The Technological Pedagogical Content Knowledge Framework

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Matthew J. Koehler, Punya Mishra, Kristen Kereluik, Tae Seob Shin, and Charles R. Graham

Abstract

In this chapter, we introduce a framework, called technological pedagogical content knowledge (or TPACK for short), that describes the kinds of knowledge needed by a teacher for effective technology integration. The TPACK framework emphasizes how the connections among teachers' understanding of content, pedagogy, and technology interact with one another to produce effective teaching. Even as a relatively new framework, the TPACK framework has significantly influenced theory, research, and practice in teacher education and teacher professional development. In this chapter, we describe the theoretical underpinnings of the framework, and explain the relationship between TPACK and related constructs in the educational technology literature. We outline the various approaches teacher educators have used to develop TPACK in pre- and in-service teachers, and the theoretical and practical issues that these professional development efforts have illuminated. We then review the widely varying approaches to measuring TPACK, with an emphasis on the interaction between form and function of the assessment, and resulting reliability and validity outcomes for the various approaches. We conclude with a summary of the key theoretical, pedagogical, and methodological issues related to TPACK, and suggest future directions for researchers, practitioners, and teacher educators.

Keywords

TPACK • Professional development • Teacher knowledge • Technology integration

Introduction

The increasingly ubiquitous availability of digital and networked tools has the potential to fundamentally transform the teaching and learning process. Research on the instructional uses of technology, however, has revealed that teachers often lack the knowledge to successfully integrate technology in their teaching and their attempts tend to be limited in scope, variety, and depth. Thus, technology is used more as "efficiency aids and extension devices" (McCormick & Scrimshaw, 2001, p. 31) rather than as tools that can "transform the nature of a subject at the most fundamental level" (p. 47).

One way in which researchers have tried to better understand how teachers may better use technology in their classrooms has focused on the kinds of knowledge that teachers require

Matthew J. Koehler and Punya Mishra have contributed equally to this chapter. We rotate authorship in our writing.

M.J. Koehler (✉) • P. Mishra
Michigan State University,509 Erickson Hall,
East Lansing, MI 48824, USA
e-mail: mkoehler@msu.edu; punya@msu.edu

K. Kereluik
Michigan State University, 401 Erickson Hall,
East Lansing, MI 48824, USA
e-mail: kereluik@msu.edu

T.S. Shin
Hanyang University, Rm 509 College of Education, 222 Wangsimni-ro,
Seongdong-gu, Seoul 133-791, Republic of Korea
e-mail: shinster@hanyang.ac.kr

C.R. Graham
Brigham Young University, 301 MCKB BYU, Provo, UT 84602, USA
e-mail: charles.graham@byu.edu

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in order to use technology more effectively. Shulman (1986) proposed that effective teaching requires a special type of knowledge, pedagogical content knowledge (or PCK), that represents "the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (p. 8). The central idea of PCK is that learning to teach a particular subject matter requires not only understanding the content itself but also developing appropriate instructional strategies and skills that are appropriate for learners.

Mishra and Koehler's (2006) formulation of the technological, pedagogical, and content knowledge (TPACK) framework extended Shulman's (1986) characterization of teacher knowledge to explicitly consider the role that knowledge about technology can play in effective teaching. Specifically, three major knowledge components form the foundation of the TPACK framework as follows:

- *Content knowledge* (*CK*) refers to any subject-matter knowledge that a teacher is responsible for teaching.
- *Pedagogical knowledge* (*PK*) refers to teacher knowledge about a variety of instructional practices, strategies, and methods to promote students' learning.
- *Technology knowledge* (*TK*) refers to teacher knowledge about traditional and new technologies that can be integrated into curriculum.

Four components in the TPACK framework, address how these three bodies of knowledge interact, constrain, and afford each other as follows:

- *Technological Content Knowledge* (*TCK*) refers to knowledge of the reciprocal relationship between technology and content. Disciplinary knowledge is often defined and constrained by technologies and their representational and functional capabilities.
- *Pedagogical Content Knowledge* (*PCK*) is to Shulman's (1986) notion of "an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (p. 8).
- *Technological Pedagogical Knowledge* (*TCK*) refers to an understanding of technology can constrain and afford specific pedagogical practices.
- *Technological Pedagogical Content Knowledge* (*TPACK*) refers to knowledge about the complex relations among technology, pedagogy, and content that enable teachers to develop appropriate and context-specific teaching strategies.

