Graph Maker</u>
Pedagogical	<p>This website is easy to navigate and makes sense. It is designed to help in the area of problem solving. I like that it is a site for the entire family not just the child. This helps parents explain, manipulate and expand upon the mathematics challenges. Often as a parent I am limited on my explanation as to why it works. I will admit it is not very appealing to the eye. It will turn a visual child off. However, once into it, the child will experience success with use. It contains many mathematics lessons everything from counting to algebraic equations.</p>	<p>This website provides a tutorial for each type of graph to be completed. There is also a help section with definitions and a tab with examples. However, each tab provides choices for the user to select, which make it very easy to use. I really like that students are able to make a lot of choices about their graph including the type of graph, how it is labeled and titled, and the scale of the graph. It allows them to manipulate how their data is represented. They can easily see how a slight change in these variables can drastically affect how their data is read and interpreted.</p>	<p>Students actively label bar graph x and y axis with correct data appropriate for fourth-grade students from the research developed on nutrition in the cafeteria. Esthetically pleasing and engages students actively.</p>
Mathematical	<p>This website has high fidelity. It relates to the real world and it gives you the opportunities to apply the answers.</p>	<p>This website allows students to represent their data in multiple graphs, such as line, circle, and bar graphs. I really like how each tab used during the creation process requires students to apply and understand the appropriate vocabulary for graphing. Words such as: legend, horizontal, vertical, minimum, maximum, and data set are all used in an authentic way. It also requires students to insert their own, authentic data. It serves as an extension to the data they have already collected. In this context, students are now organizing their data. Once they have</p>	<p>The bar graph is mathematically correct. Its design and results maximize student understanding of the data virtually and it allows students to manipulate the parts of the graph to ensure correctness.</p>

		created their graph, they can save and print it for analysis.	
Cognitive	This website has high fidelity. This site makes sense. It enables children to see the steps that are involved in the arriving at the answer. It walks through step by step and allows the child to see explanations of why. It also contains a way for the students to interact with the program. The student can choose the level and it gives you the opportunity to check yourself.	This website allows students to gain a deeper understanding of graphing. They can easily and quickly see how manipulating certain aspects of the graph can affect how their data is interpreted. After choosing all the elements of their graph, students can preview the graph, and then go back and change certain features. For example, they may notice that to read their graph more accurately they might need to have more gridlines or they might notice that they need to add a legend.	Students can manipulate the bar graph to construct and demonstrate the data with student understanding and reflect what student depth of knowledge.

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