Charoula Angeli · Nicos Valanides
Editors

Technological Pedagogical Content Knowledge

Exploring, Developing, and Assessing TPCK

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Preface

Technological pedagogical content knowledge (TPCK or TPACK) is a rather young research field, which is still searching for a generally accepted and solid theoretical conceptualization. During the last decade, the concept of TPCK has received great attention from the research community, and, as a result, a significant number of articles have been published. The Editors acknowledge that research surrounding the conceptualization of TPCK has been primarily based on Shulman's (1986, 1987) seminal work on pedagogical content knowledge (PCK). In essence, TPCK researchers worked toward enhancing or extending Shulman's PCK to address the knowledge needed to teach with technology. Early work on the theorization of TPCK includes the work of Pierson (2001), who suggested adding technological knowledge (T) to the existing model of PCK in order to better define teacher technology integration, as well as work by Margerum-Lays and Marx (2003), who worked toward developing a PCK of educational technology. However, it was not until 2005 that research on TPCK started to flourish. Niess (2005) used the term TPCK to refer to technology-enhanced PCK. Based on the work of Shulman (1987), as well as Grossman's (1989, 1990) work on the four central components of PCK, she amended Grossman's (1990) components with technology and provided a framework for describing teachers' TPCK development. Around the same time, Angeli and Valanides (2005) proposed ICT-related PCK (ICT-TPCK), a framework that extended Shulman's (1986) and Cochran, DeRuiter, and King's (1993) work on PCK by adding ICT (knowledge about Information and Communication Technologies), and proposed ICT-related PCK as a unique body of knowledge/competencies defined in terms of the interaction of five different knowledge bases, namely, content knowledge, pedagogical knowledge, learner knowledge, knowledge of context, and ICT knowledge. It was also in 2005 that Koehler and Mishra introduced their framework of TPCK, and proposed to understand TPCK in terms of three knowledge domains, namely, content (C), pedagogy (P), and technology (T), and in terms of their intersections—PCK, TCK, and TPK (Koehler & Mishra, 2005). In 2007, Mishra and Koehler's TPCK changed to TPACK, which was proposed as a term that could be more easily spoken and remembered (Thompson & Mishra, 2007). TPACK, which, as a term, was adopted to a good extent by educational researchers and was used considerably in the literature, emphasizes, through its letters in the acronym, the three kinds of knowledge, namely, content, pedagogy, and technology, which are deemed important for successfully integrating technology in teaching and learning. Later work by Koehler and Mishra (2008) expanded the notion of TPACK into a situated form of knowledge, acknowledging that successful technology integration requires teachers' understanding of the complex relationships between content, pedagogy, technology, and knowledge of the surrounding educational context, including knowledge about students, the school, the available infrastructure, and the environment.

From 2009 onward, there has been an interesting discussion in the literature about the nature of TPCK knowledge. In essence, two different epistemological stances about the construct of TPCK dominated the discourse, namely, the integrative view and the transformative view. The integrative view is reflected in the TPACK framework proposed by Koehler and Mishra (2008), and it conceptualizes TPCK as an integrative body of knowledge defined by its subcomponents as these are formed in consequence of the intersections between pedagogy and content (PCK), technology and content (TCK), and technology and pedagogy (TPK). The transformative view is suggested by Angeli and Valanides' (2005) ICT-TPCK framework, and it conceptualizes TPCK as a unique and distinct body of knowledge. In the transformative model, content, pedagogy, learners, technology, and context are regarded as significant contributors to the development of TPCK. A focal point of the discourse has been whether it is methodologically plausible to identify and measure instances of TPACK's subcomponents, such as, for example, TPK and TCK. After a number of empirical studies, Angeli and Valanides (2009) and Valanides and Angeli (2008a, 2008b) concluded that it is difficult to differentiate among the different subcomponents of TPACK, because of the inherent ambiguity in terms of defining solid boundaries among the different subcomponents. There is a considerable body of research in the literature that adopted the TPACK framework (Koehler & Mishra, 2008) and sought to find methodologically sound ways to measure TPCK in terms of its subcomponents (Chai, Koh, Tsai, & Tan, 2011; Harris & Hofer, 2011; Schmidt et al., 2009), despite the fact that empirical findings from this line of research have not always been supportive of the validity of the TPACK framework (Angeli & Valanides, 2009, 2013; Archambault & Barnett, 2010; Archambault & Crippen, 2009; Graham, 2011; Shinas, Yilmaz-Ozden, Mouza, Karchmer-Klein, & Glutting, 2013). Indicatively, it is mentioned here that Archambault and Barnett's (2010) study revealed that the highly accepted seven mutually exclusive domains of the TPACK framework may not exist in practice, since it is difficult to distinguish each of the knowledge domains. The authors concluded that the only clear domain that seems to distinguish itself is that of technology.

Current TPCK research about the theoretical conceptualization of TPCK includes efforts that seek to enrich and deepen the existing theoretical TPCK models in order to better address the complexity of technology integration (Benton-Borghi, 2013; Jang & Chen, 2010; Kramarski & Michalsky, 2010; Porras-Hernández & Salinas-Amescua, 2013; Yeh, Hsu, Hwang, & Lin, 2013). In parallel, researchers have also undertaken intensive research efforts about the development and assessment of TPCK (Angeli, 2013; Ioannou & Angeli, 2013; Jimoyiannis, 2010; Kushner Benson & Ward, 2013; Mouza & Karchmer-Klein, 2013).

The Editors of this book aspire to contribute to the further development of the construct of TPCK, its development, and assessment. The book consists of 16 chapters that are organized into six different parts, namely, (a) The Significance of TPCK, (b) Theoretical Orientations Concerning the Nature of TPCK, (c) The Development of TPCK in Teacher Development Contexts, (d) TPCK in Subject-Specific Contexts, (e) The Assessment of TPCK, and (f) Future Directions.

The first part consists of a chapter by Kushner Benson, Ward, and Liang (Chap. 1) and a chapter by Niess (Chap. 2). In their chapter, Kushner Benson, Ward, and Liang contend that, in an era in which technology applications and usage have exploded, technology integration has not been fully realized. The chapter begins by providing a brief description of a critical time period from the 1980s to 1990s, when computer technology use exploded in classrooms and educational settings. The authors explain that during this time, the quest for technology integration got sidetracked, taking the path toward technology skills professional development rather than a more essential route toward student learning. The authors then present some of the research from the 1990s that examined the impact of technology on learning, eventually serving as a catalyst for the development of the TPACK framework. They conclude with recommendations for professional practice.

Niess, in her chapter, defines TPACK as knowledge that describes teachers' knowledge for teaching with technologies. She refers to four components that illuminate teachers' TPACK, namely: (a) overarching conceptions of teaching content with technologies, (b) knowledge of students' understandings, thinking, and learning with technologies, (c) knowledge of curriculum and curriculum materials, and (d) knowledge of instruction and instructional representations. She then proposes five levels of acceptance for teaching with technologies, such as recognizing, accepting, adapting, exploring, and expanding. These acceptance levels are examined by the four TPACK components to clarify the development of the knowledge, skills, and dispositions comprising teachers' knowledge. Recommendations for the design of future educational programs highlight the importance of continued experiences for enhancing the habits of mind that support teachers in teaching with technologies.

The second part consists of three chapters; a chapter by Krauskopf, Zahn, and Hesse (Chap. 3), one by Terpstra (Chap. 4), and another by Kramarski and Michalsky (Chap. 5). In their chapter, Krauskopf, Zahn, and Hesse aim at theoretically developing the TPCK framework toward a process-oriented model of teachers' pedagogical reasoning about technology. To address this issue, the authors elaborate on the transformative view of TPCK, introducing the notion of mental models, as analogue and continuous knowledge representations. Based on this, they propose two levels of cognitive transformation. First, they claim that the cognitive transformation of knowledge in the basic sub-domains (TK, PK, CK) into knowledge in the intersecting sub-domains (PCK, TPK, TCK) can be defined as the construction of mental models. Second, regarding TPCK as a construct, namely, the construction of knowledge supposedly integrating all sub-domains, they claim that TPCK can be conceptualized as meta-conceptual awareness of the demands of the teaching task, the teachers' knowledge in the sub-domains and the respective context. These claims are discussed in terms of the background of coherent versus fragmented theories, based on the conceptual change literature.

In Chap. 4, Terpstra presents the TPACKtivity lens as a means for examining pre-service teachers' TPACK development. TPACKtivity employs activity theory to identify objectives, mediating tools, rules, and community, as part of activity settings that contribute to, or detract from, TPACK development. The lens is described and applied in examining seven pre-service teachers' experiences and perceptions of various activity settings' impacts on their learning to teach disciplinary content with technology. The TPACKtivity lens identified mediating tools for developing TPACK, made explicit the roles of the community members in contributing toward subjects' TPACK development, and brought to light rules about technology use in classrooms that impact TPACK development. The findings illustrate the effectiveness of the TPACKtivity lens in sorting through the complexities of TPACK development across multiple settings.

In the last chapter of the second part (Chap. 5), Kramarski and Michalsky examines whether enabling pre-service science teachers to use the TPCK-SRL model for integrating SRL (self-regulated learning) into TPCK influences (a) beliefs about teaching and learning pedagogy, (b) self-efficacy beliefs in the context of using technology in the classroom, and (c) the extent to which these beliefs are connected to teachers' TPCK-based lesson design. Two groups of teachers were compared. One group practiced the TPCK-SRL model in a hypermedia environment, and the other practiced TPCK only in the same hypermedia environment. The findings indicated that after exposure to the TPCK-SRL training model, pre-service teachers' pedagogical beliefs tended more to favor student-centered learning than the TPCK group. TPCK-SRL teachers also showed the strongest beliefs in their own technological self-efficacy, which influenced their ability to develop TPCK-based lesson designs in a constructivist way.

The third part consists of a chapter by Mouza and Karchmer-Klein (Chap. 6), a chapter by Jaipal-Jamani and Figg (Chap. 7), and another by Hervey (Chap. 8). In Chap. 6, Mouza and Karchmer-Klein present one approach to the design of standalone educational technology courses that is aligned with research-based principles for the preparation of pre-service teachers, while utilizing the framework of TPACK as an instructional guide. They present insights from pre-service teachers' reflections on the TPACK framework, and their anticipated uses of technology in their student teaching placement and future classrooms. Pre-service teachers' reflections indicated that key components of the course were beneficial in fostering a greater appreciation of technology in the context of content and pedagogy. Further, all pre-service teachers expected to use technology in their future classrooms although their descriptions did not provide detailed information on how they would do so, while considering issues of content and pedagogy. The chapter concludes with a discussion and implications for future practice.

In Chap. 7, Jaipal-Jamani and Figg present TPACK-in-Practice, a framework of identified characteristics and actions demonstrated by teachers in practice, when they effectively teach with technology. This framework highlights the TPACK knowledge that elementary teachers use in practice. An illustrative example of the framework's usefulness in designing technology professional learning, for a variety of professional learning contexts (i.e., teacher education technology courses, in-service workshops), is discussed. Four stages for the design of professional learning workshops for teacher development of TPACK-in-Practice knowledge are presented. These four stages are: (a) modeling a technology-enhanced activity type (learning with the tool) to set the context and purpose for tool use, (b) integrating pedagogical dialog in a modeled lesson, (c) developing activity-specific technical skills (TK in context) through short tool demonstrations, and (d) applying TPACK-in-Practice to design their own task. The four stages provide guidelines for designing content-centric professional learning contexts for teacher development of TPACK-in-Practice knowledge.

In Chap. 8, Hervey presents a multiple case study, where six veteran secondary education teachers participated in videotaped lessons, and simulated recall and semi-structured interviews. The findings highlight veteran teachers' desired autonomy in selecting professional development, combined with opportunities to learn and practice with peers, as well as the unique generational challenges they face, while practicing in 1:1 settings. The findings suggest that: (a) veteran teachers will need customized, just-in-time professional development to help them acquire nuanced and critical understandings of how to best use their readily available technologies to enhance student content learning; and (b) intentional leveraging of veteran and novice teachers' skills and talents in tandem, when professional learning communities are developed. Future theory building and description must include research-based strategies to best support secondary veteran teachers' successful development of TPACK.

The fourth part consists of four chapters, namely, Chap. 9 by Otrel-Cass, Chap. 10 by Tzavara and Komis, Chap. 11 by Ioannou and Angeli, and Chap. 12 by Crompton. In Chap. 9, Otrel-Cass explores how conceptualizing teacher pedagogy has shaped the idea of TPCK and how this model contributes to understanding ICT use in inquiry science. ICT-TPCK is expanded further to include ideas from the Community of Inquiry framework to accommodate when learning expands into online environments and create hybrid spaces of interaction and learning. The chapter reviews how theories of teacher pedagogy have contributed to understanding technology integration and suggests a possible conceptual expansion, but it also recognizes that more work is needed. A review of cornerstone research suggests a trajectory for future research.

In Chap. 10, Tzavara and Komis, propose Technological Didactical Content Knowledge (TDCK), which emerges from the need to take into account the teaching particularities of each subject area (e.g., mathematics, language, science). The effort is not to examine pedagogical principles, such as those presented by Shulman's model, but to focus on individual teaching problems that arise within each subject. In the chapter, the authors describe the three main conceptual areas of the proposed model—Technology, Content, and Didactics, and their interrelations. They then present a case study of students in an Early Childhood Education Department integrating the TDCK framework in the development of their educational scenarios.

In Chap. 11, Ioannou and Angeli adopt the transformative model of TPCK in order to redesign the teaching of three computer science lessons about (a) three basic computer science concepts, namely, data, processing, and information, (b) the representation of data in computer language, and (c) the differences between main and secondary memory. The authors apply the systematic guidelines of technology mapping to transform the teaching content with the use of educational technologies, and, in particular, spreadsheets. While the framework of TPCK and the guidelines of technology mapping proved to be adequate methodological frameworks for the teaching of computer science, it is pointed out that the focus of the current work has been on the cognitive domain of learning, and that the frameworks have to be also tried out within the context of other subject-matter areas where the emphasis is also placed on the affective domain of learning.

In Chap. 12, Crompton asks fundamental questions about why technology is not used adequately in mathematics classrooms. Do teachers lack the ability to use the technology, or do they not believe it is effective in the mathematics classroom? The purpose of the chapter is to conduct a review of the literature in order to examine the development of pre-service teachers' TPACK and changes in beliefs from relevant preparation experiences. The findings of the review indicate that pre-service teachers develop TPACK skills as they progress through the teacher education programs, which also lead to a more positive stance toward the use of technology for mathematics.

The fifth part consists of two chapters; Chap. 13 by Haley-Mize and Bishop and Chap. 14 by Yew Tee and Shing Lee. In Chap. 13, Haley-Mize and Bishop used TPACK as a conceptual framework to evaluate specific ways pre-service teacher educators learn about technology integration throughout undergraduate coursework. A mixed methodology combined three overlapping phases of data collection and analysis: (a) pre-service teacher surveys reporting perceptions, attitudes, and beliefs surrounding notions of "*technology*," (b) facilitation and evaluation of "*Technology-Enhanced Lessons*" (TELs), and (c) case interview and classroom observation of exemplary use of TPACK practices. Findings indicate that many candidates did not articulate a transformative understanding of technology, but individual differences emerged. Pre- and post-survey data supported a quantitatively correlation of specific pre-service course experiences with technology and TPACK participant skill levels.

In Chap. 14, Yew Tee and Shing Lee undertake an action research study to explore how to best facilitate the development of teachers' TPACK. This approach combined problem-based learning (PBL) with the SECI framework (socialization, externalization, combination, internalization). Based on survey data, teachers believed that their TPACK had improved. Qualitative data derived from one of the groups also demonstrated TPACK improvement. The teachers' initial understandings toward teaching tended to put the blame on students, but this changed through a cycle of action and feedback. Throughout these cycles, teachers began to focus more on what could be done to improve learning, and, as a result, began to realize that technology in itself is not likely to improve ineffective teaching practices. Consequently, their use of technology for teaching and learning became more purposeful.

In the last part of the book, two authors present their plans for future research. In Chap. 15, Benton-Borghi presents her vision for educational change, which includes a universally designed for learning (UDL) infused TPACK practitioner's model in order to prepare twenty-first century teachers. This chapter considers the intersection of two transformative conceptual frameworks, UDL and TPACK, and the impact of a new merged model—UDL infused TPACK—on teacher preparation. General and special education teachers should be prepared to graduate with the knowledge, skills, and dispositions to teach all students in the digital age. The TPACK model provides a theoretically sound and coherent conceptual framework to prepare general education teachers to effectively integrate technology, but this model alone cannot enable general education teachers to teach the full spectrum of learners, without an understanding of UDL.

In Chap. 16, the last and final chapter of this book, Angeli, Valanides, Mavroudi, Christodoulou, and Georgiou discuss the design and implementation of e-TPCK, an adaptive e-learning system that targets the development of teachers' TPCK. This adaptive system deploys a technological solution that promotes teachers' on-going TPCK development by engaging them in the design of learner-centered and ICT-infused scenarios, fostering a self-paced and personalized learning experience, while taking into account teachers' diverse needs, information processing constraints, and preferences. The design and implementation of e-TPCK followed the methodology of design-based research, and, thus, the system itself has undergone three cycles of revisions during the last 3 years. The design of the system was informed by different theoretical and methodological frameworks, such as the framework of TPCK, theories of SRL, as well as the necessary affordances of adaptive learning. Empirically, the system was pilot-tested with two cohorts of pre-service teachers during the academic years 2011–2013. The chapter concludes with recommendations about how to improve the design of e-TPCK by incorporating built-in features to support adaptive scaffolding and self-regulatory processes in order to provide a complete personalized learning experience to the learner.

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Contents

Part I
The Significance of TPCK

The Essential Role of Pedagogical Knowledge in Technology Integration for Transformative Teaching and Learning

Susan N. Kushner Benson, Cheryl L. Ward, and Xin Liang

Introduction

The use of technology in the classroom, and the speculation on ways that technology can impact student learning, is not a new phenomenon. In 1913, Thomas Edison predicted that books would become obsolete in schools. In an interview with newspaper reporter Fredrick James Smith, Edison (1913) told Smith that "books will soon be obsolete in the public schools. Scholars will be instructed through the eye. It is possible to teach every branch of human knowledge with the motion picture. Our school system will be completely changed inside of ten years" (The Thomas Edison Papers, 2012). Reflecting on Edison's statement, educational technology historian Paul Saettler (quoted in Tamim, Bernard, Borokhovski, Abrami, & Schmid, 2011) concluded that not only was Edison's (1913) prediction not realized, but that:

> …in general, we know now that this did not exactly happen and that, in general, the effect of analog visual media on schooling, including video, has been modest. In a not so different way, computers and associated technologies have been touted for their potentially transformative properties. No one doubts their growing impact in most aspects of human endeavor, and yet strong evidence of their direct impact on the goals of schooling has been illusory and subject to considerable debate. (p. 4)

The question of whether and how technology has impacted learning in K-12 and higher education classrooms has not changed much in the past century. Although the technology has changed from motion pictures to iPads, Blin and Munro (2008) shared that the use of technology in true transformational learning is infrequent and that technology has not disrupted teaching practices and pedagogical decisions enough to make an impact. In the next section, we provide a summary of the key technological developments that we contend stymied rather than fostered technology integration.

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Modern Technology Leads to a Focus on Professional Development

The year 1965 was a watershed year in public education in the United States. The Elementary and Secondary Education Act was signed into law and, among many noteworthy components, the law brought new money into schools for technology. Mainframes and minicomputers were put into place in some schools, although they were used mostly for administrative purposes, such as creating and maintaining databases. With the invention of microprocessors in the 1970s, personal computers (PCs) and Apple computers became more commonplace in schools. Skill and drill computer programs and computer-aided instruction appeared in the 1980s. By the early 1990s, most classrooms in the United States had at least one computer, and, by the end of the decade, the Internet—dubbed the Information Superhighway—had transformed the way we communicated and sought information. Fueled by futuristic thinking and commercial interests, technology experienced exponential growth in the classroom. Educators, who had grown up in an era of encyclopedias, filmstrip projects, and mimeograph machines, were pushed—sometimes unwillingly—to learn the "how to" of technology. As new technologies emerged, so did professional development opportunities to learn how the technology worked. The impetus was on getting technology into classrooms, developing user skills—not necessarily on how technology impacts student learning. Provided by technology "experts," who touted the latest and greatest technology tool or application, the focus of professional development was on how to replace traditional learning experiences with technology rather than on how to use technology in new and innovative ways to impact student learning. Although one can hardly argue with the need to learn the basic "how to" of technology tools, the push to learn how to operate technology was powerful and strong, more often than not overshadowing the real question—how can technology be used to positively transform the teaching and learning process. There are a number of excellent references available for readers, who wish to delve into the history of educational technology in greater depth. (See, for example, Cuban, 2003; Saettler, 2004; Spector, Merrill, Van Merrienboer, & Driscoll, 2007).

Teacher Knowledge and the Integration of Content and Pedagogy

At about the same time that the computers were appearing in schools and classrooms, the National Commission on Excellence in Education published its 1983 report, *A Nation at Risk: The Imperative for Educational Reform*. Authored by a blue-ribbon panel of educators and elected officials, the report describes a "rising tide of mediocrity" that threatened the nation's future (National Commission on Excellence in Education, 1983). In inflammatory tones, the commissioners reported that the United States had engaged in "unthinking, unilateral educational disarmament," asserting that if an unfriendly foreign power had attempted to impose on America the mediocre educational performance the commissioners found, the nation might well have viewed it as an "act of war."

A Nation at Risk was a catalyst for educational reform, prompting a surge of local, state, and national reform initiatives. One focus of the educational reform movement that followed was on teacher education. In 1985, noted scholar and teacher-education researcher Lee Shulman served as president of the American Educational Research Association. His presidential address, titled *Knowledge Growth in Teaching*, was subsequently published in the journal *Educational Researcher* and titled *Those Who Understand: Knowledge Growth in Teaching*. In reflecting on teacher knowledge, Shulman (1986) expanded on the concept of a teachers' content area subject matter knowledge by introducing the notion of a unique type of content knowledge—pedagogical content knowledge, "which goes beyond knowledge of subject matter per se, to the dimension of subject matter knowledge for teaching" (p. 9). Shulman (1987) contended that preparing teachers with general pedagogical skills and subject matter knowledge independently was insufficient. Instead, the foundation of teaching was at the intersection of content and pedagogy.

> Pedagogical content knowledge identifies the distinctive bodies of knowledge for teaching. It 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. Pedagogical content knowledge is the category most likely to distinguish the understanding of the content specialist from that of the pedagogue. (p. 4)

Interest and excitement over Shulman's work was palpable within scholarly communities, and Shulman's work had a big impact in the realm of K-12 teacher education. In the immediate years that followed Shulman's work, the emphasis on technology-focused professional development and the importance placed on teacher knowledge remained parallel endeavors. In the next section, we discuss how research on the relationship between technology and student achievement compelled educators and scholars to think more deeply about the differences between technology *uses* and technology *integration*.

Research on the Impact of Technology and the Development of TPACK

Not surprising, by the 1980s educational research began to focus intently on the impact that technology was having in the classroom. Two studies are particularly noteworthy, because of their comprehensive nature. Although the two studies described in this section are themselves contemporary, both summarize and synthesize primary research on instructional technology that was conducted in the mid-1980s to mid-1990s. Schacter (1999) analyzed five large-scale studies that were selected for their “scope, comprehensive samples, and generalizability to local, state, and national audiences” (p. 3). The large-scale studies included a meta-analysis of 500 individual research studies on computer-based instruction, a review of 219 studies that examined the impact of technology on learning, a 5-year evaluation of interactive technology on learning in Apple Classrooms of Tomorrow, a study of 950 fifth graders and 290 teachers across 18 elementary schools, and a study that assessed the simulation and higher-order thinking technologies on a nationally representative sample of 6,227 fourth graders and 7,146 eight graders. Although each of the studies reported positive outcomes, the outcomes were tempered by inconclusive or negative findings. For example, Schacter (1999) reported that effectiveness of educational technology is influenced by the characteristics of the students, the software design, the role of the educator, and the access that students have to the technology. Furthermore, in one study, students who used technology to play learning games and develop higher-order thinking scored only 3–5 weeks ahead of students who did not use the technology. In the same study, students who used drill and practice performed worse on National Assessment of Educational Progress assessments than students who did not use drill and practice software. Finally, in the Apple Classrooms of Tomorrow, students performed no better than comparison groups, or nationally reported norms that did not have access to computers. Schacter (1999) concluded that “instructional technology is less effective, or ineffective, when the learning objectives are unclear and the focus of technology use is diffuse” (p. 10).