The TPACK framework suggests that teachers need to have deep understandings of each of the above components of knowledge in order to orchestrate and coordinate technology, pedagogy, and content into teaching. Most importantly, TPACK is an emergent form of knowledge that goes beyond knowledge of content, pedagogy, and technology taken individually but rather exists in a dynamic transactional relationship (Bruce, 1997; Dewey & Bentley, 1949; Rosenblatt, 1978) between the three components (Koehler & Mishra, 2008; Mishra & Koehler, 2006). An important part of the TPACK framework is that TPACK does not exist in a vacuum but rather is grounded and situated in specific contexts as represented by the outer dotted circle in the TPACK diagram.

Relationship Between TPACK and Similar Constructs

The TPACK framework is not the only framework developed to understand and explain teachers' use of technology. Though these alternative approaches may employ slightly different labels they are in broad agreement that the advent of new technologies requires teachers to possess knowledge that connects the affordances (and constraints) of these new technologies to the transformation of content and pedagogy. Our focus on the TPACK framework (as opposed to the others) in this review is that amongst the similar and related approaches, the TPACK framework has received the most traction in research and in professional development approaches, as evidenced by over 600 journal articles about TPACK.

Similar frameworks have been developed both independently and directly out of the TPACK framework, most based upon Shulman's (1986) model of Pedagogical Content Knowledge Similar frameworks include (but are not limited to): *ICT-Related Pedagogical Content Knowledge* (ICT-Related PCK); *Knowledge of Educational Technology*; *Technological Content Knowledge*; *Electronic Pedagogical Content Knowledge* (ePCK); and *Technological Pedagogical Content Knowledge-Web* (TPCK-W) (Angeli & Valanides, 2005; Franklin, 2004; Lee & Tsai, 2010; Margerum-Lays & Marx, 2003; Rhonton & Shane, 2006; Slough & Connell, 2006). Each of these alternative approaches are briefly defined below, highlighting significant departures from the TPACK framework.

ICT-Related PCK

ICT-Related PCK is an instructional systems design model based on Shulman's (1986), and Cochran, Deruiter, and King's (1993) conceptualization of PCK defined as an integrated understanding of four components: pedagogy, subject matter content, student characteristics, and the environmental context for learning. Specifically According to Angeli and Valanides (2005), ICT-Related PCK comprises the body of knowledge educators must possess to teach with ICT, and consists of a combination of five components of teachers' knowledge: pedagogical, subject area, students, environmental context, and ICT. ICT-Related PCK is defined as knowing how to: (a) Identify topics to be taught with ICT; (b) Identify

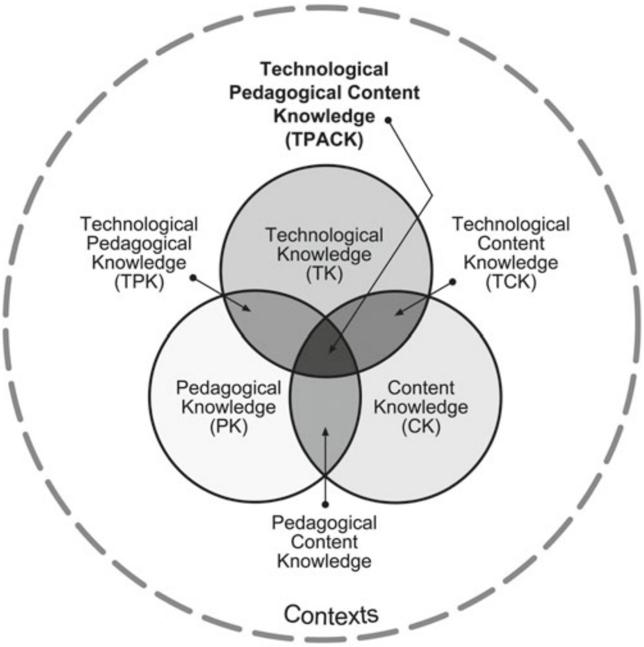

Fig. 9.1 The technological pedagogical content knowledge framework

representations for transforming content; (c) Identify teaching strategies that were difficult with traditional technology; (d) Select ICT tools to support content and teaching strategies; and (e) Infuse ICT activities in classrooms.

ICT-Related PCK differs from TPACK in that it conceptualizes the integration of technology into teaching as happening within the realm of PCK, and requiring additional types of knowledge within PCK. Whereas the TPACK framework considers technology knowledge as its own body of knowledge (Fig. 9.1), it should interact with other bodies of knowledge (CK, PK, and PCK) to form new types of knowledge (TCK, TPK, and TPCK).