In their article, “What forty years of research says about the impact of technology on learning: A second-order meta-analysis and validation study,” Tamim et al. (2011) conducted a second order meta-analysis of 25 primary meta-analyses published since 1985, a time when the authors contend that computer technology became widely accessible to many schools. In addition to the publication date, the primary focus was on the impact of computer technology on student achievement or performance. Overall the authors examined 25 effect sizes from 25 different meta-analyses of 1,055 primary studies (approximately 109,700 participants). The analyses compared student achievement between technology-enhanced classrooms and more traditional types of classrooms without technology. The authors concluded that that there was a small to moderate effect size, favoring the use of technology over traditional, technology-free instruction, and that computer technology that supports instruction has a marginally higher average effect size compared to technology applications that provide direct instruction.

The authors cite the work of Richard E. Clark (1983, 1994) and cautioned that the effectiveness of technology depends on the degree to which technology helps teachers and students achieve the desired instructional goals. They asserted that “it is aspects of the goals of instruction, pedagogy, teacher effectiveness, subject matter, age level, fidelity of technology implementation, and possibly other factors that may represent more powerful influences on effect sizes than the nature of the technology intervention” (p. 17). Finally, they concluded that one of the main strengths of technology is in supporting student learning rather than as a tool for delivering content.

Mishra and Koehler's (2006) TPACK framework became a powerful mechanism for crystallizing educators' thinking about the importance of technology integration that supported student learning rather than technology as a tool for delivery content. "It is becoming increasingly clear," explained Koehler and Mishra 2005), "that merely introducing technology to the educational process is not enough to ensure technology integration, since technology alone does not lead to change" (p. 132). Emerging literature combined with our own work point to the important role that pedagogical knowledge plays in technology integration.

The Key Role of Pedagogical Knowledge

Although the TPACK framework has been instrumental in stimulating thinking and understanding about how content, pedagogical, and technological knowledge intersect to impact student learning, scholars have called for the transformational use of technologies for learning, asserting that educational practice has focused more on the technology rather than on new pedagogies that are needed to truly use technology in a transformative way (Herrington, Herrington, Mantei, Olney, & Ferry, 2009; Hilton, Graham, Rich, & Wiley, 2010). Veletsianos (2011) calls for investigations that present evidence of online learning approaches for transformation as well as a more "formal description of the online pedagogy of transformation" (p. 46).

In the next sections, we summarize our own research in which pedagogical knowledge emerged as a critical factor in technology integration and in the ability to articulate how technology is used in teaching and learning. We describe two studies that support the notion that the level of pedagogical knowledge and the ability to discuss this knowledge within the context of TPACK significantly impacts the ability of instructors to use technology to effectively support learning. These examples focus on instructors in higher education using technology in online learning environments. Both studies look at the development of TPACK in veteran instructors.

TPACK Profiles for Instructor Self-Reflection and Development

We conducted a case study of three experienced university-level instructors in a college of education. We chose experienced instructors who held advanced graduate degrees in their subject area (Content Knowledge) within a college of education. We focused on education faculty, because pedagogy is central to teaching and learning within the domain of education; thus, professors of education were likely to display Pedagogical Knowledge, as a distinct and/or integrated domain. We collected data during a 16-week semester. Partway through the semester, we conducted face-to-face interviews with each professor. The professors were asked to describe various aspects of their online course, their use of technologies and pedagogies, and successes and challenges they have faced. The interviews were audio-taped and then transcribed.

The professors gave consent for us to be nonparticipant observers in their respective online classes. We focused our observations on four components of each course: (a) syllabus, (b) news, (c) instructional modules, and (d) discussion boards.

We used thematic content analysis methods to analyze the data. In thematic content analysis, qualitative data are analyzed holistically for broad themes and patterns, rather than counted and analyzed statistically. Our decisions about the size of the circles and the degree of overlap were based on patterns identified in the data. We used the three main knowledge domains (Content, Pedagogy, and Technology) and the four intersecting knowledge areas of the TPACK model as a priori coding categories. First, we independently read and highlighted the interview transcripts and online documents, and noted instances of the three broad knowledge domains in each of the respective courses. For example, the “alignment of instructional materials with professional standards” was evidence of an instructor’s Content Knowledge. Next, we made independent and holistic judgments about the relative size of the knowledge domains—classifying the domains as large, moderate, or small. We then compared and discussed our independent classifications, until consensus was reached. Finally, we created initial knowledge domain circles to illustrate the relative size of instructors’ distinct knowledge domains. We followed the same process for creating the models that illustrated overlap. The actual visual profiles were created in a holistic way, by evaluating the amount of knowledge in each TPACK, as small, medium, or large. The main areas of Content, Pedagogy, and Technology Knowledge for each case were labeled as large, medium, or small, based on data triangulated from interviews, LMS sections, course components, instructor/student interactions, and other data, as described in the methodology. From here, we combined these core areas to produce the amount of overlap or intersecting knowledge described in a similar way with large, medium, small, or no, area of overlap. Two TPACK profiles are shared in Fig. 1, as examples that show the impact of pedagogical knowledge on the development of technological knowledge observed in the study.

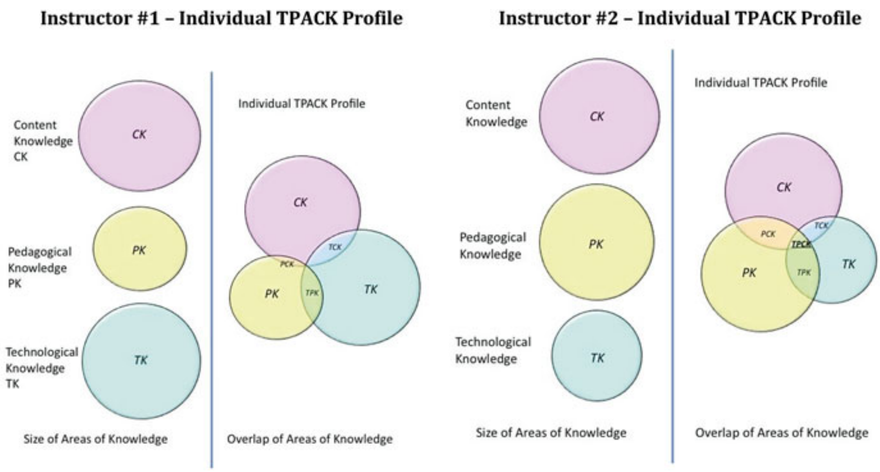

Fig. 1 Individual instructor TPACK profiles

In the first profile, CK and TK are the largest circles, followed by PK, which is the smallest. Although this instructor demonstrated a large degree of TK, we did not find a significant overlap between the three knowledge domains, the middle sweet spot of TPACK. For example, although the instructor explained that student interaction is important, we observed that the discussion board was used as a one-way communication tool, where students posted questions, rather than as a mechanism for facilitating an interactive and emerging discussion. Although the instructor had significant knowledge of technology, her knowledge was not obtained, nor had developed in an integrated way with pedagogy or content. By contrast, in the second profile the instructor demonstrated strong PK (illustrated with a large PK circle), smaller TK, but still a significant overlap in the desired TPACK sweet spot area. This instructor had limited technological knowledge, but had obtained, or developed, this knowledge in an integrated way with pedagogy and content; hence, the larger overlap areas and some growing integrated TPACK. For example, the instructor talked with her students about the course discussion board that served as both an instructional and an assessment tool. Both in her interview and in her syllabus, she identified her expectations for discussion board postings, her rationale for using the discussion board, and how she used discussion board data to evaluate learning.

As our data analysis process unfolded, we became more aware of the dynamic interaction that Mishra and Koehler (2006) speak of, when referring to the developing knowledge in teachers, as they strive to use technology for teaching and learning: "thoughtful pedagogical uses of technology require the development of a complex, situated form of knowledge" (p. 1017). One may assume that if instructors have a large circle for technology that they will have a large overlap area of TPACK and consequently be a good integrator of technology. What we found, however, is that large circles of technology knowledge do not necessarily translate into the overlapping knowledge needed for the development of TPACK. The instructor in our research with the smallest technology circle actually showed the greatest TPACK development. She was able to discuss pedagogical technological decisions in an intentional way. Her intentional discussion demonstrated that she had an awareness of the dynamic interaction between the three areas, and could articulate how certain pedagogy was supported by a specific technology. In our study, Pedagogical Knowledge stood out as core to the development of TPACK, more so than a high level of non-situated Technology Knowledge.

Harris and Hofer (2009) addressed situated technological knowledge in their work on instructional planning activity types, as a vehicle for curriculum-based TPACK development. The authors explained that activity-based instructional planning strategies are not new, but are intentional activities that facilitate instructors' discussion about technology, pedagogy, and content that supports the growth of TPACK in an embedded and dynamic way.

Scholars have called for professional development focused more on broadening teachers' instructional skills, not only with technology tools, but with their overall understanding of the transformative nature of technology in teaching and learning (Doering, Scharber, Miller, & Veletsianos, 2009; Polly & Barbour, 2009). In their summary of more than a decade of TPACK research, Mishra and Koehler (2010) concluded that teachers who can negotiate the relationship between technology, pedagogy, and content develop a form of expertise greater than the knowledge of any individual area. This integrated knowledge supports a process of understanding technology within the context of pedagogy and content rather than an isolated set of skills or knowledge. Mishra and Koehler (2010) further concluded that scholars have recognized and validated that the application of technology in teaching and learning is not context free; yet professional development centered on isolated technology skills has been prevalent. Technology skills learned in isolation may even have a negative impact on an instructor's ability to see the complex application of that technology in a pedagogical and contextual nature.

Quality Matters Professional Development and TPACK

Our study of university professors, involved in professional development focused on quality in online teaching and learning, found their knowledge of technology, content, and especially pedagogy increasing as they developed online coursework. These professors were all veteran instructors with at least 10 years of teaching experience. They were moving to online instruction based on the current motivators to accommodate a wider student population, and the pressure from their institutions to offer more flexible venues to increase enrollment. These instructors created their first online courses simply by duplicating face-to-face course materials into a learning management system. The content and pedagogy remain largely the same with only a delivery mode change and without much consideration about the unique needs of online learners and the complexity of course design and pedagogy in a totally online environment.

Following their initial foray in online teaching, the instructors then engaged in professional development focused on quality in online course construction. Thus, the instructors became learners in a quality online environment. During their online professional development experience, the instructors learned about Quality Matters (QM). QM is a nationally recognized process used by colleges and universities that facilitates the development, maintenance, and review of online courses. It is both faculty centered and peer reviewed. The professional development training focused on the instructors' ability to apply the 8 general QM review standards and 41 specific standards to their own course development, and to develop their online course to meet all QM required standards. The QM process entails the use of a rubric scoring system and a set of online tools that help facilitate the course evaluation by the review team. Quality Matters emphasizes that the scoring rubric specifically focuses on course design, rather than on course delivery or course academic content. The rubric includes seven critical online course components: (a) course overview and introduction, (b) learning objectives, (c) assessment and measurement, (d) resources and materials, (e) learner engagement, (f) course technology, and (g) accessibility.

We interviewed instructors in the study before and after their participation in the QM training. Their online courses, student–instructor interactions, and course development strategies were evaluated before and after they engaged in an online Quality Matters professional development.

We found that working with the QM rubric increased the instructors' knowledge of the importance of aligning learning objectives to assessment, instructional activities, and technology integration. All participants had a positive gain in meeting QM standards reviewed by independent reviewer using QM rubric and comparing their courses pre- and post-QM training. None of the participants reached QM quality standard with their online course before participating in QM training course, but all of them passed the QM rubric criteria after training. Multiple data resources collected from the participants in the study revealed that becoming online learners themselves in the QM training LMS helped the participants understand the needs of online learners, resulting in a more integrated view of pedagogy, content, and technology. Even though QM training and the QM rubric did not specifically introduce the TPACK conceptual framework to the instructors, it was clear that the instructors grew to be more sophisticated online instructors as TPACK grew, and as they designed, modified, and implemented their online courses through the knowledge they gained. We surmised that this could be due to the high correlation between the pedagogical elements on the rubric and the TPACK framework.

We created a process where we mapped the QM rubric (2009) items to the single areas (CK, PK, TK), the overlap areas (TPK, CPK, TPK), and the main core of TPACK. The mapping was done by a group of graduate students, who, after training on each piece of the rubric and the TPACK areas, aligned each QM rubric item with a specific TPACK area. The mapping was summarized and then validated by three professors of Instructional Technology very familiar with both the QM rubric and TPACK. A final mapping was triangulated using the summary and the individual professor mapping. There were very few discrepant areas, but those were discussed and then decisions were made about the placement in a TPACK area. This mapping work was done for two reasons. We wanted to see whether all areas of TPACK were represented in the rubric, and then, specifically, which TPACK areas were most supported through the QM professional development and QM rubric.

As illustrated in Fig. 2, there were varying degrees of alignment between the TPACK knowledge domains and the QM Standards. Pedagogical knowledge (PK), pedagogical content knowledge (PCK), and technological pedagogical knowledge (TPK) were aligned with more QM standards, indicating that pedagogy is central to the development of online learning. The QM Rubric is highly aligned with the core PK areas of the TPACK conceptual framework, which helps instructors develop knowledge in key areas in order to move toward higher levels of TPACK. The highest areas of alignment correspond with the pedagogical rubric elements, even though the intent of the QM process is not specifically to impact changes in pedagogy. The use of the QM rubric and QM Peer Collaboration process, the QM rubric and peer training process helped develop TPACK, especially in the highly aligned areas of PK, PCK, and TPK leading to growth in TPACK. This does not mean that *any* increase in TPK, PCK, and PD leads necessarily to increased TPACK, but to emphasize again the important role that pedagogy plays in the instructors' ability to create quality online coursework as well as intentionally articulate technological, pedagogical, and content decisions.

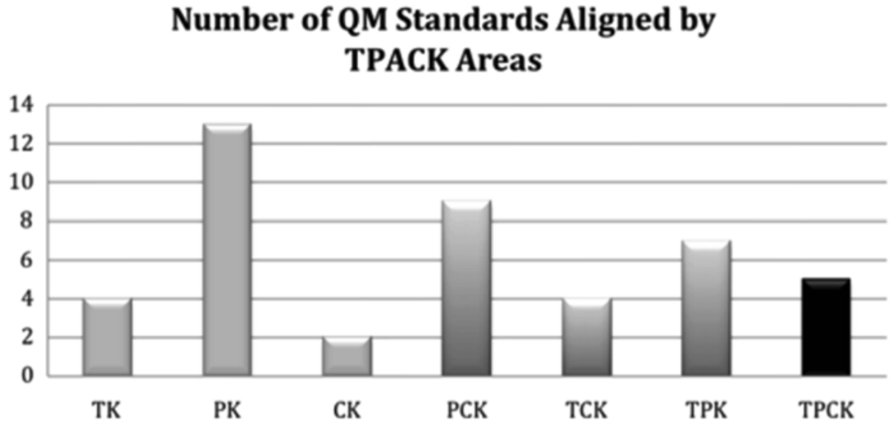

Fig. 2 Number of QM rubric items aligned with each area of TPACK

During the development of their initial online courses, the participants faced challenges that continue in the development of their post-QM courses. Common challenges include (a) different levels of preparedness for online learning among students of different age, computer literacy, time management skills, reading and writing capability; (b) unrealistic expectation of online learning in terms of flexibility, amount of time, and work load; (c) limited pedagogical or content training available for instructors transitioning to online teaching; (d) limited knowledge and implementation skills of the learning management system that caused the content presentation to lack interactive and diverse media to arouse student interest; (e) course requirements too mechanical and rigid to encourage interaction among learners; and (f) underestimation of time commitment in online instruction. With these challenges in mind, instructors seek theoretical frameworks, instructional strategies, and technology design skills to be successful with the integration of technology in learning and teaching.

The growth of TPACK, as a result of the QM professional development training, revealed that change does not happen overnight. The development of TPACK knowledge goes through a more complicated process with key transitional stages. The instructors' experiences with the development of their online courses suggest that they work through five stages of transition in their journey to integrate technology:

1. Instructors decide to move toward online learning in response to perceived students need and expectations of higher education institutions.
2. Instructors change course delivery mode and just duplicate the content and pedagogy of a traditional face-to-face course to the online environment.
3. Instructors experience unexpected challenges unique to online learners and instructional design, in both content and technology implementation.
4. Instructors search for solutions and learning opportunities to address the unexpected challenges, and look for professional development opportunities to learn instructional strategies, technology implementation skills, theoretical frameworks, and assessment tools.

5. Instructors implicitly articulate how to support learning and connect instructional objectives to content presentation and pedagogy, and design the most effective technology delivery to promote maximum learning.

Not everyone moves through each stage, and some may enter at any stage, but our studies identified instructors at every stage of transition. For example, typically those instructors who are asked to move their coursework online enter at stage 1, because they have not given much thought or consideration to this transition before they were asked to move coursework online. Without resources or help, these instructors move to stage 2, where they find the simplest and most time effective way to get a course online, by just duplicating their face-to-face class to a replication online. In this example, live lectures can be recorded in whole, Power Point presentations and readings are posted, and quizzes are converted to online multiple-choice tests. Stage 3 movement happens when instructors begin to get feedback or collect data on the course replication, indicating that the course is not interactive enough, lacks adequate feedback channels, or may not foster connections between students. Some instructors enter at stage 4, either being fearful of the move to online without support and resources, or realizing that they need professional development in order to begin the transition. Instructors, who enter at stage 4 and engage in the QM, or TPACK professional development, move quickly to stage 5, where they can begin to clearly articulate how and why they make technological, pedagogical, or content choices.

Our observation of these key transition points showed that, once instructors were able to articulate clearly the link between pedagogical and content choices, supported through technology, their overlap TPACK area increased. This happens around stage 4 and 5, when instructors begin to reflect and discuss frameworks and the areas of content, pedagogy, and technology in an integrated way. Instructors begin by acknowledging that some type of change needs to happen, they duplicate what they feel has been successful in their face-to-face classes, they begin to feel challenges, and then they search for solutions and investigate more fully all the elements of instruction. Once instructors realize that this is an integrated process and not just about the technology, true growth and knowledge development begins to take place depending on the professional or personal development paths they choose. Providing opportunities for these instructors to engage in professional development that includes reflective practice, real-world implementations with integrated curriculum work, and a focus on pedagogical development, are promising practices.

Practical Implications

TPACK Profile Development

Creating individual TPACK profiles can be useful tools for promoting a reflective process in teachers working on technology integration for teaching and learning. Instructors can reflect on their degree of technological, pedagogical, and content knowledge, and the manner in which their knowledge areas overlap and are integrated. One way to visualize their skills and plan for growth is for instructors to create their own TPACK profiles and visualize their own patterns. Professional development that begins with a typical TPACK Venn diagram, and challenges instructors to create visuals about where they see their own skills, can become a baseline for growth and information about where personal growth should begin. For example, helping instructors become more reflective and collect data on their own teaching enables higher-level discussion on topics, like, pedagogical decisions, technology use, and TPACK.

Doering et al. (2009) used a teacher-reported model (TRM) that allowed teachers to identify where they view themselves within the TPACK framework. This TRM about their work creates metacognitive reflection, as their teachers begin to understand their own strengths and challenges. TRM is part of a larger system called GeoThentic, which is an online environment that engages teachers and learners in solving real-world geography problems. They share that evaluation of TPACK in instructors must be determined by looking through different lenses to establish a holistic view of how technology is used for teaching. GeoThentic's interactive assessment modules include TRM, EAM (evaluative assessment model), and UPM (user-path model). Their design is grounded in TPACK and it is embedded into their interfaces. When teachers and learners interact with technology, pedagogy, and content in the interface, data are collected. Based on these data, teachers are encouraged to think about their awareness of TPACK and reflect on their progress. "With access to the three different assessments (TRM, EAM, and UPM), teachers are able to assess, reflect, and document their TPACK while planning a course of action for professional development" (Doering et al. 2009, p. 331).

Harris (2008) recognized that experienced teachers need a different type of professional development than novices, in order to develop TPACK. She proposed that professional development should be designed around activity types within and across curriculum-based disciplines, which naturally will include discussions of pedagogy and content. Harris (2008) suggested that "well-developed TPCK may be positively correlated with general teaching expertise" (p. 256). This supports our notion that instructors who had more pedagogical experience were more capable of technology integration, regardless of their specific technology skills. In conclusion, she argued that the activity structures/types approach is the way forward for in-service professional development that would provide opportunities for the experienced teachers to move toward a deep philosophical change.

Philosophical change surrounding learning and technology integration can move instructors toward more transformative learning strategies. Technology integration has historically been narrowly perceived in that instructors did not understand the scope or potential for technology in education. Okojie, Olinzock, and Okojie-Boulder (2006) acknowledged "that the degree of success teachers have in using technology for instruction could depend in part on their ability to explore the relationship between pedagogy and technology" (p. 66).

The development of a process to help develop individual TPACK profiles for instructors can provide a practical use for the growing importance of the TPACK conceptual framework. Providing instructors with a systematic process, for evaluating their journey toward the development of TPACK, is essential. Studies of the TPACK profiles of instructors, involved in professional development that included an integrated focus on pedagogy, content, and technology versus simply technology training, can inform professional development planning and make a significant impact on the way training is developed for instructors involved in the development of online learning for twenty-first century students.

Engagement in Quality Measures for Online Development

Teachers, who are actively aware of TPACK and its development, as well as those who are not specifically working on this knowledge development, are impacted through real-world work that integrates the key components. The instructors engaged in the Quality Matters training were unaware of TPACK, but the structure of the process enabled them to show significant growth in the areas of technology, pedagogy, and content. They also increased their ability to intentionally articulate knowledge identified in the overlap areas of technological pedagogical knowledge (TPK), a key area in the overall TPACK growth and a connection that is not necessarily automatic.

Development of quality in online instruction, as well as technology integration, cannot simply be a discussion of technology. As we have found, work focused on quality in online development, or the integration of technology, inevitably circle around to pedagogical discussions and deeper exchanges about philosophical beliefs concerning teaching and learning. These discussions lead to profound realizations about the value of technology for transformative learning among instructors open to improving their craft. Processes, like Quality Matters, set the stage for these discussions in a peer-critical friend venue that facilitates safe environments for growth. Many instructors would not be willing to participate in discussions about "how they teach" in a technology professional development course, so creating safe integrated environments for this work is essential to engage larger numbers of instructors.

Pedagogical Change for Transformation

Through our short historical introduction and research in the area of technology integration, it becomes clear that we cannot think about technology as an isolated solution to transform teaching and learning. We are also not sure that the term "integrating technology" is even an accurate description of the desired results anymore. Clearly, our research, and the research of others, has shown that strong Pedagogical Knowledge and growing TPK and TPACK are the key dynamics in transformational teaching and learning experiences. Technology integration is almost too weak a term to describe the role that technology plays in this *transformative process*, reducing it to merely an injection of a technology versus a pedagogically driven intentional decision at the core of the transformation.

Mishra, Koehler, and Henricksen (2011) explore extending the TPACK framework toward transformative learning and discuss seven cognitive tools that are key to the kinds of transformation we are seeking for twenty-first century learning. They carefully qualify this with discussion that educators are required to repurpose existing tools based on pedagogical decisions. Pedagogical decisions then become the linchpin that is the core to keeping this focused on the transformative potential of TPACK.

Conclusions

A connection between technology implementation and pedagogical decisions is essential for teaching and learning that desires to move toward transformation. Using technology specifically to improve learning through intentional pedagogical decisions is the cornerstone for professional development for twenty-first century transformative practice.

We are realizing that professional development that is embedded in real-world work that includes pedagogical and content development is most effective. Identification of, and solutions for, specific learning problems, goals of increased student achievement, or movements to transform learning mode of delivery, are some of the initiatives that would establish a need for this transformative work. Establishing a need with a focus that promotes authentic professional development centered on problem-solving and how technology can transform teaching and learning. The instructors that made marked TPACK growth through the use of the Quality Matters process, the GeoThentic teacher's metacognitive reflection in problem solving tasks, and the instructors using technology in the development of their online classes were all engaged in authentic tasks that necessitated thinking about technology, pedagogy, and content in a transformative way.