Knowledge of Educational Technology

Knowledge of Educational Technology (Margerum-Lays & Marx, 2003) views teachers' understanding of educational technology through the lens of Shulman's (1986) conceptualization of teacher knowledge—content knowledge, pedagogical knowledge, and pedagogical content knowledge. Knowledge of Educational Technology is different from the TPACK framework, in that the TPACK framework emphasizes the interactions between content, pedagogy, and technology—treating technology knowledge as separate but interacting with all other forms of teacher knowledge. In contrast, Knowledge of Educational Technology treats the integrated understanding of teaching with technology as understandable, for the most part, using the Shulman's existing framework of teacher knowledge. Specifically, teachers' knowledge of educational technology can be understood as three components: Content Knowledge of Educational Technology, Pedagogical Knowledge of Educational Technology, and Pedagogical Content Knowledge of Educational Technology.

Technological Content Knowledge

Technological Content Knowledge is a theoretical framework defined by an emphasis on the "total intersection" between technology and content (Slough & Connell, 2006). Slough and Connell use the analogy of lenses, one each for technology and content through which teaching and learning can be viewed, as such the two components, technology and content become one. Additionally, according to Slough and Connell the lenses serve to "magnify" teaching and learning providing a more focused approach and collaborative professional development process. Slough and Connell offer the example of computer-generated visualizations, as the total overlap of technology and content, offering a new way building scientific understanding. The Technological Content Knowledge framework differs from the TPACK framework in that the TPACK framework conceptualizes technology as a realm of knowledge separate from content or pedagogy and focuses on the areas of overlap between the three realms of necessary knowledge.

Electronic Pedagogical Content Knowledge

Electronic Pedagogical Content Knowledge (ePCK) consists of knowledge that teachers must possess in order to successfully integrate technology into their classrooms (Franklin, 2004; Irving, 2006). ePCK is not a framework necessarily but a specific type of teacher knowledge that exists alongside knowledge of content, pedagogy, and curriculum. This type of knowledge is distinctly different from basic technical knowledge and linked to teacher efficacy, a necessary component of technology integration (Becker, 2000; Dawson, 1998). Teachers who possess ePCK are able to develop and implement a curriculum that includes methods and strategies for integrating technology in content areas in an effort to maximize student learning. Electronic Pedagogical Content Knowledge differs from the TPACK framework as ePCK emphasizes pedagogical practices specific to educational technology rather than conceptualizing technology as a distinct realm of knowledge.

Technological Pedagogical Content Knowledge-Web

Technological Pedagogical Content Knowledge-Web (TPCK-W) consists of knowledge of TPACK components content and pedagogy, and in place of general technology, the World Wide Web (Lee & Tsai, 2010). TPCK-W is identified as an extension of both Shulman's (1986) original framework and Mishra and Koehler's (2006) TPACK framework. This framework was specifically developed in response to the generality of technology in the TPACK framework and attempts to elaborate and clarify the more advanced knowledge necessary to teaching specifically on the Web. The new Web component includes knowledge regarding general uses of the Web, specific Web tools, and advanced use of the Web. An example of TPCK-W is being able to select proper (to desired content and pedagogy) existing Web-based courses to assist teaching.

To summarize, although these alternative approaches employ different labels, they are in broad agreement that the advent of new technologies requires teachers to develop new forms of knowledge that connect the affordances (and constraints) of these new technologies to the transformation of content and pedagogy. Early research on TPACK focused on establishing and developing the underlying conceptual framework (Koehler & Mishra, 2005a, 2005b; Mishra & Koehler, 2006). As the TPACK framework has been increasingly adopted, research has turned to measuring TPACK as well as to test the effectiveness of various TPACK-based interventions (Graham, Tripp, & Wentworth, 2009; Guzey & Roehrig, 2009).

Research on Measuring TPACK

A wide range of instruments have been developed to assess pre- and in-service teachers' use and understanding of TPACK (Koehler, Shin, & Mishra, 2012). Using a specific set of inclusion criteria, Koehler, Shin, & Mishra (2012) identified a total of 66 research publications that implemented TPACK measures after reviewing a total of 303 TPACK-related articles that were published in journals, conference proceedings, dissertations, and conference presentations. They found that 141 instruments, which included 31 self-report measures, 20 open-ended questionnaires, 31 performance assessments, 30 interviews, and 29 observations, were used across those studies to assess participants' understanding of TPACK. The following section briefly reviews each of the five types of instruments and provide some concrete examples (see Koehler et al., 2011 for a more detailed analysis of these different instruments).