Professional development solely focused on the development of technology knowledge will not lead to effective technology integration, and may actually impede the instructors' ability to look at the knowledge in an integrated way. Misconceptions can form that lead instructors to believe that narrow technology training can equip them to successfully integrate technology in complex and transformative ways. When these initiatives fail, most look to the technology as the point of breakdown, when in fact it is usually the absence of focus on pedagogical, content, or implementation strategies which lead to the lack of perceived success. Our research, and the research of others, supports the premise that pedagogical knowledge (PK) and technological pedagogical knowledge (TPK) are key factors to the development of TPACK, even more than extensive technology skills training. TPACK is critical to the process of integrating technology for transformative teaching and learning in the twenty-first century. Universities, schools, and agencies looking to technology to make strides toward transforming teaching and learning need to ensure that the implementations include discussions and professional development focused on increasing the technological, pedagogical content knowledge of the instructors in integrated, authentic real-world ways, to ensure TPACK growth for all.

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Transforming Teachers' Knowledge: Learning Trajectories for Advancing Teacher Education for Teaching with Technology

Margaret L. Niess

Introduction

A new teacher is hired to teach middle school pre-algebra in her first year of teaching after completing a teacher preparation program. She has a solid mathematics content background and has been introduced to the mathematical practices of the reformed United States national curriculum called the Common Core State Standards for Mathematics (CCSSM) (National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010). She is aware of the new expectations for redesigning the school's mathematics curriculum to meet these standards. She plans to organize her students in groups of four to support small group interactions. Although her learning in mathematics was more lecture driven, her teacher preparation program stressed the importance of guiding small groups and engaging students in discourse about the mathematical ideas. The textbook for the class is aligned with the shift to electronic media; this year students will be issued iPads with chapters that match the school's revised pre-algebra curriculum. This virtual textbook provides new learning tools, such as *Linear Explorer*, for engaging students in inquiry about how variables affect linear equations. Revising the curriculum to meet the new content standards, along with integrating new technologies as teaching and learning tools, presents new challenges for any teacher (not only new teachers) entering a new school. What knowledge do teachers need to adequately respond to these challenges?

Posing this question in the nineteenth century literature displays the prevailing belief that strong content knowledge is adequate for teachers to teach new content in new ways. In the early twentieth century, beliefs shift with recognition of the

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importance of knowledge of pedagogy as well as knowledge of the content. Toward the end of the twentieth century, views about the knowledge that teachers need for teaching not only recognize the importance of content and pedagogy, but also the specialized teacher knowledge described by the intersection of content and pedagogy called pedagogical content knowledge (PCK). Shulman (1986) poses PCK as the special amalgam of content and pedagogy that presents teachers' transformations of subject matter ideas into forms comprehensible by the diversity of students in the classroom, making use of the "*most powerful analogies, illustrations, examples, explanations and demonstrations – in short, ways of representing and formulating the subject that make it comprehensible*" (p. 9). This representation implies that PCK is "*a transformation of subject matter knowledge so that it can be effectively and flexibly used in the communication exchange between teachers and learners*" (Angeli & Valanides, 2009, p. 155).

With the influence of digital technologies in education, a different response to the question of teacher knowledge emerges. Numerous scholars and researchers redirect attention toward the integration of technology, pedagogy, and content in much the same way that Shulman proposed PCK. Technological pedagogical content knowledge (TPCK) is proposed as the interconnection and intersection of technology, pedagogy (teaching and student learning), and content (Angeli & Valanides, 2005; Margerum-Leys & Marx, 2004; Mishra & Koehler, 2006; Niess, 2005; Pierson, 2001; Zhao, 2003). Over time the TPCK acronym is recast as TPACK (pronounced "*tee – pack*") to describe the transformation of teachers' knowledge as an integration of **t**echnology, **p**edagogy, **a**nd **c**ontent **k**nowledge (Niess, 2008a, 2008b; Thompson & Mishra, 2007). In essence, the researchers propose TPACK as a dynamic construct that describes the knowledge teachers rely on when designing and implementing curriculum and instruction while guiding their students' thinking and learning with digital technologies in their specific content areas.

The TPACK model presents teachers' knowledge as an intersection of three circles in a Venn diagram—content, pedagogy, and technology. This presentation reveals multiple intersections of these three circles (as shown in Fig. 1) to clarify the knowledge construct: content knowledge (CK), pedagogical knowledge (PK), technological knowledge (TK), pedagogical content knowledge (PCK), technological content knowledge (TCK), technological pedagogical knowledge (TPK), and TPACK for technological pedagogical content knowledge (Koehler & Mishra, 2008). A purposeful addition to this description is the emersion of these subsets within the educational contexts, where "*teachers' understanding of technologies and pedagogical content knowledge interact with one another to produce effective teaching with technology*" (Mishra & Koehler, 2006, p. 12). Mishra and Koehler (2006) further clarified the importance of educational contexts:

> In short, context matters. Solutions to "wicked problems" require nuanced understanding that goes beyond the general principles of content, technology and pedagogy. A deep understanding of the interactions among these bodies of knowledge and how they are bound in particular contexts (including knowledge of particular students, school social networks, parental concerns, etc.) impacts the kind of flexibility teachers need in order to succeed. (p. 22)

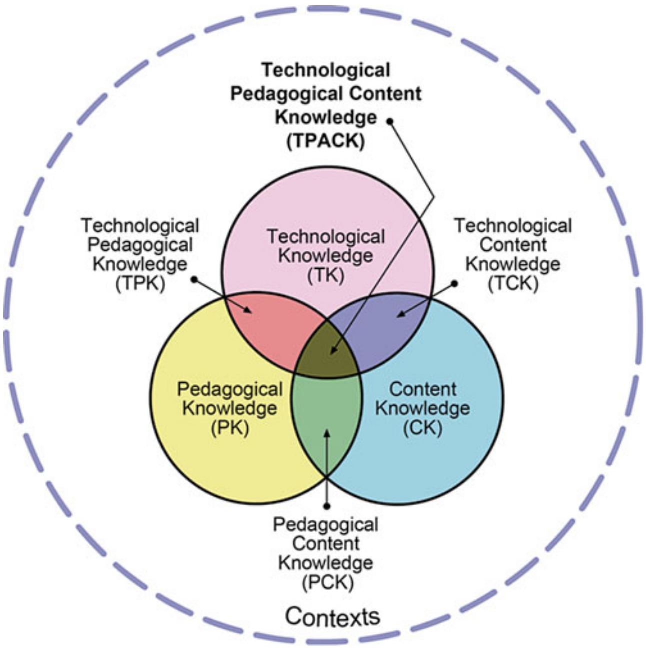

Fig. 1 TPACK model highlighting its knowledge subsets situated within multiple educational contexts (Reproduced by permission of the publisher, © 2012 by tpack.org; http://tpack.org)

Interestingly, the entire model in Fig. 1 is labeled TPACK, while the center subset is also labeled TPACK. This duality suggests TPACK as the sum of the parts in the model with the center subset as a distinct and unique form of knowledge. In essence, the center TPACK highlights the knowledge transformation, where the inputs have been rearranged, merged, organized, assimilated, and integrated, such that they are no longer individually discernible. The center intersection called TPACK is the desirable teacher knowledge that teachers rely on, when designing and implementing curriculum and instruction, while guiding students' thinking and learning with digital technologies in various content areas. Yet, a new question emerges: What are the specifics and details about the nature of this transformation of knowledge for teaching with technology?

Central Components of TPACK

As with Shulman's description of PCK, the center of the TPACK model is conceptualized as a transformation of teacher knowledge. Angeli and Valanides (2008) indicated that this knowledge construct "*goes beyond mere integration, or accumulation of the constituent knowledge bases, toward transformation of these knowledge bases to something new*" (pp. 13–14). Four components from Grossman's

(1989, 1991) work with PCK illuminate the transformation in teachers' knowledge in ways that support them in teaching with technologies (Niess, 2005). Teachers rely on their:

1. Overarching conceptions about the purposes for incorporating technology in teaching subject matter topics: This component describes what teachers know and believe about the nature of the subject matter, what is important for students to learn, and how the technology supports learning as the basis for their instructional decisions.
2. Knowledge of students' understandings, thinking, and learning in subject matter topics with technology: For this component, teachers rely on and operate from their knowledge and beliefs about students' understandings and thinking when engaged in learning specific content topics with appropriate technologies.
3. Knowledge of curriculum and curricular materials that integrate technology in learning and teaching subject matter topics: With respect to this curricular component, teachers examine and implement various technologies for teaching specific topics. Through this activity, they consider how concepts and processes within the context of a technology-enhanced environment are organized, structured, and assessed in the curriculum.
4. Knowledge of instructional strategies and representations for teaching and learning subject matter topics with technologies: This instructional knowledge focuses on teachers adapting their instruction for guiding students in learning about specific technologies as they learn the content with those technologies. They employ specific representations with technologies to meet specific instructional goals and the needs of the learners in their classes.

A dynamic interaction exists among these four components for clarifying the nature of TPACK. When pre-algebra teachers contemplate the addition of the iPad technology for teaching in a revised curriculum, they rely on what they know about teaching mathematics in a different curriculum without the use of the iPad. How should students use iPads to learn specific mathematics topics? What about the nationally mandated curriculum with its new mathematics standards and emphasis on mathematical practices? What are these mathematical practices and do students need to be engaged in them or only be able to describe them? Does the iPad textbook curriculum follow the CCSS-M? Does it support the mathematical practices? How should the classroom be managed when students work with iPad applications? These teachers did not learn to teach mathematics with the iPad. How is the iPad useful in learning specific pre-algebra topics? Are these applications games or are they learning aids? What are students' conceptions of learning mathematics with the iPad? What graphing capabilities are available? What about students' understandings as they work with the particular applications? Many of the students have iPads in their homes where they have likely had previous experiences in working with the technology. Are students going to expect lots of game-like applications? Will their familiarity with the tool mean that learning to use it for the pre-algebra class is shortened? Will the linear equation tool with sliders for changing the variables in equations make it easier for students to grasp the concept of slope and y-intercept? Will their personal graphing skills be lacking as a result of limited practice in graphing with paper and pencil? Will students' mathematical understanding be as deep with a reliance on the iPad technology where the concepts are easier to display visually? Questions abound for any mathematics teacher facing the shift to iPad technologies for teaching mathematics.

Teachers' reflections on potential implications for using the iPad technology impact both the development of the content and the pedagogy of teaching with iPads. Teachers lacking experience with iPads need opportunities to play with ideas for using it in learning particular mathematical topics, and must consider ways to organize the instruction. Their reflection and thinking consistently interacts with the ideas described in the four TPACK components. Likewise, their thinking processes must extend over a period of time as they adjust their thinking for the impact of the potential changes in the classroom environment. As Shreiter and Ammon (1989) have suggested, attention to these challenges requires engagement in a process of assimilation and accommodation, leading to a reconstruction of their personal experiences and understandings in learning mathematics as well as in teaching mathematics. In other words, the teachers' engagement with new ideas for teaching with digital technologies requires time for an effective transformation of their thinking about teaching their content with the technology.

Teacher Knowledge: Levels for Teaching with Technology

Rogers (2003) has been recognized since the early 1960s for his analysis and description of the process involved in adopting new technologies and innovations. His study of the diffusion of innovations describes the innovation-decision process as:

> … the process through which an individual (or other decision making unit) passes from gaining initial knowledge of an innovation to forming an attitude toward the innovation, making a decision to adopt or reject, to implementation of the new idea, and to confirmation of this decision. (p. 168)

Rogers' model consisted of five stages: knowledge, persuasion, decision, implementation, and confirmation. Several researchers and research projects have since followed on this work by describing the changes that teachers experience when implementing digital technologies. For example, the Apple Classroom of Tomorrow (ACOT) project (beginning 1985) revised the five stages of teacher development of expertise in pedagogy (Berliner, 1988) to describe the stages teachers experience in utilizing technology: entry, adoption, adaptation, appropriation, and invention/innovation (Dwyer, 1994). The Concerns-Based Adoption Model (CBAM) focused on seven stages of concerns (awareness, information, personal, management, consequence, collaboration, and refocusing) and levels of use of the innovation (nonuse, orientation, preparation, mechanical, routine, refinement, integration, and renewal) that educators evolve through in the process of change with particular innovations, such as integration of specific technologies (Anderson, 1997; Christensen & Knezek, 2001; Hord, Rutherford, Huling-Austin, & Hall, 1987). In essence, many researchers and authors throughout the 1980s and 1990s focused on levels of technology integration to describe the processes through which teachers evolved in adopting digital technologies.

Deeper thinking about the development of the TPACK construct suggests a developmental process as constructive and iterative, where teachers confront, reflect on, and carefully revise multiple experiences and events for teaching their content with appropriate technologies based on their existing knowledge, beliefs, and dispositions (Borko & Putnam, 1996). Thus, an important recognition revolves around how teachers differ in their actions with respect to each of the four TPACK components, as they are confronted with decision-making tasks in their specific educational contexts. These differences are functions of specific contexts embedded in their knowledge of the content, specific technologies, and pedagogy (teaching and learning). From more than 5 years of research-based observations of teachers exploring spreadsheets as mathematical learning tools and teaching mathematics with spreadsheets, my research group (Niess, Sadri, & Lee, 2007; Niess, Suharwato, Lee, & Sadri, 2006; Niess, van Zee, & Gillow-Wiles, 2010–2011) formulated and clarified five TPACK levels describing teachers' acceptance, or rejection, of spreadsheets as mathematical learning tools:

1. *Recognizing* where teachers are able to use spreadsheets and recognize an alignment of spreadsheet capabilities with mathematics topics.
2. *Accepting* where teachers form a favorable, or unfavorable, attitude toward the teaching and learning of specific mathematics topics with spreadsheets.
3. *Adapting* where teachers engage in and implement in their classrooms activities that lead to a choice to adopt, or reject, teaching and learning mathematics topics with spreadsheets.
4. *Exploring* where teachers integrate spreadsheets as learning tools, when teaching and learning of multiple mathematics topics, and where they consistently explore opportunities to use spreadsheets as learning tools in additional mathematics topics.
5. *Advancing* where teachers evaluate students' understanding using spreadsheets as mathematics tools and where they actively support the decision to integrate teaching and learning mathematics topics with spreadsheets (Niess et al., 2007).

Extended research efforts enhanced the descriptions of the five levels with respect to the four TPACK components as shown in Table 1 (Niess, 2013). Although these descriptions focus on the incorporation of a specific technology (spreadsheets) in a specific content area (mathematics), they describe the process of assimilation and accommodation directing the reconstruction of TPACK through the four components: teachers' overarching conceptions of teaching particular topics with technologies; their knowledge of students' understandings, thinking, and learning; their knowledge of the curriculum and curriculum materials; and their knowledge of instruction and instructional representations. As teachers confront, reflect on, and carefully revise multiple experiences and events for teaching their content with

Table 1 Detailed description of TPACK levels

Overarching conception where the teacher views that:	
Recognizing	Spreadsheets are tools for engaging in mathematical concepts and processes
	Spreadsheets as mathematical tools have capabilities for engaging in mathematical thinking, reasoning, and problem solving
	Mathematics is a subject learned through memorization of rules, algorithms and procedures, when studying it without the use of spreadsheets
Accepting	Spreadsheets have capabilities for applying mathematical concepts and processes
	Spreadsheets have capabilities as problem-solving tools
	Spreadsheets are potentially useful tools for teaching some mathematics
Adapting	Spreadsheets are learning and teaching tools to explore, experiment, and practice mathematics, primarily after learning the mathematics
	Spreadsheets are tools to enhance mathematics lessons, primarily providing students with a new way to approach the mathematics they have studied
	Concerns of personal ability with spreadsheet interfere with guiding students in learning with spreadsheets
Exploring	Benefits exist for exploring, experimenting and practicing mathematics learning and teaching with spreadsheet tools
	Spreadsheets are valuable tools for teaching and learning mathematics
Advancing	Spreadsheets are tools for learning and teaching mathematics in ways that accurately translate mathematical concepts and processes into forms understandable by students
	Integrating spreadsheets as mathematical learning and teaching tools sustains motivation and persistence in exploring, experimenting and practicing with mathematical ideas
	Sustained activities with spreadsheets reveal teaching and learning tools in mathematics
	Spreadsheets are useful and appropriate tools for supporting student thinking and understanding of the mathematics and that this is a result of their personal planning, implementing and reflecting on teaching and learning
Knowledge of students' understandings, thinking, and learning holds that:	
Recognizing	When students work with spreadsheets, the spreadsheet is likely doing the mathematics rather than engaging the student in learning the mathematics
	Motivation for exploring, experimenting and practicing integrating spreadsheets interferes with students' mathematical thinking and reasoning
Accepting	Mathematical thinking is used when exploring problems with spreadsheets
	Spreadsheet activities divert students' attention to and learning of appropriate mathematics
Adapting	Students improve their understandings of mathematical ideas when using spreadsheets after initial understanding of the mathematics
	The depth and level of student thinking with spreadsheets as tools for learning mathematics is questionable
Exploring	Student explorations with spreadsheets are helpful in developing more robust understanding of the mathematical ideas
	Students are engaged in mathematical thinking and problem solving when designing spreadsheets
	Students require little direction for exploring mathematics problems using spreadsheets

(continued)

Table 1 (continued)

Advancing	Spreadsheets engage students in high-level thinking activities (such as project-based and problem-solving and decision-making activities) for learning mathematics using spreadsheets as learning tools
	Enhanced student engagement happens in mathematical explorations with spreadsheets
	Spreadsheets provide multiple representations of mathematical ideas (graphical, tabular, algorithms) that deepens student understanding of mathematical ideas
Knowledge of curriculum and curricular materials views that:	
Recognizing	The mathematics curriculum is directed toward memorization of rules, algorithms, and procedures, when studying it without the use of spreadsheets
	Spreadsheet applications in the curricular materials are a distraction from mathematical thinking and reasoning
Accepting	The mathematics curriculum can include spreadsheet recommendations as applications of the mathematical ideas
	Integrating spreadsheets is an interesting idea but demonstrates difficulty in identifying many topics in own curriculum for including spreadsheets as learning or mathematical tools
	Spreadsheets are motivational for engaging students in specific mathematical topics
Adapting	Spreadsheet activities are useful as supplementary tools in the mathematics curriculum
	Adapting the lessons for students' background can happen using curricular activities with spreadsheets from their personal learning experiences
Exploring	Spreadsheets are learning tools for specific topics in the mathematics curriculum
	Curricular ideas place the technology in a more integral role for the development of the mathematics students are learning
	Integrating spreadsheets as problem-solving tools supports the curriculum's problem-solving standard
	Retaining the current curriculum is needed but spreadsheet applications for learning in specific topics are useful
Advancing	Spreadsheets are integral (rather than additive) to the mathematics curriculum where students are engaged in using spreadsheets as mathematical learning tools
	Evaluating the impact of spreadsheet capabilities is important when considering revisions in the curriculum to take advantage of the capabilities for higher-level thinking
	Exploration and investigation for using spreadsheets in a variety of ways builds mathematical concepts and ideas
	Spreadsheets are essential tools, when assessing students' progress in meeting mathematical objectives
	Rearranging and changing the traditional curriculum takes advantage of the use of spreadsheets as learning tools

(continued)

Table 1 (continued)

Knowledge of instructional strategies and representations views that:	
Recognizing	Learning about spreadsheet capabilities should be taught separately from learning mathematics ideas
	Spreadsheet activities might introduce more difficult concepts to encourage learning of prior mathematics or apply concepts after understanding
	A teacher-directed, teacher-centered view is the way to use spreadsheets for demonstrating applications of the mathematics learned
Accepting	Teachers should deliver and tightly manage the instruction with spreadsheets where spreadsheet instruction is the first lesson with subsequent mathematics lessons after students have sufficient knowledge and skill with spreadsheets
	The time to learn about spreadsheets conflicts with the inclusion of spreadsheets as a mathematical learning tool
	Technology classroom access and classroom management, when technology is included in instruction, are problems that arise with the integration of spreadsheets
Adapting	Instructional strategies with spreadsheets are primarily deductive and teacher-directed to maintain control of the progression of the activity
	Instruction should be primarily teacher-centered (not student-centered)
Exploring	Multiple instructional strategies (both deductive and inductive) with spreadsheets engage students in thinking about the mathematics
	Student-centered activities are helpful when using spreadsheets as mathematics learning tools
	Teachers can find ways to minimize the impact of the challenges that arise when adding spreadsheets as learning tools
	Planning, implementing and reflecting on teaching and learning focusing on students' understandings of mathematics are important when integrating spreadsheet tools
Advancing	Spreadsheets engage students in high-level thinking activities (such as project-based and problem-solving and decision-making activities) for learning mathematics using spreadsheets as learning tools
	Enhanced student engagement results from mathematical explorations with spreadsheets

new and emerging technologies, their classroom environments convert from teacher-centered to learner-centered. In the upper TPACK levels, learners explore and experiment with content ideas with the technologies, and their teachers willingly encourage this experimentation to engage the learners in higher-level thinking with the technological tools. An important recognition is that teachers should not be viewed as either having or not having the transformed knowledge for teaching, i.e., TPACK. The developmental process occurs over time and is a constructive and interactive process. As Angeli and Valanides (2009) note, "*teachers' knowledge of representations of subject matter, and their understandings of students' conceptions and content related difficulties*" constitute key elements for advancing TPACK (p. 159).

Transforming Teachers' Knowledge in the Twenty-First Century

The presentation and description of TPACK as the knowledge that teachers need for teaching with technology mirror that which happened after Shulman's introduction of the specialized knowledge that teachers need for teaching, i.e., pedagogical content knowledge or PCK. With the introduction of PCK, teacher educators questioned, challenged, researched, and redesigned more appropriate learning trajectories for preparing teachers to teach. Similarly, with TPACK, teacher educators are actively investigating methods for preparing teachers to teach with multiple technologies. The challenge is to identify learning trajectories for guiding pre-service and in-service teachers' knowledge development, such that through thoughtful engagement involving technological knowledge (TK), content knowledge (CK), pedagogical knowledge (PK), pedagogical content knowledge (PCK), technological pedagogical knowledge (TPK), and technological content knowledge (TCK), a new knowledge called TPACK is established, such that none of the subsets are individually discernible. New visions for teacher education are emerging, positioning TPACK as transformed teacher knowledge rather than an accumulated knowledge of the separate subset knowledge bases. The final question is: How, if at all, do the extended descriptions of TPACK—the components and the levels—support the design of learning trajectories aimed at developing TPACK in pre-service and in-service programs?

Learning Trajectories to Transform Pre-service Teacher Knowledge

Pre-service teacher preparation programs are charged with establishing the knowledge needed for entry-level teaching. This preparation typically consists of four groupings: technology courses, content courses, methods courses, and practice/internship experiences. Today, students in these programs actively engage with new and emerging digital technologies produced in the twenty-first century. They have computers and use them in their educational programs. They have cell phones; many have iPads and are well versed in the social media widely available through the Internet. This access does not, however, mean they have learned their content with these technologies; it simply means they are technically comfortable with these tools in their personal lives. They need interactive experiences with thinking that involves the four TPACK components. What learning trajectories engage pre-service teachers in a constructive and iterative process of confronting, reflecting on, and revising their thinking for teaching with technology?

Learning to Teach: Technology Courses

Rather than a traditional technology course, Angeli and Valanides (2009) examined an Instructional Technology course, incorporating Technology Mapping (TM) and peer assessment learning experiences that provide potential avenues for developing TPACK competency. The elementary pre-service students are considered novices in the design of technology-enhanced learning and have only basic computing skills. The lectures emphasize instructional design processes with examples from a variety of content domains to demonstrate how the pedagogical affordances of specific technological tools might "*transform content into powerful pedagogical representations tailored to the learners' abilities, interests, and previous knowledge and/or alternative conceptions*" (pp. 164–165). During labs, students learn how to use the technologies and identify pedagogical affordances of the tools for designing technology-enhanced lessons. Organized in peer-assessment groups, the students engage in design tasks using a four-step design process: (1) gather initial information (based on the lectures); (2) engage in real-world tasks (applying their knowledge to an authentic teacher task); (3) share, discuss, and reflect with others to eliminate uncertainty (sharing with other students in the class); and (4) discuss with an expert (the course instructor). After completing the activities, the students engage in strategic thinking about integrating technologies in lessons as they design their own lessons.

This model provides a learning trajectory that engages the students in the thinking, designing, and reflection about the technologies with respect to the content and particular pedagogical strategies to be incorporated. The process potentially involves the four TPACK components. The interactions confront the students' overarching conceptions of the purpose for incorporating the technology. The instructor's lectures provide opportunities that engage the pre-service teachers in considering potential students' understandings and thinking when learning with the particular technology, as they think through the use of the technology for teaching the content in the curriculum and focus on specific instructional strategies. This study highlights the importance of instructor expertise. While often instructors in technology courses are technology experts, this trajectory relies on the instructor's expertise in the areas represented by the four TPACK components—content specialty and pedagogical specialty in addition to expertise with the technologies.

Learning to Teach: Content Methods Courses

In classrooms today, interactive whiteboards (IWB) are replacing the teacher-centered overhead projectors with far superior dynamic visualization capabilities for motivating students to examine content ideas and processes. Holmes (2009) identified the teacher as the key factor in determining the effectiveness of its application but most pre-service teachers have not experienced learning with the

IWB. Holmes (2009) used the TPACK framework in the design of activities in the mathematics methods course to examine students' lesson descriptions incorporating IWB technology in a lesson. Students are introduced to the "*technical capability of the IWB and its software*" and made aware of the literature related to its use in classrooms (TK) (Holmes, 2009, p. 356). They are asked to rely on "*their knowledge of theories of quality pedagogy*" (PK) as they select "*the mathematical content for their activity from any school mathematics content*" in the 7–12 mathematics syllabus documents in New South Wales (CK) (Holmes, 2009, p. 356). The students are also asked to justify "*the design of their learning activities with reference to current pedagogical theories*" (PK) (Holmes, 2009, p. 356). Holmes (2009) claimed that the challenge of developing a selected mathematical content and transforming that content through a lesson activity with IWB maximized the student teachers' TPACK.

Examining this learning trajectory in relationship to the four TPACK components reveals that the activity explicitly emphasizes two of the four components—knowledge of curriculum and curriculum materials and knowledge of instructional strategies and representations. Student teachers justify their choices of the topics (focusing their attention on the curriculum) and the instructional activity (focusing their attention on instructional strategies). The student teacher reflections and class discussions provide a potentially rich environment for engaging students with the other two TPACK components. The student teachers note the IWB's potential to engage students with its interactive features. They also emphasize the use of color and interactive, virtual manipulatives in the development of the lessons. Are those choices made as a result of the student teachers' understanding and knowledge of students' understandings, thinking, and learning? Or, are those choices made because it was the way they personally would want to learn the topics? This reflection and discussion emphasis may be an important feature of the transformation as pre-service teachers deconstruct and reconstruct their knowledge for teaching with technology. Since teachers tend to teach in ways that they have been taught (Ball, 1988), they need to be engaged in specific activities where they must think outside their personal frames of reference. Through these experiences, they are challenged to specifically ask students what features are useful for their understanding in learning with the specific technologies.

Koh and Divaharan (2011) proposed a TPACK-Developing Instructional Model as a learning trajectory in a course designed for guiding pre-service teachers' development through the five development TPACK levels. Their model reveals three phases with recommendations. Phase 1 (*Faculty Modeling*) is framed by ideas from the first two TPACK levels—recognizing and accepting. In this phase, the teacher education faculty models the use of specific technological tools through their instruction in the course (TK). The claim is that this "*vicarious experience*" fosters pre-service teachers' acceptance of the technological tool for educational purposes. Phase 2 (*Technological Proficiency*) shifts to a content-specific modeling to reveal the technological affordances of the tool, showing how these affordances can be used to support different methods of teaching. The important feature of this phase is that the content is the content that the pre-service teachers are planning to teach. Thus, this phase supports them with experiences that have "*relevant connections between their technological knowledge and content knowledge, thereby formulating technology content knowledge*" (TCK) (Koh & Divaharan, 2011, p. 42). Phase 3 (*Pedagogical Application*) engages the pre-service teachers in designing technology—integrated lessons for a specific content topic (TPACK).

This model is similar to the Technology Mapping process described by Angeli and Valanides (2009). One difference is the focus on the first phase, where the emphasis is on faculty modeling the course instruction to provide the students with experiences in learning with the technology. Whether this type of modeling challenges students' overarching conceptions about the purposes for incorporating the technology in teaching their specific subject matter topics is a question. Many pre-service teacher preparation programs are generic, where the emphasis is on pedagogy and the instructors may, or may not, have specific subject matter competence. Is the instructor able to model the integration of the technology in teaching all subject matter topics? It may be that, in this case, the instructor focuses on specific instructional ideas and thus emphasizes TPK rather than TCK as was claimed. Koh and Divaharan (2011) share this idea, as a result of their study, "*More emphasis on subject-focused pedagogical modeling, product critique, and peer sharing may better develop their Technological Content Knowledge and TPACK*" (p. 35).

Learning to Teach: Practicum Experiences

Harrington (2008) examined pre-service teachers' overarching conceptions of what it means to teach mathematics with technology in a content-specific teacher preparation program, recognizing the situated nature of teaching specific content topics with technologies. Partnerships of two or three pre-service teachers and a cooperating mathematics teacher from the middle school plan, teach, revise, and reflect on a technology-infused unit. In these groups, the pre-service students are the experts with the newer digital technologies, the cooperating teacher is the pedagogical expert, and all have subject matter expertise. The cooperating mathematics teacher identifies the specific class for teaching the developed lessons. The pre-service teachers and the cooperating teacher collaboratively identify a specific technology to be used in teaching these middle school students, and then identify an appropriate topic to teach with that technology. Using a lesson study model, the group designs lessons for the unit. Each pre-service student and the cooperating teacher teach a lesson in the unit. After each lesson, the group collaborates to revise and improve the future lessons.

Through observation of the interactions and the teaching, Harrington (2008) identified key features in the pre-service teachers' thinking that are facilitated by this Technology Partnership Project: (a) opportunities to advocate for their own ideas and convince others of the validity of those ideas, (b) opportunities to teach using the ideas of their peers and the in-service teachers and to learn from those ideas, and (c) a method for connecting preconceptions about the way students learn with actual examples of student learning. These practicum experiences provide the pre-service teachers with experiences, where they are engaged with middle school students, and are able to gain and enhance their understandings, thinking, and learning. The addition of the cooperating teacher brings current and actual classroom experiences to the discussions and thinking about the instruction and curriculum. As a group, they are challenged to consider their personal conceptions of teaching the topics with the technologies. In this way, the conversations, revisions, and reflections attend to each of the four TPACK components.

Learning Trajectories to Transform In-service Teacher Knowledge

In-service, professional development teacher preparation programs must build on and enhance teachers' knowledge for teaching. With respect to knowledge for teaching with technology, in-service teachers have limited educational experiences with an emphasis on TPACK. Thus, teacher educators are actively involved in the design, development, and validation of new professional development strategies for guiding the transformation of in-service teachers' knowledge into the form described in the TPACK model.

Learning to Teach: Learning by Design

Extending the Learning by Design approach (Koehler & Mishra, 2005), Mishra, Koehler, Shin, Wolf, and DeSchryver (2010) proposed a trajectory for TPACK development spiraling stages of more complex instructional design, where TPACK reflection is at the end of the process. After explorations with micro-design problems followed by macro-design problems, teachers reflect on pedagogy, technology, and content and their interrelationships when considering a specific and difficult instructional problem. Through the process, the teachers engage in all four TPACK components, as they develop technological solutions for authentic pedagogical problems—problems they identify.

At the micro-design stage, the teachers learn about the features of a particular technology (e.g., a digital camera) by compiling digital photos of a particular topic, such as geometric design, (e.g., patterns in brick sidewalks). In the macro-design stage, they use the technology in a different manner—to conduct research and present the results in a video. They might use the technology to explore students' understandings of area versus perimeter with common misconceptions considering these two ideas as interchangeable, or that the units of measurement are the same for both. These activities challenge the teachers' conceptions of teaching particular topics with the technology they select. During the macro stage, they focus on students' understandings, thinking, and learning.

In the reflection stage, the teachers are challenged to identify a content-specific instructional problem, such as area, where they rely on their TPACK for addressing the problem. This effort potentially results in the design of a set of activities with micro-worlds for guiding students in understanding how area results in a square measure. Their reflections incorporate a defense for how and why teachers might focus students' attention on a visual representation of area versus perimeter. Throughout each phase, these in-service teachers investigate and experience the technology using their educational lenses—interacting with the curriculum and curriculum materials as well as considering different instructional representations for teaching the concepts.

Learning to Teach: Extended Professional Development Programs

Professional development in-service programs for developing TPACK are highly varied, but researchers and teacher educators recognize the value of extended programs in the development of TPACK (Hofer & Grandgenett, 2012; Polly, McGee, & Martin, 2010). Lyublinskaya and Touranki (2012) initiated a professional development program for guiding mathematics teachers learning experiences to incorporate TI-Nspire (advanced calculator technology) in their instruction. Rather than providing the teachers with pre-prepared instructional materials, the professional development focuses the teachers on authoring their own materials for the classroom. The initial question for the professional developers is to identify the extent that these actions change the teachers' TPACK levels. The researchers wanted to identify the teachers' changing levels based on their written artifacts and observed teaching behaviors. For this purpose, they created and validated a rubric based on the TPACK levels organized by the four TPACK components. With this rubric to make judgments about the teachers' developing TPACK, the scores of the teachers' observed lessons were either at the same level or lower than the scores of the lesson plans. Over the period of a year, none of the teachers reached the two highest TPACK levels (*exploring* and *advancing*). The authors noted that this transition requires teachers to make changes in the curriculum they teach and how they teach as a result of the power of the technology. They also noted that the pattern of TPACK growth is nonlinear. The teachers did not improve with every lesson and they wavered among the first three TPACK levels throughout the year. In essence, then, although the study is small, and in the early stages of development, the results suggest that TPACK development for in-service teachers (a) takes time and (b) is nonlinear, varying with the different topics and features of the technology used in the instruction.

Özgün-Koca, Meagher, and Edwards (2011) also used the five-level TPACK model to follow one teacher's progress in learning about and teaching with the TI-Nspire. These researchers tracked changes in the teacher's conceptions of teaching mathematics with the technology, her understandings of students' understanding, thinking and learning, her understanding of the technology (TK), the content

(CK) and how the content influences pedagogy (PCK), the relationship between the technology and the pedagogy (TPK), and the content and the technology (TCK). The study specifically tracked changes in the teacher's decision-making processes and TPACK development through journal writings, observations of teaching, and interviews, as she began to incorporate the technology in her classroom instruction. The teacher's conception of the use of this technology for doing mathematical topics was limited by her belief that the students need to complete the mathematical tasks by hand, before adding the technology. The researchers noted that when she was designing her lessons, she made conscious decisions to meet her students' needs through her created activities.

One important result of this study is the support for the idea of a nonlinearity of development through the levels. As the teacher progresses, and perhaps encounters negative experiences, her TPACK progress regresses. They also indicated that the teacher's progress is a function of the content topics and how those topics are supported by the technology. In other words, "*Her development standings will likely differ for different mathematical topics based on her experiences with the technology, and her 'paper-and-pencil first' belief will likely resurface*" (p. 222). In this study, the TPACK model in conjunction with the TPACK five-level model provided a useful tool for "*tracking the deepening sophistication of a teacher's TPACK and to study the teachers' professional growth*" (p. 223). In conclusion, the researchers described the importance of reflection in professional development learning experiences, indicating, "*not only do teachers need technological knowledge, but they also need to reflect on how these technological capabilities might help their students' learning*" (p. 223).

Conclusion

TPACK as a dynamic framework describes the knowledge that teachers rely on, when designing and implementing curriculum and instruction, while guiding their students' thinking and learning with digital technologies in various content areas. The model describes teacher's knowledge as combinations of subsets (TK, CK, PK, PCK, TPK, and TCK) that while distinct are shown transforming into a new form of knowledge called TPACK. The question of "What is TPACK?" has been answered—as a new and distinct form of knowledge, where these subsets have been rearranged, merged, organized, assimilated, and integrated, such that none are individually discernible, and, in fact, have been transformed into something new.

Now, more than ever, questions have shifted toward the identification and design of fruitful learning trajectories that are effective in transforming teachers' knowledge. While the general description of TPACK and its subsets provides a vision, the results of the extended observations of teachers' artifacts and observations of their teaching provide a deeper conception of TPACK. The five TPACK levels describe a developmental process. Further research has demonstrated the process is not linear, with the realistic possibility of regression amidst the progression. As new content and new technologies are introduced, teachers must reconsider their conceptions of it, and if so, how the new technology supports the content. They naturally revert back at least to the stage of determining whether they accept or reject the technology. The process requires rethinking, unlearning, and relearning in ways that change, revise, and adapt the content and pedagogy in light of the use of the technology. As teachers are engaged in assimilating and accommodating the new and emerging technologies, the new technologies impact the nature of the subject matter content, the nature of the curriculum and instruction, how students think and how they learn, and, in essence, the context of education itself. The four TPACK components highlight attention to important challenges for teachers at each TPACK level—their overarching concepts about the purposes for incorporating the technology in teaching subject matter topics, their knowledge of students' understandings, thinking and learning in these situations, their knowledge of the curriculum and curricular materials, as well as their knowledge of instruction and instructional strategies.

Reflection has long been recognized as an important teacher development practice and naturally emerges as a valued activity in the descriptions of each of the learning trajectories. Schön's (1983) summary of what he found in his work with professionals' reflections indicates the actions of teachers in the TPACK learning experiences as they rearrange their understandings about particular technologies:

> There is some puzzling, or troubling or interesting, phenomenon with which the individual is trying to deal. As he tries to make sense of it, he also reflects on the understandings, which have been implicit in his action, understandings, which he surfaces, criticizes, restructures, and embodies in further action. (p. 50)

Reflection is not about a single event in time, but occurs over time as teachers begin to construct meaning for themselves (Clarke, 1995).

The enhanced descriptions of TPACK support teacher educators in the design of learning trajectories for engaging pre-service and in-service teachers in the habits of mind essential to TPACK, in the discourse that results when they are involved in planning, organizing, critiquing, and abstracting for specific content, specific student needs and understandings, and specific classroom situations, while concurrently considering the multitude of the potential impact of the new and emerging technologies. The key is to support the development of teachers toward this transformation of knowledge to an understanding at the intersection of content, pedagogy, and technology in ways that ultimately affect student learning. This challenge does involve actions for building teacher knowledge for the twenty-first century—for teaching with new and emerging technologies.

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Part II
Theoretical Orientations Concerning the Nature of TPCK

Cognitive Processes Underlying TPCK: Mental Models, Cognitive Transformation, and Meta-conceptual Awareness

Karsten Krauskopf, Carmen Zahn, and Friedrich W. Hesse

Introduction

Emerging technologies can be utilized as cognitive tools for learning (Koehler et al. 2011; Putnam & Borko, 1997; Zahn, Krauskopf, Hesse, & Pea, 2012; Zahn, Pea, Hesse, & Rosen, 2010). For example, they can be used to enable learners to access information in constructive ways, by writing Wikipedia articles or by annotating digital videos with specific video tools (e.g., Zahn et al., 2012). However, educational uses of emerging technologies are manifold and not predetermined in advance. This reinforces the demand on the teacher to repurpose technology for classroom instruction (Koehler et al., 2011). Repurposing includes two parts. First, teachers have to understand the different affordances and constraints of emerging digital technologies (Angeli & Valanides, 2009; Gamage, Tretiakov, & Crump, 2011; Koehler & Mishra, 2008; Suthers, 2006) for teaching and learning. Second, the teacher needs to be aware of what the underlying learning processes are that she is aiming at (cf. Oser & Baeriswyl, 2001). Based on this, the teacher needs to carefully plan the integration of technology in teaching and learning by selecting appropriate tools and creating appropriate learning activities (Bromme, 1992; Harris, Mishra, &

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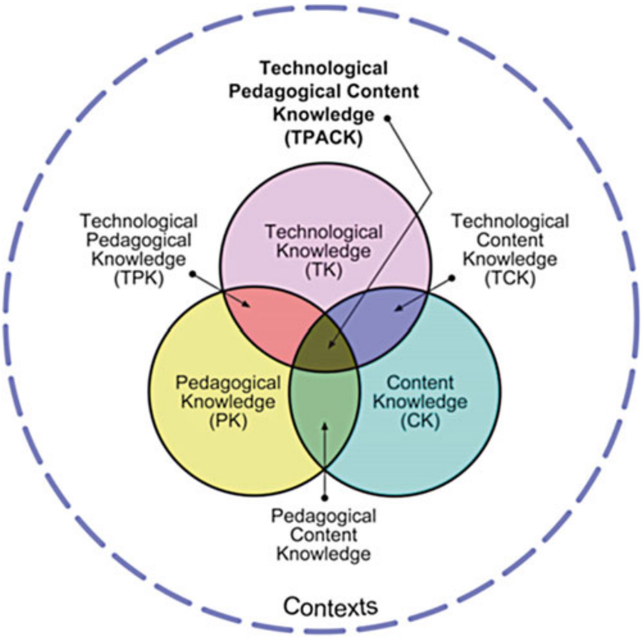

Fig. 1 Graphic representation of the TPCK framework [sic!], http://TPACK.org/

Koehler, 2009; Webb, 2011; Webb & Cox, 2004). To sum up, the challenge for the individual teacher to leverage the potential of any technology begins with understanding and adequately representing its (socio-)cognitive functions in the light of their prior professional knowledge.

The Technological Pedagogical Content Knowledge (TPCK) framework has provided a common ground for discussing this issue, based on its central claim that technology can only add value to learning environments, when considered *simultaneously* with pedagogy and the subject matter (Angeli & Valanides, 2009; Harris et al., 2009; Mishra & Koehler, 2006; Niess, 2005). TPCK research has largely focused on the practice of teacher training and professional development, as well as on measures to evaluate respective training programs. Less effort has been put into developing TPCK *as a theory* (cf. Graham, 2011) and specifying the assumed cognitive processes underlying the development of TPCK.

The pervasive representation of the framework in a Venn diagram (see Fig. 1) does not add to the clarification of these issues. In the research literature, this problem has been discussed as the competing *integrative* view of TPCK, as spontaneously emerging knowledge when the teacher possesses knowledge in the sub-domains TK, PK, and CK versus the *transformative* view, defining TPCK as a unique body of knowledge that is qualitatively different from all other proposed sub-domains (Angeli & Valanides, 2009; Graham, 2011). However, the cognitive processes that characterize this transformation have not been conceptualized in detail.

In this chapter, we elaborate on the transformative view of TPCK research by proposing two levels of cognitive transformation characterizing the development of

Table 1 The constructs proposed by the TPCK framework and hierarchical structure, as proposed in this chapter

Hierarchical structure proposed in this chapter	TPCK constructs
Basic sub-domains	Technological knowledge (TK)
	Pedagogical knowledge (PK)
	Content knowledge (CK)
Intersecting sub-domains, *first level of transformation*	Technological pedagogical knowledge (TPK)
	Pedagogical content knowledge (PCK)
	Technological content knowledge (TCK)
Meta-conceptual awareness, *second level of transformation*	Technological pedagogical content knowledge (TPCK or TPACK)

TPCK (cf. Table 1). On the first level, the transformation of knowledge of the basic sub-domains (TK, PK, CK) into knowledge of the intersecting sub-domains (PCK, TPK, TCK) is defined as the construction of mental models (Brewer, 1987; Johnson-Laird, 1980, 1983). On the second level, considerations from the conceptual change literature are followed (Clark, D'Angelo, & Schleigh, 2011; diSessa, Gillespie, & Esterly, 2004; Ioannides & Vosniadou, 2002; Vosniadou, 1994), and TPCK is conceptualized as meta-conceptual awareness of the demands of the teaching task. In conclusion, implications for research, teacher training, and professional development are described.

First Level of Transformation: Teacher Knowledge as Mental Model Representations

Our first claim is that the cognitive transformation of knowledge in the basic sub-domains (TK, PK, CK) into knowledge in the intersecting sub-domains (PCK, TPK, TCK) is defined as the construction of mental models. This claim is substantiated and specified in the following paragraphs.

Mental Models Mapped on the TPCK Framework

The Venn diagram shown in Fig. 1 depicts the most common representation of the TPCK framework. As Graham (2011) puts it, this visualization adds to the theoretical fuzziness and suggests that growth in either of the basic sub-domains (Graham, 2011, speaks of core categories) would automatically result in growth in all the sub-domains depicted as overlaps of the basic sub-domains. Such an assumption does not adequately represent the current empirical results (e.g., Angeli & Valanides, 2005, 2009) and contradicts the initial reasons to introduce the TPCK framework. Even though Mishra and Koehler (2006) have described TPCK in a *transformative* way from the start (Graham, 2011; Mishra & Koehler, 2006), that is, conceptualizing TPCK as a distinct body of knowledge not arising automatically from its adjacent sub-domains, the literature has not directly addressed the assumed relations among the seven (TK, PK, CK, TPK, TCK, PCK, and TPCK) proposed constructs. The precise definitions of the TPCK constructs introduced by Cox and Graham (2009) provide a clearer understanding of each sub-domain and their unique features (see Table 1); however, it remains an open theoretical question as to how the knowledge in different sub-domains is cognitively represented, and how they relate to each other. In sum, TPCK has only been formulated as a structural model, and the formulation of a process model, such as the more generic one by Baumert and Kunter (2011), has not been the focus of prior research.

This is furthermore an open empirical question. Studies applying TPCK surveys and quantitative analytic methods (Archambault & Barnett, 2010; Chai, Koh, & Tsai, 2010; Koh, Chai, & Tsai, 2010; Lee & Tsai, 2010; Schmidt et al., 2009) have focused on factor analyses and on examining the intercorrelations of the subscales investigating the questions of whether preservice teachers could differentiate between the proposed constructs in self-reported statements in their respective sub-domain knowledge. Most of these studies did not have any prior assumptions about which constructs should show stronger or weaker relations. Only one study (Chai et al., 2010) used regression analytic techniques to test TK, PK, and CK self-efficacy ratings, as predictors for TPCK, assuming that the basic sub-domains are prerequisites for TPCK. Qualitative studies (Graham, Borup, & Smith, 2012; Koehler & Mishra, 2005; Koehler, Mishra, & Yahya, 2007) similarly coded the occurrence of discourse that was attributable to each of the sub-domains, but did not elaborate on the relations between them, even when looking at TPCK development over time (Koehler et al., 2007). Similarly, studies using other methodologies, such as design-based research (Angeli & Valanides, 2005, 2009) or experimental designs (Kramarski & Michalsky, 2010), focused on participants in tasks designed to assess their overall TPCK, without looking into which constructs might act as prerequisites for performance on TPCK tasks.

Alternatively, we propose a mental model perspective on TPCK. Based on the identified contradictions and gaps in the existing literature, we claim that teachers need to construct a mental model of the functions of the respective technology in relation to the impact of these functions on learners' access to the subject matter. Constructing a mental model of the task, and the constraints for solving it, is necessary for drawing inferences and making predictions based on innately incomplete information, like in the classroom context.

In short, mental models are representations of elements in situations, and their interrelations that people construct based on their prior knowledge and beliefs. With regard to how they are represented, cognitive psychology assumes that they are analogue and continuous representations of elements and their interrelations that can be directly manipulated. They are more situated and specific than general beliefs or declarative knowledge (Brewer, 1987; Johnson-Laird, 1980, 1983; Westbrook, 2006). Mental models also exceed what is explicitly asserted in given premises, and are, therefore, effortful to construct. As a result, mental models signify a deeper understanding (Azevedo & Cromley, 2004; Chi, 2000)—compared to list-like propositional representations. Following Johnson-Laird (1980) and Brewer (1987), mental models are considered representations of deeper understanding, because they are cognitive structures that are constructed in the situation. In the present case, for example, when teachers are confronted with tasks such as lesson planning. Hence, we do not consider mental models long-term memory structures here (cf. the notion of mental models as rather long-term memory structures, Gentner & Stevens, 1983).

However, we do assume a feedback process: Over time, the creation of different solutions (=lesson plans) enables the teacher to characterize the commonalities of such a set of solutions (Johnson-Laird, 1983). From the set, the teacher can infer abstract characteristics across concrete task contexts and improve the construction of mental model representations. Thus, task solutions, such as lesson plans or experiences with implementation in class, are likely to be "*stored*" in propositional representations, that is, abstract and list-like. Nevertheless, such a propositional representation of combined knowledge of the sub-domains for a specific lesson does not suffice to accomplish the next task ahead. An example for a propositional representation could be to present cases of teachers' implementing a certain digital technology, which alone, as seen in the study by Angeli and Valanides (2005), was not sufficient to develop preservice teachers' identification, selection, or infusion of Information and Communication Technologies (ICT) for teaching purposes themselves.