Self-Report Measures

A total of 31 self-report measures have been developed and utilized, most commonly for pre- or in-service teachers (29 of 31). Typical self-report measures take the form of asking participants to numerically rate their agreement with statements regarding technology and teaching. For instance, the Survey of Preservice Teachers' Knowledge of Teaching and Technology consists of 47 self-report items that assess pre-service teachers' knowledge of 7 subscales of TPACK (Schmidt et al., 2009).

Open-Ended Questionnaires

A total of 20 TPACK instruments utilized open-ended questionnaires, all with pre- or in-service teachers. Typical TPACK open-ended questionnaires contain items that ask teachers to write about their overall experience in an educational technology course or professional development program that are designed to promote pre- or in-service teachers' TPACK. For instance, So and Kim (2009) used a prompt such as "what do you see as the main strength and weakness of integrating ICT tools into your PBL lesson?" in their research. The authors then coded pre-service teachers' responses focusing on their representations of content knowledge with relation to pedagogical and technological aspects of the course.

Performance Assessments

Performance assessments are intended to directly evaluate participants' TPACK by examining their performance on tasks that are designed to represent authentic teaching tasks or scenarios. There are 31 known TPACK instruments that utilize performance assessments, most of which are designed for use with pre- or in-service teachers. Performance assessments take many forms; for instance, some ask participants to create artifacts such as lesson plans, portfolios, or reflective journals (Graham et al., 2009; Harris, Grandgenett, & Hofer, 2010; Kereluik, Casperson, & Akcaoglu, 2010; Suharwoto, 2006). Other types of performance assessments ask participants to respond to a teaching scenario that involves complex problem solving (Curaoglu, Bu, Dickey, Kim, & Cakir, 2010; Graham, Borup, & Smith, 2012).

Interviews

As of June 2010 there were 30 known TPACK interview assessments. Interviews typically include a pre-determined set of questions and are typically recorded for later transcription, analysis, and coding. A vast majority of interviews were conducted with pre or in-service teachers. For examples, to examine changes in pre-service teachers' TPACK, Ozgun-Koca (2009) interviewed those teachers and asked them about the advantages/disadvantages of calculator usage and the effects on the teaching and learning process and environment.

Observations

Observations are intended to directly observe participants' TPACK at a given time point and to track the development of their TPACK over time. Observations were typically conducted either in classrooms or during a professional development session. There are 29 known studies that utilized observation, and a vast majority of the observations were conducted on pre- or in-service teachers. Observations, like interviews, were typically recorded for later analysis. For example, in Suharwoto's study (2006) researchers videotaped all the courses taught by internship teachers to see how they implemented technology in their own teaching. Once the observations were completed, researchers analyzed the transcript of the observation by following the coding scheme that was grounded in the TPACK framework.

Issues of Reliability and Validity in Measuring TPACK

Koehler et al. (2011) found that of the 141 TPACK instruments used as assessment tools, most were done so without any evidence of reliability or validity. Approximately 69 % of the studies included in their analysis did not present any evidence of reliability. Over 90 % of them failed to establish the validity of the measures that were used in their research. As research in TPACK becomes more empirical, it becomes more important that researchers scrutinize the measurement properties of TPACK instruments. The critical issue of "does my instrument accurately capture my participants' levels of understanding in TPACK?" needs to be addressed first as it is essential for good research (Kelly, 2010; Koehler et al., 2011).

Researchers who develop TPACK survey instruments, however, have devoted attention to the reliability and validity properties of TPACK measurement. Specifically, TPACK survey research has allowed researchers to further address the following issues about the measurement of TPACK: Internal consistency, test–retest reliability, and discriminant and convergent validity.

Internal consistency of TPACK surveys. Across several different TPACK survey instruments, researchers have found high levels of internal consistency (a form of reliability), indicating that the items of the TPACK survey correctly focus on the individual factors comprising TPACK. For example, Schmidt et al. (2009) created a 47 Likert item survey designed to measure each of the seven components of TPACK. One hundred and twenty-four preservice teachers completed the survey and showed significant growth in all seven TPACK areas, with the largest growth in their TK, TCK, and TPACK. Schmidt et al. (2009) report good to excellent internal consistency (using Cronbach's alpha between 0.75 and 0.92) for each of the seven constructs.