Interrelations of the TPCK Sub-domains

When mapping the described notion of mental models onto the TPCK framework, how should we assume that the seven sub-domains relate to each other? Following Brewer (1987), generic knowledge provides a frame of reference that guides the construction of mental models. Thus, when getting to know a new technology or planning a lesson to apply technology, prior knowledge in the basic sub-domains contributes to the construction of knowledge in the higher-level sub-domains. The question following from this is: *how* is prior knowledge integrated into knowledge in the higher-level sub-domains? We propose that transforming knowledge in the basic sub-domains needs to happen in a specific way in order for teachers to solve the complex task of teaching subject matter utilizing emerging technologies (cf. Calderhead, 1996; Leinhardt & Greeno, 1991; see also Fig. 2). Teachers need to combine rather independent basic knowledge domains into more interrelated aspects, in order to solve the overall lesson planning and implementation task, *and* they need to transform their combined knowledge into a mental model representation. It is not sufficient to merely combine the factual elements of prior knowledge. Instead, elements need to be represented together with their interrelations in such a way that they can be mentally manipulated, so that inferences can be made.

For example, on the one hand, a teacher may know about the possibility to edit, annotate, and comment on YouTube videos (TK), including examples, which former users have created for different contexts. On the other hand, this teacher may also know about constructivist or inquiry-based approaches that support students in

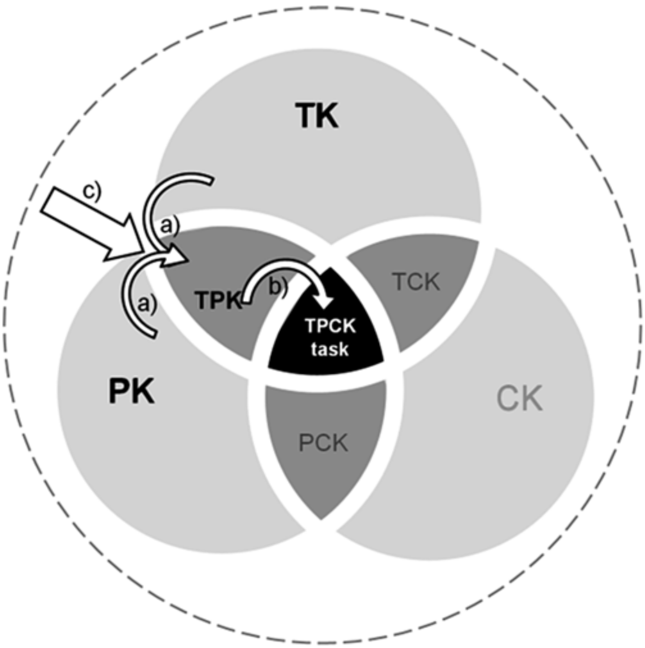

Fig. 2 The notions of independent knowledge domains (*light gray*), mental models (*dark gray*), and lesson plans (*black*) mapped onto the TPCK framework. *Curved arrows* indicate the cognitive process for translating aspects of pedagogical and technological knowledge into mental models (*a*) here of TPK, as an example, and subsequently into lesson plans for concrete content and technology (*b*), considering that these processes might need external support (*c*)

discovering their own understanding of a topic based on sources (PK). In order to come up with a lesson plan that leverages the potential of the YouTube functions for inquiry-based learning (arrow b in Fig. 2), the teacher is challenged to first construct a mental model that contains how specific technological functions open up new possibilities for students (arrow a in Fig. 2). This includes that the mental model needs to contain elements that allow inferring, whether these functions can support students' individual learning or whether certain potential can only be leveraged in collaborative settings, such as the collaborative annotation of a video segment influencing the discussion about the content (e.g., Zahn, Krauskopf, Hesse, & Pea 2010; Zahn, Pea et al., 2010). However, because this mapping of technological and pedagogical information can be considered an effortful cognitive process, it is likely that this teacher requires support to be able to transform the pedagogical knowledge and technological knowledge into a mental model (arrow c in Fig. 2).

To illustrate this point, it seems appropriate to also alter the Venn diagram shown in Fig. 1 (Cox & Graham, 2009; Graham, 2011). As a first step, the sub-domains should be clearly separated, and the different levels of transformation could be further visualized by the intensity of the shading. By doing so, it becomes apparent that crossing the depicted borders is related to cognitively effortful processes and that the complexity of the knowledge representation also increases from the periphery to the center. With regard to TPCK as a construct, this has broader implications, which are discussed in a later section.

Keeping the constructs of PCK, TPK, and TCK in the model suggests that these are actually helpful for describing the complexity of what teachers need to understand when teaching with technology. Keeping these constructs also allows for making more precise assumptions about the cognitive processes involved in developing TPCK. Figure 2 depicts these changes to the framework, as an attempt to illustrate the relations between the content of the sub-domains, representational form of knowledge, and knowledge building processes, the following can be considered relevant in teaching with digital media: For a teacher to get from the outer areas (light gray) to the inner areas (gray and black), it is not only a matter of connecting different content areas, but rather a matter of transforming the knowledge (see arrow a in Fig. 2) representation by constructing a mental model of elements within this domain and the interrelations between them. The subsequent steps should then be in part concerned with combining mental models based on prior knowledge into possible solutions for planning a lesson (for the example of TPK, see curved arrow b in Fig. 2). However, it is also of importance to consider whether the construction of mental models happens spontaneously or, if not, how this process needs to be supported (see arrow c in Fig. 2).

Following Fig. 2 as a tentative visualization, our description of the TPCK framework also includes that the light gray shapes in the periphery refer to knowledge in the three basic domains, technology, pedagogy, and content. These are independent from each other and also rather unrelated to the task of teaching a specific content with the support of emerging technology, when considered separately. Regarding their representational format, these knowledge domains can be represented *propositionally,* as a linear string of symbols in an abstract mental language, as well as in analogue *mental models* that contain elements and their interrelations (cf. Johnson-Laird, 1980). In this respect, a propositional representation signifies a more superficial understanding, and a mental model a deeper understanding. It is an open question whether new information is always translated into propositional representations and whether mental models are based on such propositional representations; however, to solve complex tasks that require drawing inferences, mental models need to be constructed (Johnson-Laird, 1980, 1983). This is because propositional representations only include given information, but do not integrate prior knowledge or further constraints (cf. also Shulman, 1986).

For example, considering content knowledge separately, a physicist's knowledge of electronic circuits can be propositionally represented, so that she can name important elements and a set of rules related to the building of electronic circuits. When being confronted with the task of evaluating the functionality of an existing circuit or planning for building a new one, however, following Johnson-Laird (1980, 1983), a propositional representation is not sufficient to accomplish these tasks. The physicist needs to construct a mental model of the relevant elements and interrelations of electric circuits, integrating the new information that was presented in the task problem. This analogue representation can then be manipulated mentally and different versions can be simulated. This allows the physicist to predict which modifications to a circuit should still be acceptable to create a functioning exemplar. This example illustrates that taking the general definitions of mental models into account a superficial propositional representation might be necessary, but not sufficient to accomplish a domain-specific task that requires drawing inferences. Instead, the accomplishment of such a task requires the construction of a mental model. Similar cases could be made for the technological knowledge of a software developer or the pedagogical knowledge of a social worker.

As argued above, this should also hold true for the task of (planning for) teaching a specific content, while utilizing emerging technologies. The specific aspect here is that the deep understanding (mental model) of a teacher in one of the TPCK sub-domains should be sufficient to perform well in a respective sub-domain-specific task, such as, editing a video with a specific software (TK), instructing a collaborative learning task (PK), or interpreting an historical source (CK); however, it should not be sufficient to perform the overall TPCK task of teaching supported by emerging technologies. To accomplish this task, the different components need to be combined. Based on the considerations above, we propose that this combination must happen in a specific way: Teachers need to construct mental models (form of representation), when they combine knowledge of the independent basic sub-domains (content of representation), meaning that a transformative (process) needs to take place.

Even though constructing such mental models is considered more effortful, the respective knowledge is subsequently more economically accessible (Johnson-Laird, 1980, 1983). If knowledge in the higher level sub-domain is represented in this form, teachers can utilize it to "*compute*" solutions to the task at hand (see arrow b in Fig. 2). First and foremost, the value of this conceptualization emerges for solving the complex tasks of teaching that necessitate teachers to infer concrete hypotheses about the classroom situation and student learning. This assumption is also evident in the operationalizations of teachers' knowledge in the overlapping sub-domains on the second level, as well as in more general approaches to teachers' reasoning and planning for technology use (Webb, 2011).

The assumption that teachers' knowledge needs to be represented in mental models to solve their professional tasks is also implicit in the operationalization of *Pedagogical Content Knowledge* (PCK) tests, in the work of Baumert and colleagues in the COACTIV project with a representative sample of German mathematics teachers (Krauss et al., 2008; Kunter et al., 2007; Voss, Kunter, & Baumert, 2011) as well as in the international TEDS-M project of the IEA (for the German sample, see Blömeke, Kaiser, & Lehmann, 2008; for the overall framework see Tatto et al., 2008). Participants in these studies were asked to generate multiple solutions for solving the given tasks of answering a student's "*why*" question, predicting students' errors in given scenarios, or asking them to come up with various explanations for mathematical solutions. All these tasks require teachers to go beyond what they know, and to construct a mental model to produce task solutions.

Similarly for *Technological Pedagogical Knowledge* (TPK), this assumption can also be found in operationalizations as teachers' decision-making and providing rationales for lesson plan decisions (e.g., Graham et al., in press). In a similar fashion, Krauskopf and colleagues (Krauskopf, Zahn, & Hesse, 2012) followed a procedure applied in cognitive psychological research (e.g., Azevedo & Cromley, 2004). Participants were prompted to describe the three most *relevant* functions of YouTube (Krauskopf et al., 2012), or select the most *relevant* functions of a newly encountered video tool (WebDIVER) from all the functions that they had recalled. Because mental models are considered more elaborate representations exceeding mere facts, participants were asked here to prioritize functions of respective tools and additionally justify their decision. Following Angeli and Valanides (2009) claim that the role of the learners needs to be considered by the TPCK framework, we would suggest that the structural indicators of teachers' mental models (relations among elements) could be the point in the framework to anchor respective theoretical efforts.

For *Technological Content Knowledge* (TCK) this should be assumed as well, considering the specific task here to use technology in a way to represent content and single out specific features or concepts; however, as mentioned earlier, there is a lack of research on this construct and therefore no operationalizations to review here. Thus far, the discussion of TCK has pointed out that it might be subsumed under PCK or CK in the teachers' own perceptions (Hofer & Harris, 2012), but theoretically this construct needs to be considered more thoroughly first before dismissing it.

To sum up, except for the study of Krauskopf et al. (2012), there have been few studies specifically defining teachers' knowledge about teaching with technology, or trying to tap the represented elements and their functional relations more directly with instruments, such as concept mapping techniques (Kagan, 1990). Given this assumption, it follows that integrating all sub-domains, on a second level into TPCK as a construct, needs further to lead to a specific quality beyond the integrated sub-domains of PCK, TPK, and TCK. Otherwise, the construct would not add much to the understanding of teachers' reasoning for utilizing technology. In the next section, it will therefore be discussed how to conceptualize TPCK as a *construct* with regard to its representational form and its content in ways that add to its theoretical power.

Second Level of Transformation: TPCK as Meta-conceptual Awareness

So far, we described a first level of cognitive transformation of teachers' knowledge for teaching with technology, leading from rather separate basic sub-domains of Technological, Pedagogical, and Content Knowledge to mental models in the overlapping sub-domains of Technological Pedagogical Knowledge, Pedagogical Content Knowledge, and Technological Content Knowledge. However, the issue remains how to conceptualize the construct by supposedly integrating all these aspects, namely, TPCK. Our second theoretical claim is that TPCK can be conceptualized as meta-conceptual awareness of the demands of the teaching task, the teachers' knowledge in the sub-domains, and the context.

This claim takes into consideration Cox and Graham (2009), for example, who defined TPCK as knowledge of how to "*coordinate the use of subject-specific activities[…] or topic-specific activities […] with topic-specific representations using emerging technologies", when understanding emerging technologies as "not yet […] a transparent, ubiquitous part of the teaching profession's repertoire of tools*" (p. 64). The definition of TPCK as knowledge of "*how to coordinate*" different knowledge domains clearly alludes to the notion of a meta-conceptual construct. In line with this, this notion is repeated throughout the TPCK literature. Harris et al. (2009) defined TPCK as concerned with the "*multiple interactions*" (p. 401) of the sub-domains, Koehler, Mishra, Kereluik, Shin, and Graham (2014) as the knowledge to orchestrate and coordinate the different sub-domains, and Abbitt (2011) as the knowledge "of the complex interaction among the principle knowledge domains" (p. 283). In conclusion, all these definitions and descriptions allude to the specific theoretical and practical value of the TPCK construct itself, as knowledge *about* the knowledge being at the teacher's disposal in relation to the context and the instructional task.

From this, we conclude that that the second level of transformation is characterized by meta-knowledge of what—according to the TPCK approach—is necessary for mastering the domain of teaching with emerging technology. Vosniadou and others (diSessa et al., 2004; Ioannides & Vosniadou, 2002) specify that such an elaborate, scientific understanding is characterized by a meta-conceptual awareness of what a theory is about and what it is for. Therefore, we will hence refer to the knowledge representation of TPCK as a construct, as *meta-conceptual awareness*. The use of this term is in line with Shulman's work, who defined a teacher's knowledge about his or her knowledge and the capability of explaining their decisions, as being a central point for defining themselves as professionals (he uses the term meta-cognitive awareness, Shulman, 1986, p. 13). It can also explain how TPCK emerges from an initially naïve understanding of technology.

Stepping forward from a naïve understanding of technology to TPCK, how do novices in the domain of teaching with (emerging) technology develop TPCK? A naïve understanding of a new concept compared to that of an expert is considered to exhibit a relation analogous to that of children to that of adults (cf. Hatano & Inagaki, 1986). Discussions with regard to children's naïve conceptual understanding of new (complex) phenomena, and the development of more scientific understandings of important theoretical ideas and empirical research, can be found in the literature dealing with conceptual change (Clark et al., 2011; diSessa et al., 2004; Ioannides & Vosniadou, 2002; Mason, 2001; Vosniadou, 1994; Vosniadou & Brewer, 1992, 1994). If we follow this analogy and assume that inexperienced teachers—or in the present case inexperienced with utilizing technology—can be considered novices (Berliner, 1992, 2001; Leinhardt & Greeno, 1991), it is possible to apply findings and theoretical considerations of the conceptual change literature to teachers' developing a conceptual understanding of TPCK.

Considering the conceptual change literature, it becomes apparent that there are two theoretical perspectives on how naïve conceptual understanding is cognitively represented: The view of conceptual understanding assumes novices to construct a fragmented system of "*Knowledge in Pieces*," that is, a rather large number of fragmented explanatory primitives that are activated in specific contexts (Clark et al., 2011; diSessa et al., 2004). The "*Theory Theory*" view assumes novices to construct a rather coherent framework theory by which any specific explanation is constrained (Ioannides & Vosniadou, 2002; Vosniadou & Brewer, 1992).

TPCK as Incoherent Knowledge in Pieces

In the Knowledge in Pieces approach (Clark et al., 2011; diSessa et al., 2004), conceptual understanding is considered to be made up of a large number of "*intuitive elements*," whereas some of these elements might have a wider scope (covering more than one context) and others a narrower scope (covering only one context). Elements here are defined as *phenomenological primitives* that are always activated as a whole and describe "*what happens naturally in the world*," and thus can be characterized as sub-conceptual entities (diSessa et al., 2004, p. 857). Each element is specified by itself and therefore a compact specification of an overall concept is hardly possible. Boundaries are expected to be unprincipled and instable, and elements are expected to overlap between contexts (diSessa et al., 2004). Although following independent developmental trajectories, sub-groups of elements can be cued in the same situation and therefore show *local* coherence; that is, the Knowledge in Pieces perspective does not assume purely random interactions between elements. Inconsistencies in phenomena, however, can only be explained at the vague level of resolution that *something influencing the phenomenon in question must act somehow differently* (diSessa et al., 2004, p. 857).

Following this approach, learning then is defined as a process of reorganizing elements and their interrelations that *may* result in an overarching understanding (Clark et al., 2011). So, through reorganizing these elements (phenomenological primitives), learners will start making connections between contexts and they will also prioritize elements by importance, that is, by their value for explaining a certain situation. Yet, even if there are elements with common attributes, their great number and independent developmental paths constitute an "*intrinsic difficulty of developing an integrated view*[…]" (diSessa et al., 2004, p. 857). As a consequence of this, no *meta-conceptual awareness* of one's own theories can be attained.

Conceptualizing TPCK as incoherent or locally coherent, respectively, leads to the assumption that teachers abstract "'*self-explanatory' schemata*" (diSessa et al., 2004, p. 857) from everyday situations of the teaching profession. This then results in a large number of context-specific elements (phenomenological primes) that could take, for example, the following form: *In this class, using teamwork in the computer lab leads to chaos.* There may be common attributes of several elements that would lead to locally coherent explanations for related contexts, such as, *in the afternoon, when students are tired, teamwork in the computer lab leads to chaos*, or differentiation between or within domains.

When we apply these considerations to the example of digital video technology applied in our research (e.g., Krauskopf et al., 2012), this could be *Using digital video technologies as a supplement is helpful for discussing expository texts, but not for literary texts*. Accordingly, there would be loosely connected abstractions for the basic sub-domains, technology, pedagogy, and or content, as well as those on the second level: content-specific teaching strategies (PCK), the impact of different technologies on learning (TPK), and content-specific technological representations (TCK). Finally, TPCK would be assumed to also consist of a subsample of these elements, each applying to specific contexts, topics, technologies, or teaching strategies. These can be locally coherent, such as: *Using graphing calculators in project teamwork is beneficial for a number of mathematical topics*. Overall, however, this conceptualization is similar to a number of example lesson plans that do not go beyond the given facts of the examples (like propositional representations, as defined previously).

In conclusion, conceptualizing TPCK as a framework, in this manner, is less helpful for reasoning about changing constraints, such as new classes or emerging hard- and software. Finally, it is unlikely that an overall understanding on the meta-conceptual level develops systematically, that is, what a teacher understands about the factors involved in teaching with technology and how they interact.

TPCK as Coherent Theory Theory

Conceptual understanding, as a '*Theory Theory*' by Vosniadou and colleagues in the context of learning physics (e.g., Vosniadou & Brewer, 1992), assumes that learners initial ontological and epistemological presuppositions are organized into general framework theories. The framework theories are causal and explanatory frameworks organizing physical phenomena (Clark et al., 2011). Constrained by these framework theories, specific theories (e.g., mental models) and beliefs are constructed based on everyday observations and culturally transmitted information (beliefs) to explain, interpret, or predict specific phenomena (Vosniadou, 1994). Constraining framework theories are such that only a few specific theories are extrapolated, and they are considered rather stable and hard to change. Learning following this conceptualization is thought of as a developmental progression from mental model to mental model by incorporating new information and forming of interim models (Clark et al., 2011), by processes of *enrichment* or *revision* (Vosniadou, 1994). Whereas revision varies between weak restructuring, referring to increasing differentiation and hierarchical formation of existing structures, and radical restructuring, referring to the emergence of new theoretical structures out of several preexisting ones (Vosniadou & Brewer, 1992), this kind of change is considered difficult to achieve. One reason is that changes in the ontological and epistemological presuppositions are bound to have serious implications on all the knowledge structures based on them (Vosniadou, 1994). To further develop such naïve theories into a scientific understanding, a person would need to acquire meta-conceptual awareness of her framework theory, which insinuates a different cognitive representational form (Ioannides & Vosniadou, 2002).

The notion of mental models in this approach is congruent with the one described above (Brewer, 1987; Clark et al., 2011; Vosniadou & Brewer, 1992, 1994). They are conceived of as analogue representations of "*the state of affairs*" that have a dynamic structure and are created on the spot for the purpose of solving problems. The creation of mental models is thought to be based on and constrained by underlying conceptual structures (framework theories, above) that act as presuppositions that are often based on everyday experiences. Thus, initial mental models are formed based on such a set of presuppositions. New information is assimilated into synthetic models, while trying to keep as many of their presuppositions intact. Learning in the sense of conceptual change would ultimately mean a reinterpretation of the underlying presuppositions. In conclusion, this debate about knowledge structure coherence of the naïve understanding of scientific concepts adds valuable theoretical perspectives to consider, with regard to how different conceptualizations of TPCK can inform the research on its development.

For TPCK, the task to be mastered is the use of technology in teaching. In this way, basic framework theories could hold ontological and epistemological presuppositions, such as, *There is educational software and there is software for private use* (ontological), *The use of emerging technologies is not different from using any kind of teaching material* (ontological), *That some technologies are not made for learning does not need to be explained* (epistemological), or *Why students learn better with certain representations needs to be explained* (epistemological, cf. Figures 1 and 2 of Ioannides & Vosniadou, 2002).

The cultural context of the teacher, where information for constructing specific theories with regard to technology use is received, is constituted by the epistemologies of the subject domains (Buehl, Alexander, & Murphy, 2002; Hofer, 2006) and the teaching profession itself. It can be assumed that preservice teachers in general and experienced teachers with a low rate of technology use, while not being able to provide pedagogical reasons for this low rate, have naïve conceptions of what is circumscribed by TPCK. In line with this, they would lack meta-conceptual awareness of which knowledge of the sub-domains discussed earlier they need to orchestrate, in order to provide added value for learning scenarios with emerging technologies.

Following the perspective of a coherent theory, developing TPCK means that by constructing initial mental models based on framework presuppositions, teachers would develop meta-knowledge of what presuppositions their local theories (e.g., lesson plans and classroom decisions) are based on and how they construct these local theories. This perspective also suggests that "*teaching*" teachers about innovatively utilizing emerging technologies should be difficult, because teacher educators will have to try to alter basic presuppositions. Changing these will not only be effortful, but most likely connected to unpleasant emotions, because it deconstructs trusted ways of understanding the teaching environment.

To sum up, two figures from diSessa et al. (2004, Figs. 1 and 2) were adapted trying to illustrate the difference between the Knowledge in Pieces and the Theory Theory perspectives, as they are mapped on the TPCK framework (see Figs. 3 and 4).

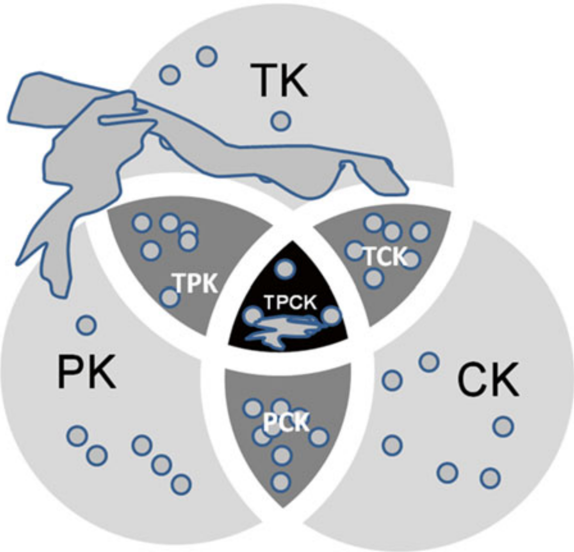

Fig. 3 TPCK as incoherent system of local explanatory elements (Knowledge in Pieces). The scientific framework theory of TPCK is "covered" by many independent elements. The boundaries of the single elements may be fuzzy, overlapping, and differ in width of scope

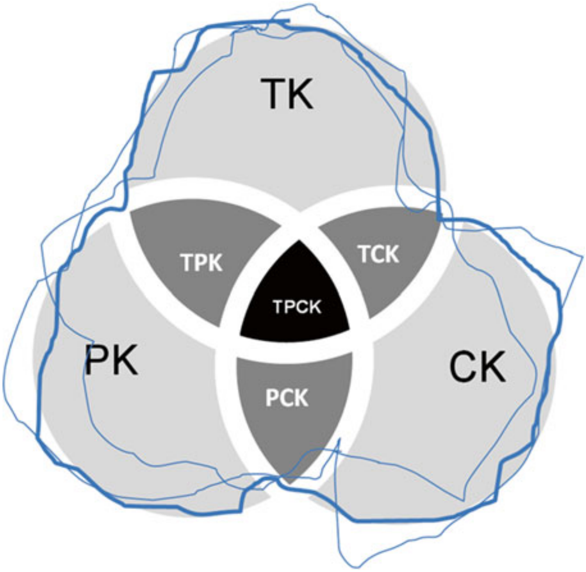

Fig. 4 TPCK as a coherent intuitive theory (Theory Theory). The conceptual boundaries roughly match those of the scientific framework theory of TPCK, while the boundaries are fuzzy and subject to change

Figure 3 depicts TPCK defined as a mostly incoherent system of single explanatory elements that are abstracted from everyday (teaching) experiences. This depicts how a novice teacher, who has not yet developed TPCK might represent his or her own understanding of professional knowledge about the domain of teaching with technology. TPCK itself in this illustration would be a subsample of these elements, where aspects of all sub-domains are considered. Figure 4 depicts TPCK defined as a coherent intuitive theory by a teacher. This depicts how a teacher who has developed TPCK would need to represent her or his own understanding of professional knowledge about the domain of teaching with technology. Following this perspective, possessing TPCK means developing a conceptualization that roughly covers the same sub-domains, their interrelations, and the role of context (as it is proposed by the TPCK framework).