Similarly, Archambault and Crippen (2009) developed a survey of 24 statements to measure teachers' knowledge with a national sample of 596K-12 online teachers. These teachers assessed their own knowledge (PK/CK/TK/TCK = 12 items, PCK/TPK/TPACK = 12 items) using a 5-point Likert scale. They established the instrument's internal consistency (using Cronbach's alpha) to be 0.70 to 0.91 for each of the seven constructs. Sahin's (2011) TPACK survey also finds internal consistency ranging between 0.88 and 0.93 for the seven constructs of TPACK.

Test–retest reliability. To date, the only TPACK survey to study test–retest reliability is Sahin (2011), reporting test–retest reliability ranging from 0.79 to 0.86 on each of the seven constructs of TPACK. The time between the two measurement periods was not reported.

Discriminant and convergent validity. Discriminant validity tests the extent to which a concept is not highly correlated with other measures of theoretically different concepts. In the Schmidt et al. (2009), Archambault and Crippen (2009), and the Sahin (2011) studies, discriminant validity was addressed through exploratory factor analysis, finding support for each of the seven factors in each study. Additionally, the Sahin (2011) study measured the correlation between the seven TPACK subscales and external variables including the grades achieved in various types of teacher education courses (content courses, pedagogical courses, technology, courses, etc.).

The flip side of the coin to discriminant validity is convergent validity—the extent to which two measures agree (correlate) when they are both theoretically related. Sahin found high degrees of convergent validity, finding that scores on Pedagogical Knowledge (PK), for example, correlated significantly with grades achieved in pedagogical courses. Sahin also concluded that there was evidence of discriminant validity because PK did not correlate with grades in content courses or technology courses. Sahin (2011) found similar results for each tpack subscale and course grade pairing, consistent with a high degree of discriminant validity (when the measure and the grade in a course shouldn't correlate) and convergent validity (when the measure and the grade in a course should correlate).

Survey studies have also shown, however, significant correlations between the seven constructs of TPACK. For example, Schmidt et al. (2009) wrote:

> With respect to correlations between subscales, coefficients varied from 0.02 (social studies and math content knowledge) to 0.71 (TPK and TPACK). TPACK was significantly correlated with eight subscales at the 0.001 level and with social studies content knowledge (SSCK) at the 0.05 level. The highest correlations were between TPACK and TPK (r=0.71), TPACK and TCK (r=0.49), and TPACK and PCK (r=0.49). (p. 135)

Similarly, Archambault and Crippen (2009) noted "correlations between pedagogy and content knowledge responses were high (0.690) as were those between pedagogical content and content (0.713) and pedagogical content and pedagogy (0.782)" (p. 318). Similar high degrees of correlation exists across studies, although which of the seven subscales of TPACK are most strongly correlated differs from study to study.

The high degree of correlation between the subscales of TPACK raise questions about the extent to which the components of TPACK are, in fact, separate components. Archambault and Crippen conclude, for example, that "We are concerned, however, that this distinction between content knowledge and pedagogic content knowledge introduces an unnecessary and untenable complication into the conceptual framework on which the research is based…" (p. 318).

Correlation between the subcales, per se, is not problematic in the TPACK framework. For example, theoretically TPK and TPACK should relate (and therefore correlate) to one another (see Fig. 9.1). TPACK, in part, derives from an understanding of TPK. To what extent the components of TPACK should correlate, however, is a question for further research. Answers to such questions have important implications for how TPACK should be measured, as well as what researchers are actually measuring when they administer TPACK instruments.

Models for Developing TPACK

The development of TPACK is clearly an important area of research due to its significant implications for teacher education and teacher professional development. Research to date, however, has not identified an ideal developmental sequence for developing TPACK in teachers, though many have raised the issue (Brush & Saye, 2009; Graham, 2011; Holmes, 2009; Niess, 2008).

There are some unique challenges in developing TPACK within the pre-service teacher population. Pre-service teacher candidates, for example, typically begin with minimal levels of all the TPACK constructs, meaning there is not a natural knowledge base upon which to build. In-service professional development programs, on the other hand, can usually depend on participants having a certain level of pedagogical content knowledge, and increasingly, as technologies become more ubiquitous and easy to use, technology knowledge, that they can use as a starting place for developing TPACK.

Several professional development approaches can be found in the literature for helping pre-service and in-service teachers develop TPACK. It should be noted that there is some overlap in the different approaches. In the sections below, we broadly characterize these approaches into three broad categories (Fig. 9.2). We also try to provide a key example of what these efforts look like in practice.

From PCK to TPACK

In this approach, technology is introduced as a way to support and enhance the strategies already being used in the classroom. For in-service teacher training this is a natural approach because it builds on teachers' years of teaching experience. Researchers have found, however, that this approach also has its limitations because in-service teachers bring prior beliefs that actually limit their vision and willingness to try new technology-supported strategies (Niess, van Zee, & Gillow-Wiles, 2010). In this approach, a teacher who first develops PCK through methods courses and experiences that don't involve the use of technology. Then later, the teacher learns how technology might be used to enhance and build upon the strategies they are already familiar with.

An example of the PCK to TPACK approach in practice is the use of activity types (Harris & Hofer, 2009; Harris, Mishra, & Koehler, 2009). In this approach, learning is driven content focused pedagogies called *activity types*, a shorthand for that which is "most essential about the structure of a

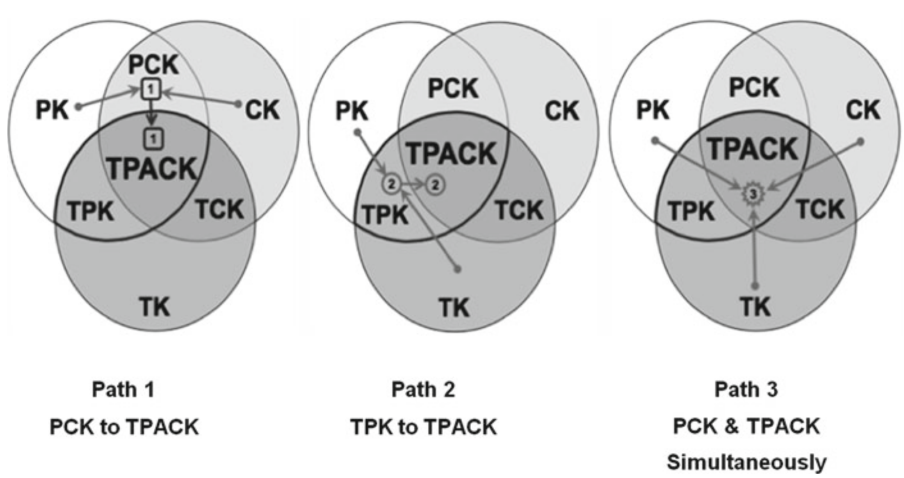

Fig. 9.2 Three paths to developing TPACK

particular kind of learning action as it relates to what students do when engaged in that particular learning-related activity." Examples of activity types include "group discussion," "role play," and "field trip" (Harris & Hofer, 2009; p. 101).

In this approach, activity types are seen as content-specific. The activity types for social studies teaching, for example, might be different than those used for mathematics teaching. Using activity types, teachers first focus on learning goals, and based upon pedagogical decisions, teachers then select appropriate activity types for a given learning experience, formulate assessment plans, and select tools (including technology) that will best help students benefit from the learning experience.

A recent study looking at the use of an instructional intervention using an activity types approach for in-service teacher professional development found that teachers' decisions around educational technology use became more deliberate and judicious and their use of learning activities and technologies became more "conscious, strategic, and varied" (Harris & Hofer, 2011, p. 211).

Other notable examples of the PCK to TPACK pathway include the use of dynamic spreadsheets for teaching mathematical reasoning and problem solving (Niess et al., 2010), the use of geospatial technologies to facilitate science inquiry (Trautmann & MaKinster, 2010) or teaching geography (Doering, Veletsianos, Scharber, & Miller, 2009), and the use of moviemaking to create digital documentaries to promote historical thinking among students (Hofer & Swan, 2006).