Conclusion—TPCK Framework

Now, after describing these two different possible perspectives, how should TPCK be conceptualized as a scientific theoretical framework to describe teachers' competence in using technology? To our understanding TPCK needs to be conceptualized as a coherent theory. A more detailed description of this conceptualization becomes possible applying the three foci for the accountability, for details in conceptual understanding proposed by diSessa et al. (2004): *contextuality*, *specification,* and *relational structure*. As a result, TPCK as a coherent scientific framework theory is (1) a unitary shape with a clear application context (teaching with technology); (2) the assumption of a limited number of presuppositions about technology, pedagogy, and content (ontological and epistemological) that constrain the construction of more specific theories (mental models) derived from them; (3) the idea of a meta-conceptual frame for the systematic relations of these presuppositions and the teacher's knowledge of the sub-domains.

We suggest this normative conceptualization, while being aware that novices might be more likely to represent their understanding as Knowledge in Pieces. Thus, it is important that, depending on the form of the initial naïve concepts, the processes of changing these naïve concepts (conceptual change) are assumed to differ. The most relevant transformation seems to be the transition from a fragmented to coherent understanding of teaching utilizing technology.

TPCK as Meta-conceptual Awareness

Following the conceptualization of the TPCK framework as a coherent theory, we define the TPCK construct as meta-knowledge. This is essential for repurposing emerging technologies, because, here, a more fine grained understanding of technology for teaching is relevant (Graham, 2011). Leaving the definition of the TPCK construct unclear and open to be subsumed under other sub-domains bears the risk of developing a very individual understanding of TPCK for teachers coming from different backgrounds. For example, a skilled pedagogue using digital technology might then just expand the boundaries of his PK concept. Or for a technology expert entering the teacher profession, teaching could fall within the boundaries of a wide TK concept. However, if TPCK is also to serve as a normative standard of how

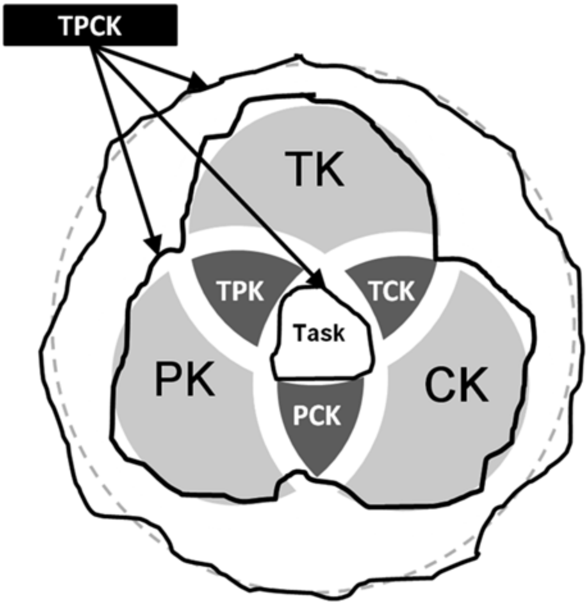

Fig. 5 Content of TPCK as a construct: Meta-conceptual awareness of the demands of the respective teaching *task*, the teacher's own *knowledge in the sub-domains,* and the *contextual* constraints. The conceptual boundaries of these elements roughly match those of the scientific framework theory

emerging technologies have to be understood in teaching, both of these examples are at conflict with the proposed conception of TPCK.

In contrast, if TPCK is defined as meta-conceptual awareness, there is no need to define boundaries or specify an array of sub-facets, as it has been done for the other sub-domains, for example, PK (Tatto et al., 2008; Voss et al., 2011), PCK (Baumert et al., 2010; Blömeke et al., 2008; Kunter et al., 2007), TPK (see previous statements and Graham et al., in press). By meta-conceptual, we refer to what a teacher knows about her or his own knowledge in the TPCK sub-domains, and their strategies to intertwine these for planning and implementing lessons that add value by technology or by consciously refraining from using technology, respectively. Furthermore, to successfully master an ill-structured and complex domain, such as teaching with emerging technologies, the current task at hand has to be understood as another source of varying constraints (Koehler & Mishra, 2008), an aspect that Berliner (1992) has described as the sensitivity to the demands of the teaching task and the situation. This is necessary for the teacher to determine the available (cognitive) resources and strategies for reaching the desired goal state of creating solutions for the task of teaching, namely, concrete learning opportunities. Overall, TPCK is then to be understood at the level of meta-conceptual awareness that provides a high level of organization to an expert's knowledge (Koehler & Mishra, 2008; Leinhardt & Greeno, 1991), but not as a body of knowledge that is circumscribable and fixed.

In sum, Technological Pedagogical Content Knowledge is defined as a construct comprising teachers' meta-conceptual awareness of the demands of the teaching task at hand, the teacher's knowledge in the sub-domains, and the contextual constraints. Figure 5 depicts this notion of TPCK by also determining these three elements as coherent concepts. The central area of the diagram, formerly pointing to TPCK as a construct, is here replaced by the teaching task at hand. This is because following the visual logic the most central area is the most specific one, which abides by more with the idea of a concrete lesson (plan) than with that of comprehensive knowledge.

Defining TPCK as meta-conceptual awareness is, furthermore, in line with operationalizations of developing TPCK in qualitative studies, as the increase in the complexity of participants' explicit argumentations for using technology in the ways they did or planned to do (Graham et al., in press; Koehler et al., 2007). Furthermore, Kramarski and Michalsky (2010) found direct empirical support of a positive influence of self-regulatory support on preservice teachers' performance in TPCK tasks (comprehension and design of study units intertwining specific technology, pedagogy, and content).

Conclusions

Emerging technologies are a relevant factor for teaching and learning, because they impact both the visible structures of the classroom activities as well as the students' learning processes (Angeli & Valanides, 2009; Koehler & Mishra, 2008). Thus, teachers need to plan carefully in order to leverage the potential of such technology in their teaching (Webb, 2011; Webb & Cox, 2004). The TPCK framework has provided a valuable common ground for discussing these issues (Angeli & Valanides, 2009; Harris et al., 2009; Mishra & Koehler, 2006; Niess, 2005). In this chapter, we suggested to promote the development of TPCK as a construct and framework toward a more comprehensive theoretical model. Basic theoretical assumptions of the TPCK framework were elaborated by introducing the concept of mental models (Brewer, 1987; Johnson-Laird, 1980, 1983) and perspectives from the adjacent conceptual change literature (Clark et al., 2011; diSessa et al., 2004; Ioannides & Vosniadou, 2002; Vosniadou, 1994; Vosniadou & Brewer, 1992, 1994).

This chapter focused on the following three issues. First, mental models that teachers construct of the (socio-)cognitive functions of a technology were proposed to play a significant role in determining how teachers leverage their specific potential in the classroom. Second, the issue whether knowledge in the sub-domains is a necessary prerequisite for TPCK was discussed. Based on an approach introducing the notion of mental models, mediating or moderating relationships between the proposed sub-domains of the TPCK framework, and a teacher's ultimate performance on teaching tasks, were suggested. Finally, as a consequence of the mental model approach, the question was addressed how to conceptualize TPCK as a framework and as a construct. This issue was discussed in the light of coherent versus fragmented theories, based on the conceptual change literature, and suggest an understanding of the TPCK framework as coherent, and the TPCK construct as a teacher's meta-conceptual awareness of the teaching task, the available knowledge in the TPCK sub-domains, and the context.

Overall, it can be concluded that the considerations presented here provide a valuable addition to the theoretical framework of the TPCK approach. With regard to further theoretical issues, it seems important to specify the sets of presuppositions that should ideally underlie a teacher's reasoning for utilizing emerging technologies. Furthermore, these considerations constitute a starting point to define a notion of *expertise* in TPCK supported by the framework. With regard to research, these then would provide a basis for comparing teachers' presuppositions found in empirical data. More important, the considerations presented in this chapter need to be followed up by empirical research to determine the actual role of teachers' mental models for lesson planning and instruction. Along with this, the assumed predictive roles of prior knowledge in the basic sub-domains, and pedagogic beliefs, need to be investigated.

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TPACKtivity: An Activity-Theory Lens for Examining TPACK Development

Marjorie Terpstra

Introduction

TPACK explicates the dynamic knowledge teachers draw upon when they employ digital technologies to engage their students in content within a context (Koehler & Mishra, 2008; Margerum-Leys & Marx, 2004; Mishra & Koehler, 2006; Niess, 2005, 2011; Zhao, 2003). The amalgamation of pedagogical knowledge, content knowledge, and technology knowledge (TPACK) (Niess, 2008; Thompson & Mishra, 2007) enables teachers to use particular digital technologies to address particular issues that students encounter when learning particular content. The development of the TPACK framework has focused needed attention on the knowledge for teaching content with technology, using pedagogically sound ways, and has opened questions of how to develop that knowledge.

While the TPACK framework explicates what knowledge teachers draw upon to teach with technology, activity theory (Engeström, 1999; Leont'ev, 1981; Wertsch, 1998) aids in understanding how TPACK develops. Instead of describing learning as a solitary and decontextualized process, activity theory emphasizes the influence of contexts on teacher knowledge development (Grossman, Smagorinsky, & Valencia, 1999; Ogawa, Crain, Loomis, & Ball, 2008; Smagorinsky, Cook, Moore, Jackson, & Fry, 2004). Activity theory seeks to learn how those social settings, whose structures were developed through historical and cultural activity (Engeström, 1999; Grossman et al., 1999), impact development toward an ideal (Engeström, 1999; Smagorinsky et al., 2004).

Integrating TPACK's teacher knowledge frame with activity theory for explanations of changes in knowledge and actions offers the new lens of TPACKtivity. The TPACKtivity lens combines the "*what*" is to be learned by preservice teachers

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(TPACK) with the "*how*" it is learned (activity theory). It describes knowledge for teaching as active, interdependent knowledge of pedagogy, content, and technology, and illuminates how that knowledge is developed in settings through mediating tools that can transfer to other activity settings. TPACK's "*knowledge as design*" (Mishra, Koehler, Shin, Wolf, & DeSchryver, 2010; Perkins, 1986) demands examining its contextualized implementation; design implies fitting for particular situations rather than generalities. Taken together, the TPACK conceptual framework and activity theory provide a complementary picture of knowledge development for teaching with technology. This chapter outlines the components of the TPACKtivity lens and then illustrates the value of TPACKtivity by applying it to a study, more clearly identifying the contributors to TPACK development.

Technological Pedagogical Content Knowledge (TPACK)

First, a brief introduction to the TPACK framework is in order. Mishra and Koehler (2006) set forth the theory that teachers draw upon a unique knowledge for teaching with technology, called Technological Pedagogical and Content Knowledge (TPACK). Mishra and Koehler (2006) built on the concept of Pedagogical Content Knowledge (PCK), a term coined by Shulman (1986), to describe the type of knowledge required for teaching. PCK "*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 PCK construct emphasizes the importance of particular kinds of pedagogies for particular content areas. It describes content knowledge (CK) and pedagogical knowledge (PK) and then the intertwining in PCK.

Content Knowledge (CK) represents the knowledge of the disciplines. Not only are the facts or concepts of the subject matter included, but also an understanding of how the discipline is structured (Shulman, 1986). The structure of the discipline describes how principles, concepts, and facts are organized, and how the discipline accepts, or rejects, claims. In understanding how the discipline is structured, teachers are equipped to help their students learn not just concepts, but why those concepts are important to the discipline, and how to help their students build disciplinary knowledge.

Pedagogical Knowledge (PK) deals with the knowledge of teaching, the knowledge of classroom management and organization (Shulman, 1987), how students learn, and what sorts of activities encourage learning, and also the knowledge of assessing learning. Pedagogical knowledge is generic in the sense that it cuts across content areas to include knowledge of learning theories and how they apply to the classroom (Koehler & Mishra, 2008).

Mishra and Koehler (2006) advocated including Technology Knowledge (TK) as a third component of teacher knowledge, arguing that TK is not a part of PCK. Unlike PK and CK, which are relatively stable domain bodies of knowledge, the domain of TK continues to change and develop, as technologies change and new

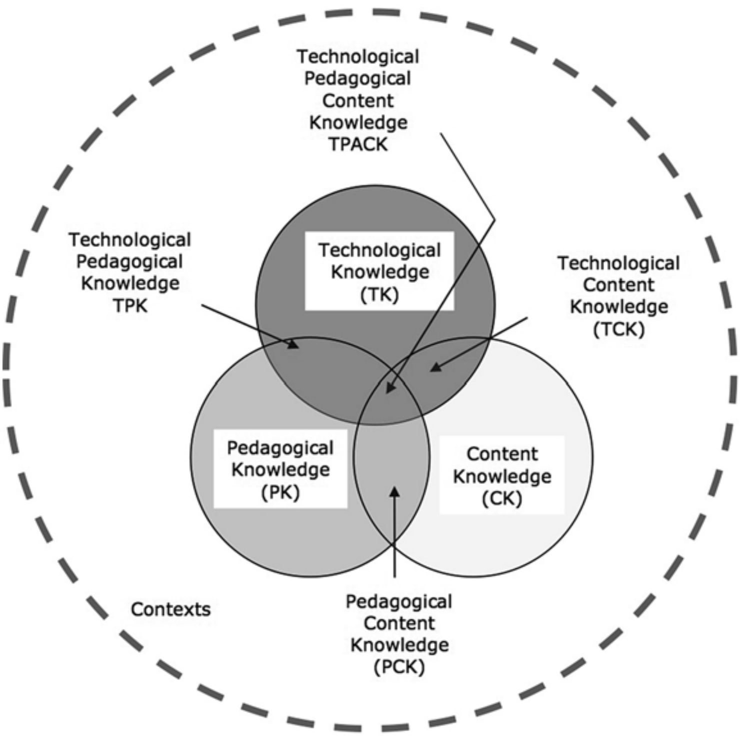

Fig. 1 The TPACK framework and its knowledge components (Reproduced by permission of the publisher, © 2012 by tpack.org from http://tpack.org, 2009)

technologies emerge. Integrating TK to CK and PK led to three more interconnections of knowledge in addition to PCK (Fig. 1). The integrations of knowledge become Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and Technological Pedagogical Content Knowledge (TPACK).

How subject matter can be changed by technology use is the focus of Technological Content Knowledge (TCK) (Koehler & Mishra, 2008). TCK refers to the combination of Technology Knowledge with Content Knowledge, and how the two support and constrain each other. Because Pedagogical Knowledge is almost always a part of classroom concerns, TCK, separate from Pedagogical Knowledge, is difficult to distinguish in K-12 classrooms.

Understanding how technology can shape teaching and learning defines Technological Pedagogical Knowledge (TPK). TPK recognizes the affordances and constraints of technologies for pedagogical purposes. Because so many of the available digital tools were developed for business or personal entertainment, TPK requires flexibility in order to repurpose technologies for pedagogical purposes. It examines technology's capabilities and determines what general pedagogical functions can be enhanced by technology's implementation. It is not used for technology's sake, but for improving students' learning (Koehler & Mishra, 2008).

Adding in Content Knowledge to interact with Technology Knowledge and Pedagogical Knowledge contributes to the complexity of working knowledge. That interaction, TPACK, entails:

> an emergent form of knowledge that goes beyond all three components (content, pedagogy and technology)…. [TPACK] is the basis of good teaching with technology, and requires an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn, and how technology can help redress some of the problems that students face; knowledge of students' prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge and to develop new epistemologies or strengthen old ones. (Koehler & Mishra, 2008, pp. 17–18)

Although each knowledge component is described separately, in reality they all interact and all need to be considered in understanding teaching (Koehler & Mishra, 2008). When any component changes, for example when a new app debuts, the other components, in this case, content and pedagogy, need to be addressed as well.

The TPACK framework emphasizes the complexity of teaching, describing the ill-structured problems that teachers face in helping their students learn (Koehler & Mishra, 2008). TPACK views teachers as curriculum designers, who draw on their knowledge and experiences to solve problems for particular situations.

Drawing upon the TPACK framework, the TPACKtivity lens focuses on identifying TPACK components in order to determine which knowledge bases are operating and how teachers incorporate their knowledge bases to employ technology to facilitate student learning. Given that TPACK is described as knowledge in action, the TPACKtivity lens looks for TPACK within instructional planning and implementing rather than through traditional knowledge testing. TPACKtivity examines TPACK development within activity settings, dynamic and interactive spaces, in order to determine which factors shape TPACK development. Thus, activity theory contributes important components to the TPACKtivity lens.

Activity Theory

Rooted in Vygotsky's (1978) work on society's role in learning, activity theory seeks to explain why humans develop the way they do (Engeström, 1999; Leont'ev, 1981). Vygotsky (1978) theorized that people interact within a culture, or context, appropriate, and then internalize that context's way of thinking with conceptual learning occurring in the taking on of public and shared meanings (Grossman et al., 1999; Ogawa et al., 2008). Activity theory suggests that individuals are involved in multiple learning and living contexts; thus, multiple contexts inform understanding of how individual preservice teachers develop (Grossman et al., 1999) teaching, technology, and content concepts and skills. Educational contexts contain ever-widening dynamic influences on preservice teachers: home life, supervising teachers, students, teacher education faculty, colleagues, school administrators, teacher education administrators, curriculum, school mission, teacher education mission, community vision, state and federal educational policies, and cultural–historical expectations of education (Smagorinsky et al., 2004). At times, the social settings of individuals conflict with each other in terms of motives, constituents and ideals, therefore emphasizing different values and practices (Smagorinsky et al., 2004). The TPACKtivity lens focuses on multiple activity settings and their interacting elements to provide insights into settings' impacts on teachers' TPACK development.

Various elements in activity theory can be described individually, yet, in reality, all interact together and impact each other. Vygotsky (1978) first conceived of activity as mediated action with *subject*, *object* (goal), and *artifact* (Engeström, 1999; Leont'ev, 1981). In order for an activity setting to exist, the subjects' actions must be goal oriented, and involve a set of practices and artifacts that mediate action toward the goal (Engeström, 1999; Grossman et al., 1999; Leont'ev, 1981).

Subjects

The subject is the individual (or smaller group) who is acting in the environment toward an object. A subject can influence the object, the social network, and artifacts either individually or with the group, although the influence may be limited by social position, culture, and history (Holland & Lachicotte, 2007; Leont'ev, 1978; Ogawa et al., 2008). Activity theory posits, therefore, that an individual cannot escape his or her social systems, even though she or he is also not completely controlled by them, nor simply pushed back and forth by alternating influences (Holland & Lachicotte, 2007; Vygotsky, 1978). In this light, Wertsch (1998) chose to use "*agent*" to communicate the subject's active role. Subject roles depend upon the context; a subject takes cues from the situations' schematic structures (Ogawa et al., 2008) and self-understandings, or identities (Holland & Lachicotte, 2007) to choose actions.

A subject tells not only others, but also himself or herself, who he or she is, what his or her identity is, and then seeks to act in accordance with that identity (Holland & Lachicotte, 2007). In the case of teaching, identity refers to the continual developing of the teaching identity one views as ideal (Grossman et al., 1999). Across social contexts, or within a social context, multiple, sometimes competing, conceptions of identity exist; in addition, multiple, sometimes competing, means for reaching the ideal also exist (Holland & Lachicotte, 2007), making it difficult for preservice teachers to navigate toward their identity (Grossman et al., 1999). Through time and experience, as preservice teachers progress toward a more-developed identity, they evaluate the options and choose those actions that best fit with their chosen ideal identity, in spite of influences to the contrary. TPACKtivity highlights the role of identity by looking in and across complex settings to note preservice teachers' identities in multiple settings, and how these identities shape actions within settings.

Objects

The object is defined as the purpose of the activity, what the individual subject is seeking as well as the goals of various subjects within the activity setting (Engeström, 1999; Ogawa et al., 2008). As an objective, it guides the actions of the subject, connects to group activity, and delivers results that might be intended or unintended (Ogawa et al., 2008). In a preservice teacher internship (also known as student teaching) placement, the preservice teacher (subject) seeks to develop the knowledge and skills for helping students learn (objective), while the collaborating teacher and supervising instructor also seek their own objectives. TPACKtivity examines how the objectives within a setting impact the interns' development of TPACK and its knowledge components, the knowledge of using digital technology for facilitating students' learning.

Mediating Tools

Mediating artifacts, or tools, of the activity setting allow subjects to pursue objects and connect subjects to others (Engeström, 1999). Both symbolic and concrete artifacts are tools that subjects construct, learn, and use, and are produced from activity (Engeström, 1999; Ogawa et al., 2008; Vygotsky, 1978; Wertsch, 1998). Examples of symbolic artifacts include language, facial expressions, principles, and visual representations, while concrete artifact examples employed by subjects include computers, markers, and desks. Without mediating tools, subjects would respond to each and every stimulus rather than being able to "control, organize, and re-signify their own behavior" (Holland & Lachicotte, 2007, p. 115). While subjects employ and shape tools, using them as intended or not, it must also be noted that tools also shape subjects and their activities (Ihde, 1990). Within an educational setting, Grossman et al. (1999) labeled mediating tools as conceptual and practical tools. Conceptual tools, such as principles, frameworks, and ideas about teaching and learning, guide decisions about instructional practices, while practical tools are of much more immediate use, such as the instructional practice of guided reading and the concrete tool resources of textbooks or computer software. Identifying mediating tools for TPACK development is an important role of the TPACKtivity lens.

Dynamic Interactions

While subjects interact with mediating tools, all actions on objects are mediated by the sociocultural context, the community with its rules and division of labor as seen in Fig. 2 (Engeström, 1987; Leont'ev, 1981; University of Helsinki, 2003–2004), also called the "*activity setting*" (Engeström, 1987; Grossman et al., 1999). Communities are defined by their members, by their shared activities, their shared resources and shared beliefs. As the community continues to act, it reinforces its

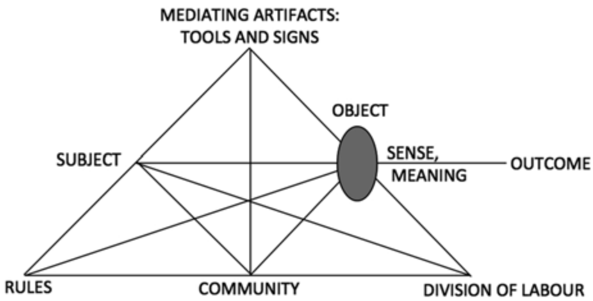

Fig. 2 The structure of a human activity system (Adopted from Engeström, 1987)

beliefs and history (Engeström, 1987; Ogawa et al., 2008). Through their cultural history, community members have set up specific outcomes, or ideals and artifacts that sustain their relationships and influence their actions within the setting (Grossman et al., 1999). Sometimes, however, competing goals toward the same outcome can be seen in a setting, making it difficult for participants to satisfy both. Additionally, with several overlapping community settings, it is likely that competing goals exist and choices will have to be made as to which to pursue. If, however, the overlapping community setting goals are the same, it is much more likely that congruence of foci will be stronger (Grossman et al., 1999).