From TPK to TPACK

An approach prevalent in my teacher preparation programs is going from TPK to TPACK. The typical example of this approach involves a pre-service candidate who has had not yet taken content-specific methods courses when he/she is required to take a prerequisite technology integration course. These courses are typically taught by an instructional technologist with either limited expertise in all subject areas, or an explicit goal to broadly cover technology that spans all content areas. Because the candidate does not already know pedagogical strategies specific to teaching science, mathematics, language arts, social studies, or other subject areas, the technology integration courses tend to focus on how technology can support teacher productivity and general pedagogical strategies. For example, candidates may learn how to use Web 2.0 technologies to increase active learning or technologies for communicating with parents and students, but that learning isn't directly connected content-specific methods such as guided inquiry in science or balanced literacy in language arts. It is only later when the candidate takes methods courses and has field experiences that she can start to integrate her TPK with PCK to develop TPACK. Thus, the first step in this path is to develop TK and TPK in these early course experiences. As candidates take methods courses specific to their content specialty, their knowledge of TPK should expand into TPACK, and they should incorporate their knowledge into their disciplinary understandings.

This approach is the "default approach" in most institutions of higher learning. Technology is relegated to a few courses and teachers are left to take those lessons and apply them to their own content areas.

A more sophisticated example of the TPK to TPACK pathway is an approach called *Technology Mapping* (Angeli and Valanides, 2009). As "an empirically-based approach for understanding and promoting a situative orientation toward the development of ICT–TPCK" (p. 160), the technology mapping approach emphasizes mapping or connecting the properties of technological tools with the ability to transform content representations and/or support student-centered pedagogies. Examples of ways that tools can transform content include making representations visual, multimodal, or interactive. So, a tool like Google Earth transforms a static visual geographic representation into one that the learner can interact with. Similarly, the affordances of a tool may facilitate or make difficult certain pedagogies. For example, Google Earth could facilitate a virtual field trip in a way that a whiteboard cannot. Angeli and Valanides (2009) conducted a study to investigate the effectiveness of the technology mapping approach for developing TPACK with over two hundred preservice teachers. They found statistically significant improvements in students' performance on design tasks towards the end of the semester as compared to the beginning of the semester.

Developing PCK and TPACK Simultaneously

A third pathway to TPACK is to try and develop PCK and TPACK simultaneously. In a pre-service context this means replacing the educational technology course, as we know it, with a systematic integration of technology-supported strategies into the methods courses and field experiences. For example, a program following this approach might not have a technology integration course at all but rather require that each of the content-specific methods courses teach candidates how to use technology for teaching within the discipline. Thus, candidates would be developing their PCK and their TPACK simultaneously.

One challenge of this approach is the cognitive load that students experience when they are simultaneously trying to develop their pedagogical, content, and technological knowledge. Brush and Saye (2009) comment on this, "Many times, pre-service teachers are simultaneously learning content, technology, and pedagogy—as well as learning the craft of teaching—which can prove overwhelming to individuals just entering the teaching profession" (p. 47).

An example of this approach in practice is the *Learning Technology by Design* approach (Koehler & Mishra, 2005a, 2005b). In this approach, teachers develop TPACK by them working in teams to design solutions to ill-structured, real-world problems of teaching and learning over an extended period of time. Instead of directly teaching technologies to teachers, teachers' learning is driven by the design-problem and a consideration of different technologies that may contribute to the final design solution. Because real problems of practice require designers to integrate content, pedagogy, and technology, learners necessarily engage with actively integrating these types of knowledge as they work on a solution.

Others have also explicitly used design as a vehicle for helping teachers to develop TPACK (Angeli & Valanides, 2005; Lambert & Sanchez, 2007; So & Kim, 2009; Valanides & Angeli, 2008). The *Learning Technology by Design* approach, however, is the only approach of these that uses the simultaneous development TPACK and PCK pathway.

Research that looked at the effectiveness of the learning by design approach found that participants on design teams significantly developed knowledge in each of the seven components of TPACK (Koehler & Mishra, 2005b), and that design team conversations increasingly demonstrated higher forms of integrated understanding, in the form of PCK, TPK, TCK, and TPACK (Koehler, Mishra, & Yahya, 2007).

Developing TPACK in the Content Areas

A central theme of TPACK development is that this kind of knowledge is situated in a content-specific context rather than a more general context. This section outlines three aspects of TPACK development that are woven throughout the TPACK research.

Teaching Strategies/Methods

One distinction between TPACK and traditional technology integration efforts is a focus on content-specific pedagogies as opposed to general pedagogies. The TPACK literature is full of examples, predominantly in social studies, math, and science. Many of the activity types identified by Judi Harris (see http://activitytypes.wmwikis.net/) are content-specific activities that are found in one content domain but not others (Harris & Hofer, 2009). Bull, Hammond, and Ferster (2008) focus on the strategy of historical investigations for social studies teachers and show how Web 2.0 tools can support that strategy. Other examples in social studies include using technology to support empathetic role-paying or historical think-alouds (Brush & Saye, 2009), using geospatial technologies to develop a "sense of place" (Doering & Veletsianos, 2007), and the use of primary sources to develop historical thinking (Swan & Locascio, 2008). In math and science, examples include using technology like spreadsheets to analyze real data in the science inquiry process (Niess et al., 2010) and the use of technology to support different phases of scientific problem-solving inquiry in biology classrooms (Toth, 2009).