The interactions of an activity setting can also be seen in differing responses to activity settings: *resistance*, *acquiescence,* and *accommodation* (Smagorinsky, Lakly, & Johnson, 2002). *Resistance* occurs when the subject refuses to be directed by the mediating artifacts and practices toward the activity setting's goal. Some activity from the individual's history, and/or a well-developed identity, works to resist the goals of the setting and, in spite of the setting's pressure, the participant does not take on the same goals and object (Grossman et al., 1999). *Accommodation* is described as a "*grudging effort to reconcile personal beliefs*" (Smagorinsky et al., 2002, p. 201) with the goals of the setting, but is not comfortable for the individual. The third option, *acquiescence*, involves submitting to the goals of the setting and complying with them (Smagorinsky et al., 2002).

The TPACKtivity lens draws attention to competing and congruent goals, identities, and the dynamic interactions among activity settings, giving a richer picture of the complexities involved in knowledge in action development. The TPACKtivity lens ensures the context of TPACK development is not discounted, and facilitates construction of a fuller picture of individuals learning within communities and embedded within cultures.

Applying TPACKtivity: A Study of Preservice Teacher Intern Development

In order to evidence the efficacy of the TPACKtivity lens, it will be applied to a study of preservice teachers, as they sought to use technological tools in their teaching practice. The following qualitative study analysis illustrates the importance and usefulness of the TPACKtivity lens, but does not show the full results. While the full study (Terpstra, 2010) revealed eight activity settings, for the purposes of illustrating TPACKtivity, this chapter will focus on only one activity setting, with passing reference to the others.

The study examined multiple overlapping activity settings to gain insights into how preservice teaching interns develop Technological Pedagogical Content Knowledge (TPACK). The study focused on seven interns' experiences with learning to teach with technology, during their year-long internships and a grant-supported project aimed at learning to use technology for teaching content.

Research Questions

A main question guided the study: To what do preservice teaching interns attribute their learning to use educational technology in their teaching? Three subsidiary questions informed by activity theory provided even deeper focus: What are the self-described roles of interns' daily life, their K-12 experiences, the technology conference, the grant program, the teacher education program, their placement setting, and online communities? What conceptual and practical tools do they describe as contributing to their learning how to teach with technology? How do they respond to settings with goals with which they do not agree?

Research Methodology

Participants

For this study, participants were recruited from a group of 17 intern grant participants. For the grant, *Getting Ready for Implementing Technology in Schools* (GRITS)[1] (Terpstra, 2010), student teaching interns at a large Midwestern United States university prepared curriculum-based technology-rich lessons for their internship classrooms.

Seven of the 17 GRITS interns responded to an email inquiry and agreed to participate. Five interns were pursuing elementary teacher certification, and two, secondary certification. The group consisted of six females and one male. Two of the interns were placed in schools with 65–95 % of students qualifying for free and reduced lunch, three in schools with 50–60 %, and two in 0–20 %. All of the interns were White, like most of the interns in the University's teacher preparation program, although five of the seven intern participants interned in schools where a majority of the students did not share the interns' race. Each participant (pseudonyms are used), setting, and GRITS project is briefly presented in Tables 1 and 2.

[1] As with all names of participants, a pseudonym has been used for the grant program.

Table 1 Interns' settings

Intern	Grade Level	School district	Total students	% Free and reduced lunch	% African American	% American Indian	% Asian	% Hispanic	% Multiracial	% White
Ambrosia	4	Midsize	560	58	57	<1	4	10	0	28
Brian	9	Midsize	1675	51	47	<1	6	14	0	33
Kelly	3	Middle sizer	327	51	37	<1	9	9	3	42
Lucy	4	Urbandale	815	89	67	<1	32	<1	0	<1
Malia	4	Suburbia	333	11	6	0	14	2	<1	78
Margaret	9–12	Suburbanado/	1411/	19/	9/	<1/	2/	5/	3/	81/
		Ruralton	1093	15	<1	<1	<1	2	3	94
Terese	3	Midsize	275	65	65	0	7	12	1	15

Table 2 Interns' GRITS projects, resources, and students

Intern	GRITS project	Resources received	Intern major	Technology in classroom	Computer lab	Students and computers
Ambrosia	Integrate SMART board into all subjects using PPT, Google earth, SMART technologies	Use of SMART board, projector, time	Math, social studies (science)	Computer in back of room, digital camera (SMARTBoard& projector) (laptop)	Sign up for lab use; weekly use unknown, tech teacher	Very few have access to computers or Internet at home
Brian	Integrate Google Earth and YouTube videos into PPT; video record and post to YouTube; Web page creation	Use of MacBook laptop, time	Social studies	Receiver, TV, DVD, VCR, projector (laptop)	Library lab, computer lab, music lab with Macs/ sign up in advance	Skills vary greatly
Kelly	wiki, podcasting, digital photography	Use of digital camera, audio recorder, time	Language arts	Teacher computer, TV as projector, VCR (laptop)	Once/week classroom teacher; tech curriculum	A lot of students do not have access to computers at home
Lucy	Interactive online community map	Use of digital camera, time	Geography, TESOL	Student computer(s?) for centers, digital camera, document camera (projector) (laptop)	Once/week tech teacher can reserve on Fridays	Not mentioned
Malia	Podcasts of state history posted on web page	Time	Social studies	Document camera, projector	Once/week; classroom teacher	Not mentioned
Margaret	Use digital pictures to learn French language and communicate with French native speakers	Use of digital cameras, MacBook laptops, time	French	Document camera, projector in Suburbanado (MacBook laptops) (laptop, digital camera)	Sign up; no YouTube access and less consistent Internet access in Ruralton	Suburbanado—more proficient, all home Internet access; Ruralton—not all home Internet
Terese	*Science Simulations*—software for plant unit plus other topics	Software, time	Language arts	Two computers for student use	Once/week, tech teacher; can reserve; YouTube and other sites blocked	Many do not have computer or Internet at home

Data Collection

The data for this study consisted of interview video and audio recordings, and their transcripts, interview field notes, plus existing artifacts from the GRITS grant program, including applications for the grant, intern emails to and from the coordinator, meeting notes, lesson plans at various stages, final reflection essays, and technology conference presentations.

Interviews were conducted with the interns between the seventh and ninth months of their nine-month internships. All interviews were either video or audio recorded and transcripts were made of all the interview recordings. Field notes were taken and fleshed out as soon as possible following the interviews.

The interview protocol included open-ended questions on the interns' use of technology in and outside of their school setting and their preparation for teaching with technology. They were also asked for suggestions for improving teacher preparation for teaching with technology. The protocol was used as a guide for the interview but varied, depending on the responses and attitudes of the interviewees and their own questions.

Data Analysis

The factors the interns listed as contributing to TPACK development were coded in an iterative process of analyzing and regrouping into categories and subcategories of activity settings in accordance with the TPACKtivity lens. In addition to those that the interns explicitly listed, online communities were also mentioned, or referenced, by interns. From the categories of influences emerged activity settings, spaces in which the interns reported gaining knowledge and skill for teaching with technology: (a) Daily Living/Home environment, (b) Other workplaces, (c) K-12 experience, (d) Technology Conference, (e) Teacher Education, (f) GRITS Experience, (g) Placement Setting, and (h) Online Communities.

Transcriptions and document artifacts were examined for activity setting factors (mediating tools, identity, setting object, and community rules and roles) that interns perceived as contributing to TPACK growth or lack of growth. Conceptual and practical tools that interns reported as contributing to their learning how to teach with technology were analyzed for patterns and similarities to each other. The data were then evaluated to determine whether TPACK development support existed, or whether development of a single knowledge component of TPACK had been supported and described.

Experiences across settings were analyzed for agreement or conflicting evidence. Responses to settings were analyzed for whether the interns responded to their activity settings with resistance, acquiescence, or accommodation (Smagorinsky et al., 2002).

Results: Activity Settings, Associated Mediating Tools and Rules

As shown in Table 3, interns related a variety of sources for their learning to teach with technology, ranging from using technology in daily life and growing up in the digital age to their internship placement and helping students learn. As previously noted, highlights from most settings will be noted, but only the setting most often identified, the GRITS experience, will be examined in depth in order to illustrate full application of the TPACKtivity lens. It's important, however, to begin with the cultural–historical context, an influence on participants' perspectives on learning to teach with technology, yet not easily recognized by participants.

Cultural–Historical Context

Each intern had his or her own internship context, yet they were all part of a broader context as well, the complex public educational system in the United States. Multiple, sometimes competing, goals have shaped and continue to shape public education in the United States: moral training and citizenship (Mann, 1848), preparing for work in the industrial economy (Ogawa et al., 2008; Tozer, Senese, & Violas, 2005), child-centered educating for democracy, building problem-solving skills (Dewey, 1938), and developing new literacies of the Internet and other information technologies (Coiro, Knobel, Lankshear, & Leu, 2008).

The federal No Child Left Behind Act of, 2001 (NCLB) (2002) brought new accountability to public education as well as defining highly qualified teachers as those certified in the content areas they teach. The state in which the study took place also adopted standards for beginning teachers, markers of what a highly qualified teacher knows and can do.

Teacher Education Program

All of the seven interns, who took part in this study, learned to teach as part of a large mid-western United States university's teacher education program. Responding to the State Standards for teachers, the teacher education elementary program stranded a theme of using technology for instruction through all of the program courses. Each course was expected to address the technology theme.

Reflecting on the teacher education setting, some interviewees talked about student-prompted technology integration discussions that mediated their learning to teach with technology. Margaret also related one of her professors had mediated her TPACK growth by giving "*us some ideas; she pushes us to use technology a lot*" (Margaret Interview, p. 2). While interns mentioned instances of using technology

Table 3 Activity settings and their reported contributors to Interns' learning to teach with technology.

Influences	Ambrosia	Brian	Kelly	Lucy	Malia	Margaret	Terese
Daily life							
Using technology daily	x	x		x	x	x	
Growing up in the digital age/feels natural				x			
Parents supported		x		x		x	
Other workplaces				x	x		
High school model		x		x		x	
University Tech conference	x						
Teacher education							
Classes			Varied	x		x	
Learning from colleagues	x	x		x		x	x
GRITS							
Working with another and getting feedback	x	x	x		x		x
Learning new ways of thinking about teaching	x	x	x		x		
Learning tech possibilities				x		x	x
Learning from colleagues		x	x		x		x
Internship placement							
CT or other teacher	Ideas	x		x	x		
Thinking about ways to help students		x	x				
Across all settings							
Passion/interest	x			x		x	
Own research/ trial and error	x	x		x	x	x	x

in their classes, the interns focused on the subject matter and did not recognize how the technologies facilitated their learning, or how their instructors had modeled teaching specific content with technology.

This TPACKtivity lens reveals the conflicting activities of the teacher education setting. Half of the interns reported that they heard the explicit message that technology was good and that they should use it in their teaching. Conflict arose, however, in how instructors did not know how to use the equipment themselves, in how some instructors excused themselves from the tool they explicitly told their students to implement, and how some instructors exempted their students from technological components of assignments. The teacher education program appeared to focus on pedagogical content knowledge, but failed to explicitly focus on TPACK development in the activity setting.

Daily Life

Four of the seven interns, Ambrosia, Brian, Lucy, and Malia, attributed their learning to teach with technology to daily living, or living in the digital age. All the interns revealed how technology mediated their living in the world. With technology use, a seamless part of all the interns' lives, their Technology Knowledge developed in an ongoing way as evidenced by their continual use of digital technologies. It is clear, however, that daily living activity settings did little to facilitate TPACK development because the interns used few of the daily life technologies in their classroom instruction (Terpstra, 2010). In examining this setting as well as the classroom setting, the TPACKtivity lens focuses attention on an important distinction, giving evidence of TPACK not as knowledge of integrated parts but a distinct knowledge resulting from a transformation of the component parts (Angeli & Valanides, 2009).

GRITS Experience

For their GRITS grant projects, participants developed detailed lesson plans for curriculum and standards-based technology rich lessons to be implemented in their internship classrooms in the coming school year. The grant required the preservice teacher interns to meet with the coordinator of the GRITS program at three strategic times over the summer to review expectations of the program, gain assistance, and report progress. The grant provided software and the use of hardware for internship classrooms, as well as payment for project development time. The participants were required to write a reflection on their grant work and present their work at a session of the College of Education's technology conference.

Object of the Setting

The GRITS summer grant experience aimed to develop participants' TPACK through their learning new hardware or software, and designing lessons for implementation in their particular internship placement. Given the specific object of developing TPACK, the tools and the setting that actually mediated such knowledge development are important to note.

Community

The social aspects of interacting with other interns and the coordinator topped the interviewees' comments about contributors to their learning to teach with technology. Kelly reported learning ideas for teaching with technology from the technology conference presentations of the other GRITS interns. Malia, Brian, and Terese, all noted that they learned from talking with the other GRITS interns and seeing their presentations of what they were doing. During their interviews, this remembering of others' projects stood out immediately.

All the GRITS participants worked with the coordinator through initial and subsequent face-to-face meetings and email discussions. Some sent lesson plans early and often, revising based on suggestions from the coordinator, and further investigations of content and technologies, but a few others sent the bulk of lesson plans at the end of the project time with little time for finessing the plans.

In both his GRITS reflection and his interview, Brian talked about how GRITS had challenged his approach to teaching and how it helped him think more critically about using technology, moving his teaching from lecturing toward small group work and more active learning. Ambrosia wrote extensively about the importance of the GRITS coordinator in her work, emphasizing the effects of collaboration:

> She has taught me the importance of keeping the focus of the lesson on the content and not on the technology, as well as giving me many different ideas in how to use the SMART Board in my lessons. Throughout the entire experience, she has demonstrated the importance of keeping an open mind about new ideas and always considers new things. I have realized, more than anything else, the importance of sharing ideas and working with others to enhance lessons in many different ways. (Ambrosia Reflection pp. 1–2)

Mediating Tools

The interns reported mediating tools from the GRITS grant program encompassing three areas: technology as a tool, technology possibilities, and lesson planning.

"*So the technology is just the tool! I'm supposed to think about how to teach the content using the tool*!" (Ambrosia Meeting, June 18, 2007). Ambrosia's expression of enlightenment came with the "*light-bulb on*" look after she peppered the coordinator with clarification questions. "*Technology is the tool*" became an important mediating conceptual tool as she planned her lessons with the SMART Board. It freed her to plan for mud and water,[2] when those tools were more effective and helped her examine the SMART Board tools for best application. Terese echoed Ambrosia's perception of technology as a tool. "*I believe that technology is an important tool to be used in the classroom, but it is important to remember that it is simply a tool; it should not be the complete basis of a lesson*" (Terese Reflection, p. 1). "*Technology is a Tool*" keeps emergent technologies with older technologies in their rightful places as tools, means to learning, and not content to be learned. The TPACKtivity lens aids deeper analysis into the cultural–historical context. It may be that this conceptual tool is only explicitly necessary for the immediate future, as the educational paradigm shifts from digital technology as content to be learned toward technology as a powerful tool that changes the processes of learning itself (ISTE, 2008).

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[2] Ambrosia's rivers and watersheds lesson planned for her to pour water over a large mound of clay to help her students visualize how watersheds functioned.

Another conceptual tool developed and employed by the interns opened the interns' thinking to the possibilities afforded and constrained by technology. They developed varied nuances to the "*Technology offers possibilities*" conceptual tool, including one corollary conceptual tool, "*Technology is not so difficult to learn*."

Brian emphasized the possibilities technology offered for meeting the needs of his students with special needs. Malia related that GRITS made her more aware of the importance of using technology with her students, because of the immediate buy-in of students and how it enhances their learning. Margaret combined their thoughts in declaring. "*Technology is not only fun, but necessary to use in a classroom to reach all learners*" (Margaret Reflection, p. 2).

Kelly, Terese, and Lucy reflected on how one technology could be used in many ways and for many purposes. Lucy also noted how technology enabled learning content as a whole unit of study, combining many content areas. Several interns remarked on how easily they learned the technology on their own. Margaret summed it up for all of the interns, "*I feel like it's more important. Like, yeah, I can really do this. Like it's possible*" (Margaret Interview, p. 4).

The lesson planning concrete tool pushed the interns to use technology to teach particular content in a particular setting—a wicked problem (Buchanan, 1992; Koehler & Mishra, 2008), and helped them address the necessary components when using technology to facilitate student learning. The lesson plan design tool aided communication between the interns and the coordinator around content, pedagogy, and the important components of lesson design. In the GRITS setting, the interns varied in their approaches to designing lessons that capitalized on technology. Some interns, Ambrosia, Kelly, Lucy, and Malia, began with their technology knowledge; Terese began with content knowledge; and still others, Brian and Margaret, with pedagogical considerations. As examples, Figs. 3, 4, and 5 trace Ambrosia's, Brian's, and Terese's processes of lesson design, each with a different knowledge component starting point. While other knowledge components evidenced, clearly by the end of the planning process, the unique amalgam, TPACK, became the new knowledge operating.

Ambrosia began with technology (Fig. 3). She had seen a SMART Board at the Technology Conference, had demonstrated one for her senior level class, and desired to gain knowledge and experience with integrating one into a classroom. She knew objects on the SMART Board screen could be moved, and that the user could write on the board and mark up images, but wanted to learn more of the affordances of the SMART Board. Because of the known affordances, she felt that the SMART Board fit with her desired pedagogy of engaging students in active learning.

Ambrosia consulted with her collaborating teacher and received the major topics her students would need to learn in the first nine weeks of the school year. To gain more knowledge of how the SMART Board could be used with these topics, she accessed the SMART Board web site and perused the sample lesson plans in literacy, math, social studies, and science. For her GRITS work, after consulting her district standards guide, she narrowed her content focus to social studies, more precisely landforms, beginning with a lesson on US landforms. At the same time, she