Knowledge of Learners

Content-specific understandings of learners is a focus of the PCK literature, but it has not been a strong focus in the TPACK literature, even though several TPACK measurement instruments have questions related to content-specific learner understandings (Cox & Graham, 2009; Graham, Borup, & Smith, 2012; Mouza & Wong, 2009; Schmidt et al., 2009). Knowledge of learners' content-specific understandings is an implicit part of both the technology mapping (Angeli & Valanides, 2009) and activity structures (Harris & Hofer, 2009) approaches to teaching TPACK. However, more research could be done on specifically how technology supports teachers in identifying learner content-specific understandings and not just how it is used to address misconceptions or difficult concepts.

Content Representations

Many researchers have noted that the properties of a particular technology support teaching specific content, and that technological tools can transform representations in ways that afford some conceptual understandings better than others to students (Angeli & Valanides, 2009; Bull et al., 2008; Valanides & Angeli, 2008). McCrory's research on representations in science teaching (McCrory, 2008; McCrory, Putnam, & Jansen, 2008), for example, demonstrates how technological affordance can be useful to (1) speed up the time of natural events, (2) organize large bodies of data, and (3) record data that would normally be hard to gather.

The need to attend to context is by no means restricted to TPACK research—These three themes have also been identified as central in the existing PCK literature base (Lee & Luft, 2008; van Driel, Verloop, & de Vos, 1998). The further development of an understanding of the contexts in which TPACK is developed is an important dimension of future TPACK related research.

Conclusions

Clearly the TPACK framework since its introduction in 2006 has had significant impact on both theory and practice in educational technology. In conclusion we point to both what the framework has achieved as well as point to some key limitations and directions for future work.

The single biggest contribution of the TPACK framework has been in the area of teacher education and teacher professional development (Koehler, 2012; Mishra, & Wolf, et al., 2012). Research has indicated that most pre-service and in-service professional development of teachers often fail to "support and develop educators identities as fluent users of advanced technology" (US Department of Education, 2010, p. 45). The TPACK framework argues that programs that emphasize the development of knowledge and skills in these three areas in an isolated manner are doomed to fail. Thus, effective teacher educational and professional development needs to craft systematic, long-term educational experiences where the participants can engage fruitfully in all three of these knowledge bases in an integrated manner.

One of the significant limitations of the TPACK framework is that it is neutral with respect to the broader goals of education. For instance, the TPACK framework does not speak to what kinds of content need to be covered and how it is to be taught. As many scholars have pointed out the new millennium requires a great level of focus on higher order thinking skills, collaboration and creativity (see Mishra & Kereluik, 2011 for a review). A beginning in this direction has been made through an argument for the role of TPACK in developing twenty-first Century trans-disciplinary skills (Mishra, Koehler, & Henriksen, 2011).

Finally, though there has been a flowering of research on TPACK and its measurement, the review indicates that there is still much to be done—particularly in the area of measuring how TPACK works in different disciplinary contexts. The quality of research has also been patchy, and there is a clear need for better-designed studies and instruments.

Concerns, however, go beyond merely research designs and instrumentation. A key aspect of the TPACK framework has to do with teacher autonomy and seeing teachers as designers, particularly with technologies that change at a very rapid pace (Koehler & Mishra, 2008; Mishra, Koehler, & Kereluik, 2009). This open-endedness and rapid rate of change have implications for the kinds of research we do since it is challenging to develop instruments when the final goals are creative products that often cannot be specified in advance, or when the tools inherent to the pedagogy and content keep changing. This means that we need to newer methodologies and ways of capturing and analyzing phenomena that respect this open-endedness and creativity even while being sensitive to statistical variability and experimental biases. Norman (2010) recently made a similar argument new research paradigms for the design sciences as well. Thus, though we applaud the effort that has gone into extant instruments and measures for TPACK we also argue that we need to be looking beyond existing methodologies to develop newer techniques and approaches that recognize the pragmatic, applied and creative goals of teaching with technology.

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