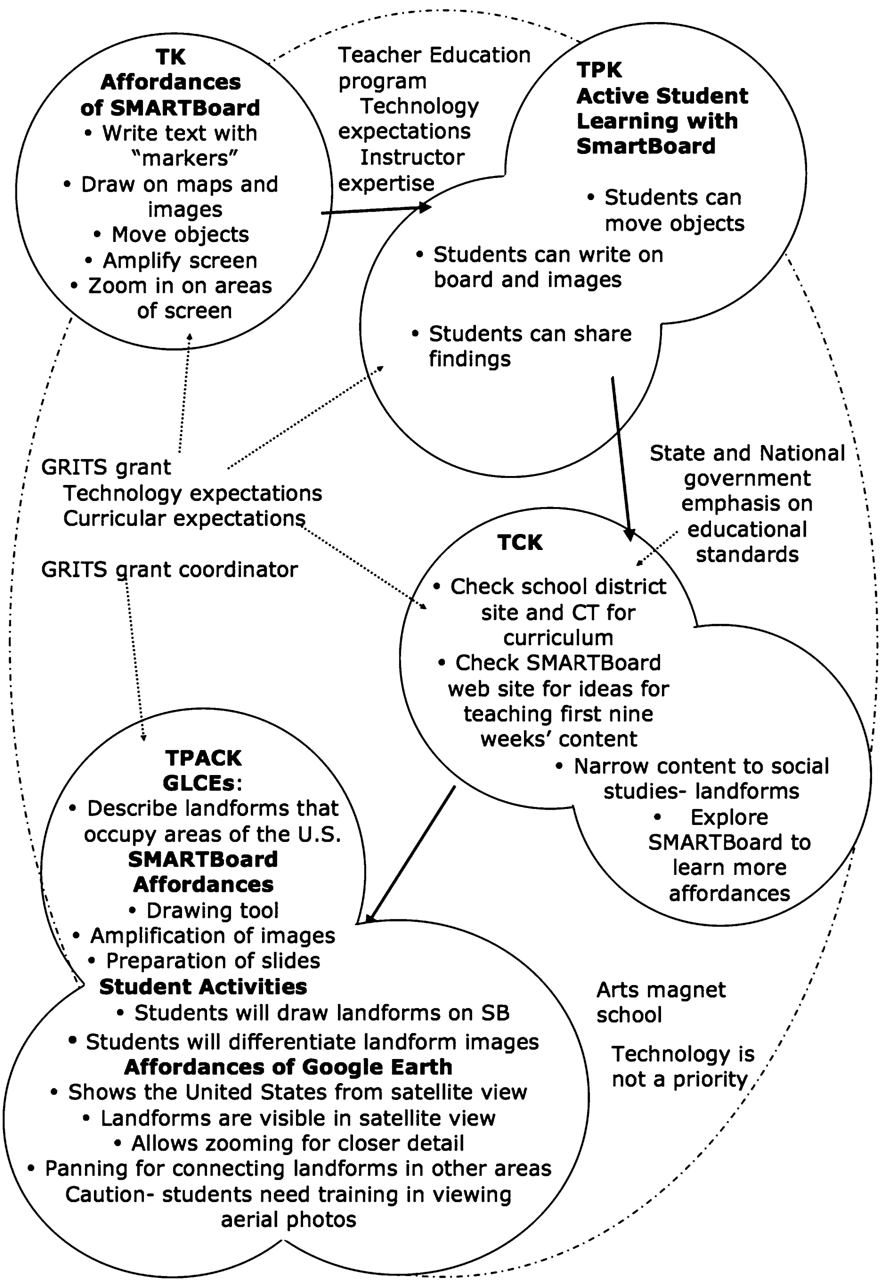

Fig. 3 Ambrosia's map of TPACK processing

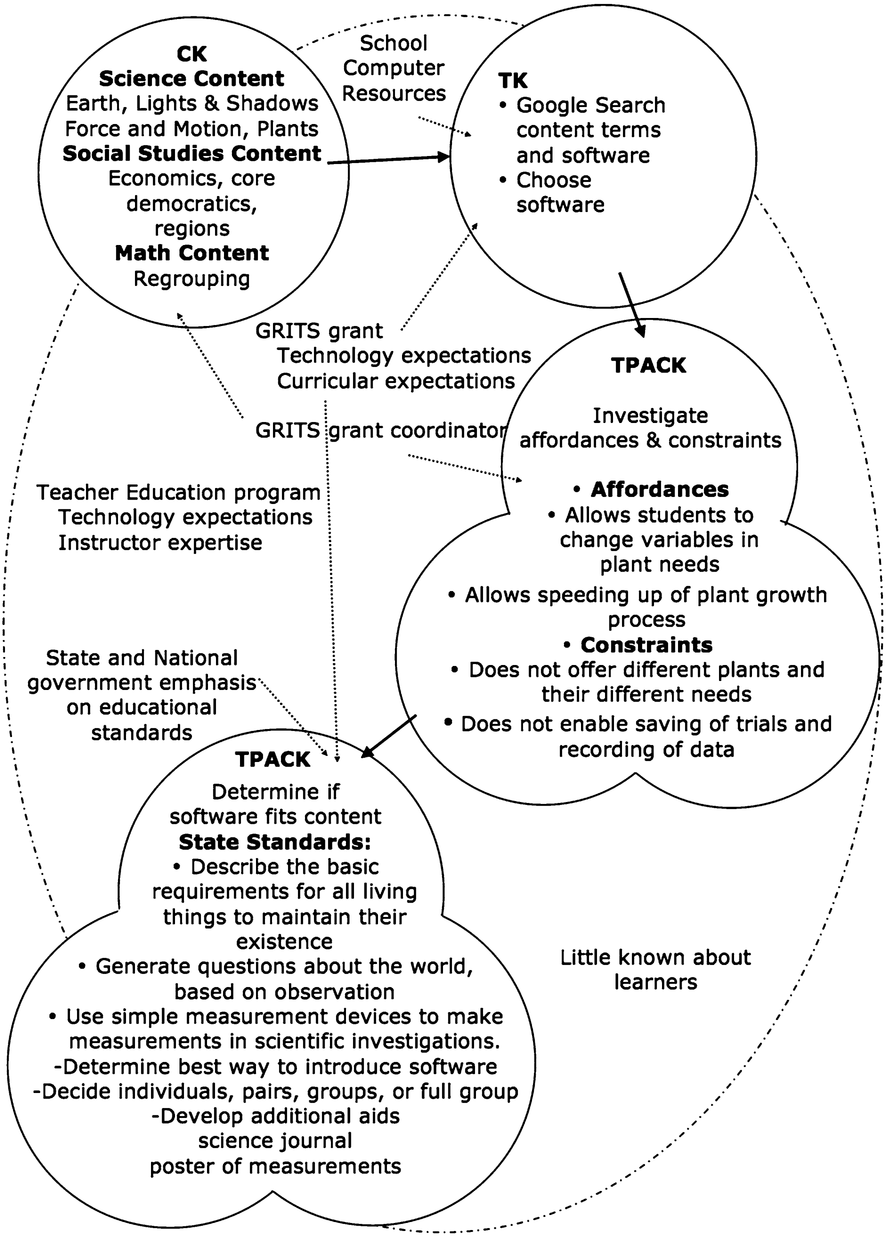

Fig. 4 Terese's map of TPACK processing

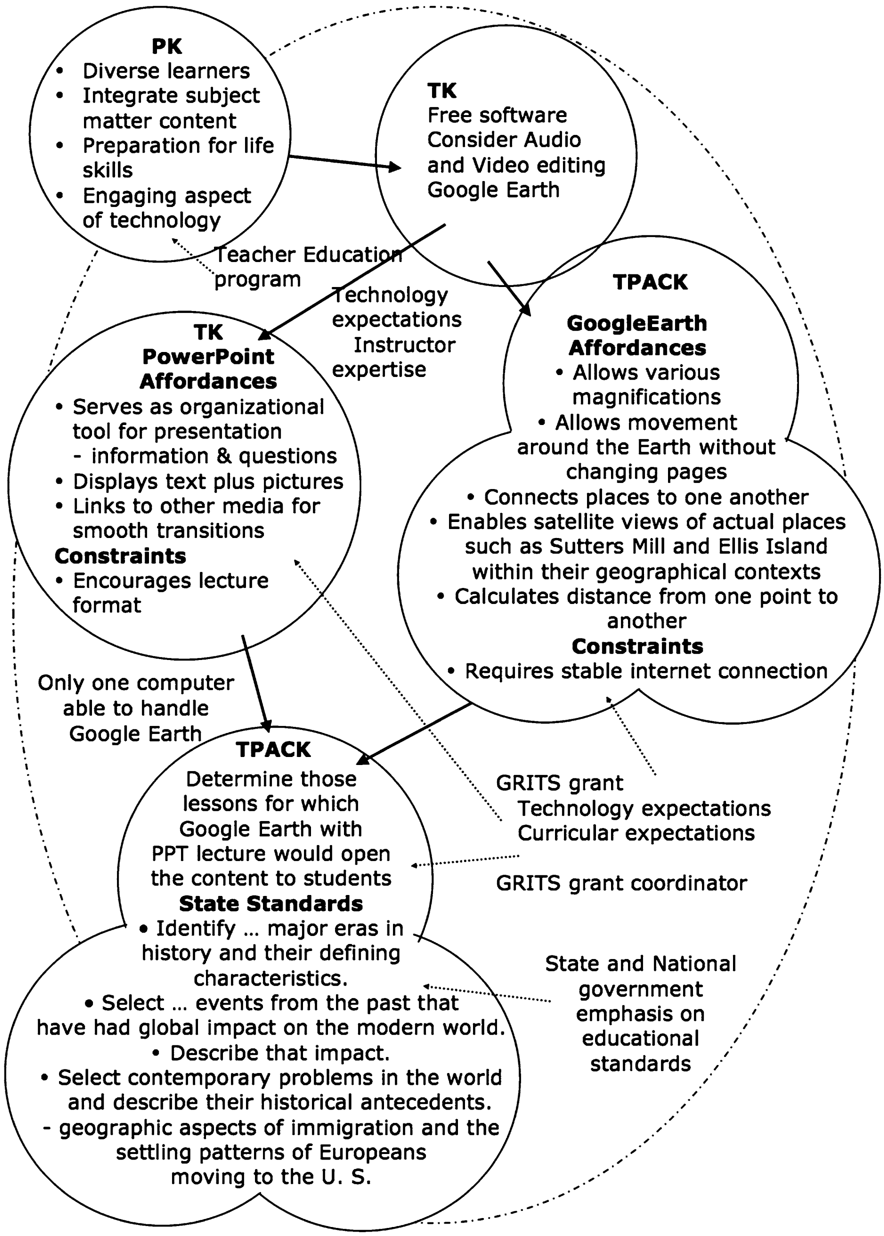

Fig. 5 Brian's map of TPACK processing

explored the SMART Board and its tools, learning more affordances, such as highlighting text and areas of the screen with the highlighting tool, as well as recording screen changes with the recording tool. She also discovered the affordances of covering parts of the screen with gray windows and of slide show creation for instruction.

Using her knowledge of the SMART Board's affordances, her knowledge of active learning and her knowledge of US landforms, Ambrosia planned a lesson introducing her students to the various landforms. While Ambrosia began with Technology Knowledge, she quickly drew upon her Pedagogical and Content Knowledge, as she planned instruction for her students with the SMART Board. As she constructed her lessons, her TPACK also developed.

Other interns, like Terese (Fig. 4), began with content. Terese's Collaborating Teacher (CT) left the door wide open for Terese's exploration. Looking for guidance, Terese emailed the GRITS coordinator with possible curriculum content topics. The coordinator responded by sharing results of a key word search using the content terms. Terese investigated the suggestions and decided to pursue software for science simulations. She built her Technology Knowledge as she worked with the software, discovering its affordances and constraints in regard to the content she had considered. She noted that the Science Simulations afforded changing of the variables in plant growth and allowed speeding up the plant growth process. She expressed disappointment in the software, because it did not offer a variety of plants and the opportunity to discover the varying needs. She noted the software did not enable saving of trials or recording of data, nor did it enable students to discover how plants grow except for learning that water, soil, and sunlight are requirements. As she and the coordinator talked, it became evident that even with these limitations the software could be used to teach about observation, generating questions, and the requirements for living things. She checked the State Standards for her grade level and realized she could use the program to meet different standards than originally planned. In order to do so, however, she needed to supplement the software's shortfalls. Terese created a poster to aid students' metric measure understanding and developed a science journal for recording hypotheses, data, and questions based on the data. She planned her lessons, drawing upon her TPACK, to create learning opportunities aiding students' scientific knowledge creation through inquiry, with scaffolds and peer learning support.

Brian approached his lesson design from the pedagogical perspective (Fig. 5). In his GRITS application, he wrote:

- Technology will enable me to reach more … diverse learners. ….
- Using technology would allow me to integrate the teaching of history into other subject matters and real world situations.
- Many of the ways I would use this technology would better prepare students for college and life in general …. They would work in groups …, improve their presentation skills, and enhance their ability to organize….
- …digital story telling. I would be able to read an excerpt of a letter in a historical context, in a way more engaging than just words on a screen. (Brian Application, p. 1)

In his application, Brian's ideas for technology integration were general and unconnected to content. In meeting with the coordinator, the MacBook laptop software and hardware surfaced as possible tools, leading to a discussion of the affordances and constraints of each. Through the discussion, Brian's Technology Knowledge surfaced, as he realized how PowerPoint served as an organizational tool for his presentations, and afforded smooth links to other applications and media, like Google Earth and YouTube. Brian appreciated how Google Earth enabled various magnifications and allowed movement around the globe without changing web pages. Based on his Content Knowledge, he wanted his students to connect places to one another, and to discuss places, such as, Sutters Mill, CA, and Ellis Island, NY, within geographical as well as historical contexts. After surveying his curriculum options, Brian decided the immigration and settling patterns of Europeans moving to the United States best fit his goals. Employing his TPACK, Brian developed a lesson on late nineteenth century immigration, embedding his lecture and classroom discussion points within a PowerPoint presentation, including Google Earth links for viewing Sutters Mill, Ellis Island, and Pakistan, to contextualize students' learning about immigration.

Teacher Education Program

While step-by-step diagrams are used here to highlight the process components, in reality the interns engaged in a process more like bricolage (Turkle, 1995). Bricolage involves "*arranging and rearranging a well-known set of materials*" (Turkle, p. 51), the process the interns employed as they worked back and forth between technological, content, and pedagogical concerns, while interacting within and across their activity settings.

These mediating tools identified by the TPACKtivity lens are important tools for teacher educators to draw upon in their work with preservice teachers. Even without in-depth knowledge of the particular technology, instructors can draw upon the "*technology has possibilities*" mediating tool to facilitate discussions about technology integration, asking students to identify the affordances and constraints of suggested technologies, and how they open or close access to content.

Subjects and Their Identities

Margaret's confidence echoed that of the others. The interns' presentations at the technology conference set them apart as experts in teaching with technology. They were beginning to identify that a well-trained teacher uses technology to help their students' literacy and learning. The experience also contributed to their identity as teachers, with writing and modifying of lesson plans, as well as collaboration with their teachers around content. The TPACKtivity lens will aid in examining whether or not identity became a mediating tool for the interns in their other settings.

Placement Setting

In the field placements, two interns, Brian and Malia, related learning to some teaching with technology from their Collaborating Teachers (CTs) or their CT's team partners. For several interns, the refrain sounded the same: "*My CT encourages me, but doesn't know how to help*." Their CTs backed their interns' technology implementations, but did not discuss them, nor feel they knew enough to aid the planning.

TPACKtivity's examining multiple settings illuminates an important point about TPACK development. The lack of transfer from personal technology (TK) to classroom technology uses (TPK and TPACK), and the participants' expression of their uncertainties with how to use technology in the classroom evidences the need for development of TPACK as a distinct knowledge. TPACK does not simply emerge as each individual component knowledge develops (Angeli & Valanides, 2009), but requires specific instruction. The difference is important for teacher preparation faculty and collaborating teachers, as they work with preservice teachers who know how to *use* technology, but still need guidance in learning how to *teach* with it.

Although teacher education instructors and CTs may feel ill-equipped to aid learning to teach with technology, because of their own lack of Technology Knowledge, they are still the More Knowledgeable Others (Vygotsky, 1978) in terms of Pedagogical Knowledge and Content Knowledge, and play a key role in knowledge and critical analysis development in their students. With the instructors, or CTs, drawing upon their Pedagogical Content Knowledge (PCK) (Shulman, 1986) and the interns drawing upon their Technology Knowledge, both could build upon each other's strengths and both could begin to develop TPACK (Margerum-Leys & Marx, 2004).

Without assistance from their CTs, most interns looked to fellow classmates in their broader community for mediating their teaching with technology. Brian's fiancée, who worked in deaf education, shared her technology ideas about webquests. Margaret collaborated with another friend who taught French, and Terese relied on Ambrosia who was at another school, but also in her weekly seminar group. Lucy, however, felt far removed from other interns and missed the opportunities to try out ideas on them before presenting them to her CT.

Some rules of the school settings became apparent in discussing the implementation of the GRITS planned lessons. Two of the seven GRITS interns did not implement their lessons, and a third still planned to implement her lessons. When discussing barriers to teaching GRITS lessons and other technology-rich lessons, several rules of the school activity settings emerged. Rule 1: Preparation for the State Assessment is of utmost importance. Rule 2: Technology is used for special projects, not for teaching content. Rule 3: Technology only happens in the computer lab during computer time. Rule 4: The district determines sites to be accessed by students and faculty. Rule 5: School is not the primary place for students to learn technology skills. These TPACKtivity-revealed rules provide some explanations for the difficulties of teaching with technology in classrooms. Such a discovery offers opportunities for developing responses to negate the power of such rules.

As in the GRITS setting, lesson designing served as a mediating tool for learning to teach. While all of the interns gained pedagogically from their lesson planning, Ambrosia and Brian, who listed several implementations of technology beyond their GRITS projects, talked about how the implementation of their designs, followed by their own reflection with feedback from others, aided their TPACK development.

Given the barriers to and the rules about technology implementation, the interns responded to their settings in various ways. Although their identity as teaching technology experts had developed through the GRITS program, for some, identity became a mediating tool.

Ambrosia best exemplified the resistance response, drawing upon her teaching identity. She determined to use the SMART Board technology as often as possible, and went on to explore other avenues of technology implementation, in spite of her teacher's lack of faith in technology's pedagogical possibilities. Margaret also resisted the status quo and worked to use technology to engage her students. She dealt with a lack of classroom projection equipment, scheduling a busy computer lab, and inconsistent Internet access. Brian pushed against the stream to use the computer lab in student-centered ways and to assist his high school students without technology experience. He challenged himself to do more than lecture with PowerPoint presentations. Lucy, too, showed resistance in pulling the document camera out of the hall closet and borrowing a projector to make it work. When it came to implementing her GRITS project, however, Lucy acquiesced to the difficulties of the setting and did not enter that realm of possibilities.

Accommodation, "*grudging effort to reconcile personal beliefs*" (Smagorinsky et al., 2002, p. 201) to the goals of the setting, describes the responses of Kelly, Malia, and Terese. Kelly showed accommodation to the idea that her GRITS plan did not fit into the time allotted for instruction. Malia, too, accommodated her teachers' last-minute style and emphasis on the State Assessment by abbreviating her planned podcasting lessons. Terese resisted the computer lab status quo in designing webquests when possible, but accommodated her teacher's beliefs on using the classroom computers as rewards.

None of the interns completely acquiesced to their situations. All of the interns looked for ways to incorporate at least some technology, but questions arise concerning the interns' TPACK development. Why did some of the interns exhibit TPACK in the GRITS setting, but very little in their internships? TPACKtivity shows TPACK to be setting dependent or perhaps a scaffolded skill requiring multiple opportunities for development. Interns might eagerly create new lesson designs but find difficulty in implementing them (Angeli & Valanides, 2009; Daniels & Warmington, 2007; Engeström, 2007; Valanides & Angeli, 2006). It seems worthwhile to delve more deeply into the classroom settings with observations to determine why implementation might not occur.

Online Communities

Activity settings overlap and interweave with one another, and these characteristics apply especially to the online communities. While interacting within the teacher education program, GRITS, their daily life, and their placement communities, many of the interns also interacted in online communities. Although none listed the online communities as contributing to their learning to teach with technology, evidence from their planning and conversations suggests that these communities played a role in developing Pedagogical Knowledge, Content Knowledge, Technology Knowledge, and perhaps TPACK. The prevalence, power, and influence of online communities underscores the importance of helping preservice teachers locate and evaluate online communities, as well as initiating online learning settings for encouraging participants' TPACK development.

TPACKtivity: Moving Forward

This is the first study to employ the TPACKtivity lens. The lens offered insights on the development of preservice teachers' TPACK across settings, providing evidence of TPACK's nonlinear developmental process and individual subject's display of TPACK as knowledge in action confined to particular activity settings. The TPACKtivity lens provides a way into the complexities of knowledge development and enactment, offering new insights for teacher education programs, as they seek to capitalize on technologies' affordances.

The TPACKtivity lens will become more robust as other investigations employ and expand upon it, especially as the TPACK framework and activity theory develop further. The lens will become more important, as it opens doors to new insights about TPACK development and descriptions of TPACK in action.

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Effect of a TPCK-SRL Model on Teachers' Pedagogical Beliefs, Self-Efficacy, and Technology-Based Lesson Design

Bracha Kramarski and Tova Michalsky

Introduction

Rapid global changes in the social, cultural, economic, and technological domains suggest that educational systems nowadays must ensure that teacher training programs can furnish students with the competencies and knowledge they need to cope with the challenges of postmodern life (National Council for Accreditation of Teacher Education, 2002; Organization for Economic Co-operation and Development, 2002). One of these essential competencies for teachers is the ability to master the constantly changing technological tools. Researchers have recently proposed a new "*TPCK*" framework (or TPACK as it is also referred to). The aim of this framework is to consolidate the multidisciplinary professional knowledge related to Technology, Pedagogy, and Content that teachers need so they can teach, and students can learn using technology tools (Angeli & Valanides, 2009; Mishra & Koehler, 2006; Zhao, 2003; Niess, 2008; Thompson & Mishra, 2008).

Researchers have argued that the addition of technology (T) to PCK is neither trivial nor obvious (Angeli & Valanides, 2009; Michalsky & Kramarski, in press; Kramarski & Michalsky, 2010; Mishra & Koehler, 2006). According to TPCK the use of technology tools means more than having access to the tool and learning the technical skills to handle it. Teachers must give careful thought to the potential of technology to address pedagogical issues in lesson design. This means making decisions about selecting, adapting, and implementing appropriate content, pedagogy, and technology in ways that can significantly *add* to the value of teaching with technology in the classroom, by using pedagogies that favor student-centered learning (Angeli & Valanides, 2009; Graham, 2011; Koehler & Mishra, 2008).

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It seems however that preservice teachers have difficulty acquiring these skills and thinking about these issues, as evidenced by their poor lesson design. In addition to the complexity of TPCK development, there are other obstacles that prevent teachers from exploiting the full potential of TPCK in their lesson design. Beliefs are a "*filter*" for teachers' pedagogical decisions and actions (Niess, 2011; Pajares, 1992). Research shows that teachers' beliefs are not always coherent. They sometimes conflict, and they are not always expressed consistently in class. It is therefore important to help teachers connect their beliefs to practice (Chen, 2008; Levin & Wadmany, 2006; Lim & Chan, 2007; Staub & Stern, 2002; Teo, Chai, Hung, & Lee, 2008). Teachers' pedagogical beliefs on issues, like teacher- vs. student-centered knowledge construction, and teachers' self-efficacy beliefs about using technology in class, can strongly influence how teachers conceptualize their teaching, how they design their lessons, and how they use TPCK in the classroom (Butler, Schnellert, & Cartier, 2013; Pajares, 1992; Staub & Stern, 2002).

It is therefore important to raise teachers' awareness of their own belief systems regarding pedagogical and technology self-efficacy, before they begin tackling the how to apply TPCK in their classrooms. Beliefs about pedagogy and self-efficacy are essential aspects of Self-Regulated Learning (SRL). SRL refers to self-generated thoughts, feelings, beliefs, and actions generated by metacognitive and motivational/affective factors within a learning context, aimed at realizing personal goals (Zimmerman, 2000).

SRL involves three cyclical processes (Pintrich, 2000; Zimmerman, 2000): planning, monitoring, and reflection. During these processes, learners (teachers) ask themselves: *What, How, When*, and *Why* questions, which help them to become self-aware and knowledgeable about their beliefs, and decisive in their approach to lesson design and teaching within the TPCK context. Research indicated that SRL is not attained spontaneously by students and their teachers, and that SRL support is needed (Zimmerman, 2000).

The purpose of this chapter was to investigate whether helping teachers to integrate SRL into TPCK using the TPCK-SRL approach (Kohen & Kramarski, 2012; Kramarski & Michalsky, 2010; Michalsky & Kramarski, in press) affects their pedagogical beliefs about student-centered learning and self-efficacy, when using technology in class, and assists them with constructivist TPCK-based lesson design. First, the chapter elaborates on preservice teachers' beliefs regarding pedagogy and self-efficacy in the context of teaching and learning with technology. Second, the TPCK-SRL approach to TPCK development is presented. Finally, a study is described that compared the *added value* of using a hypermedia training program that is based on the TPCK-SRL approach versus simply employing a TPCK program that uses the same hypermedia program.

Pedagogical Beliefs About Teaching and Learning with Technology

Beliefs about teaching and learning are referred to professionally as "*preferred ways of teaching and learning.*" Beliefs and knowledge are intertwined. However, knowledge involves more cognition than beliefs, which are linked more to emotions

(Pajares, 1992). Pedagogical beliefs are generally divided into two dichotomous concepts: knowledge *transmission* and knowledge *construction* (Chan & Elliot, 2004; Kramarski & Michalsky, 2009).

Wilson (1996) linked teachers' views about knowledge and their views about instruction. For instance, if teachers consider knowledge as content to be transmitted (i.e., traditional view), then they may conceptualize instruction as a product to be delivered. Similarly, if teachers consider knowledge as personally constructed meaning (i.e., constructivist view), they may conceptualize instruction as a rich environment emphasizing learning processes. Knowledge construction is typically contrasted with knowledge transmission-based learning. That means rather than focusing on the idea of knowledge being transmitted by one person to another, this view conceives students and teachers as part of a learning community, where learning arises from interaction, reflection, and experience (Howard, McGee, Schwartz, & Purcell, 2000; Teo et al., 2008).

Teachers with constructivist beliefs tend to organize student-centered activities that promote autonomous learning, group discussions, and student meaning-making activities, and they mainly emphasize the learning process (Brooks, 2002; Richardson, 1997). In contrast, the knowledge transmission model of learning conceives teachers as the source of knowledge and students as its passive recipients (Howard et al., 2000). Teachers who believe in the traditional teaching model favor direct instruction and are the sole providers of knowledge. When such teachers bring technology into the classroom, they usually use basic applications, like, PowerPoint or use technology as a source of information, which it can be poured into the learner. In contrast, teachers with constructivist beliefs usually look for technology (such as simulations or hypermedia with forums) that can activate students in problem solving, conceptual understanding, critical thinking, and discussing results (Chen, 2008; Entwistle, Skinner, Entwistle, & Orr, 2000; Schön, 1995).

Although studies suggest that teacher beliefs are strong predictors of teacher classroom decisions, knowledge, and behaviors (Pajares, 1992; Teo et al., 2008; Tillema, 1995; Wilson, 1996), empirical support for the link between teacher beliefs and teacher behavior in the context of using technology in class is often inconsistent (Chen, 2008). Levin and Wadmany (2006) found that teachers' technology-use practices and pedagogical beliefs changed reciprocally after a multi-year experience in a technology-based classroom. In that study, however, technology use was mainly to support content coverage. Hashweh (1996) also found that teachers with constructivist rather than traditional teaching beliefs were more likely to help students to elaborate their ideas and conceptions. However, other studies could not find evidence for this link and most have been unable to suggest causality (Levin & Wadmany, 2006).

According to Chen (2008), these inconsistencies between teachers' beliefs and actions (lesson design/teaching) in the context of technology use can be explained by two main factors: lack of a coherent belief system, and limited, or improper, theoretical understanding of the inconsistency and how to integrate TPCK in class. Findings show that teachers can hold multiple pedagogical views and even conflicting pedagogical beliefs about teacher- and student-centered learning, when making decisions linked to the use of technology in their classroom (Levin & Wadmany, 2006). Researchers argue that preservice teachers can be confronted with their conflicting beliefs by increasing their self-efficacy beliefs, which are vital to self-regulated learning (SRL), when integrating technology in the classroom (Abitt, 2011).

Teachers' Technology Self-Efficacy Beliefs as an Aspect of SRL

Self-efficacy belief is an important motivational feature of self-regulation. According to Bandura (1997), people's self-efficacy beliefs determine how they "*feel, think, motivate themselves and behave*" (p. 2). Bandura (1997) hypothesized that self-efficacy beliefs increase motivation and ultimately success in challenging tasks. Teachers' technology self-efficacy beliefs refer to "*teachers' beliefs in their capacity to work effectively with technolog*y" (Wang, Ertmer, & Newby, 2004, p. 231). In this study, technology self-efficacy refers to teachers' beliefs in their ability to use technology in the class with a constructivist view.

Researchers concluded that self-efficacy is critical in teachers' decisions to behave in a certain way. They found that teachers may not use instructional technology, due to low levels of technology self-efficacy (Littrell, Zagumny, & Zagumny, 2005; Teo et al., 2008). If teachers feel incapable of performing a TPCK task, or fear that they will fail in teaching with technology, they are less likely to try it (Henson, 2002). Researchers argued that examining the processes that build up this efficacy is vital for fostering teachers' technology self-efficacy in a constructivist way (Abitt, 2011; Henson, 2002; Ertmer, 2005), and, ultimately, for changing their behavior in class, as indicated by their TPCK-based lesson designs.

Responding to the previously noted growing demands for (a) TPCK integration into education using constructivist approaches, (b) controlling conflicting pedagogical beliefs by helping teachers achieve technology self-efficacy, and (c) supporting teachers' understanding of these processes with a conceptual framework (Chen, 2008), the current study followed the relatively new TPCK-SRL conceptual framework (Kohen & Kramarski, 2012; Kramarski & Michalsky, 2010; Michalsky & Kramarski, in press). This framework emerged from the transformative approach and shares the same view of TPCK as a body of knowledge that goes beyond mere integration, or accumulation, of the constituent knowledge bases (T, P, and C), toward their transformation into something new (Angeli & Valanides, 2009).

The TPCK-SRL approach is derived from SRL theories (such as Pintrich, 2000; Zimmerman, 2000) and focuses on strengthening teachers' technology self-efficacy as part of SRL, using three cyclical phases: planning (thinking before solving the task), monitoring (thinking in-action), and self-reflection (thinking back and ahead). These phases are intended to increase teachers' awareness of their own beliefs and reflective decision-making in TPCK construction, as described in the following two sections.

Role of the TPCK-SRL Approach in Constructing TPCK-Based Lesson Designs

The TPCK-SRL model seeks to inform and guide teachers through the dynamic interaction between TPCK components, SRL considerations, and technology-based teaching. It focuses particularly on strengthening such competencies as: *understanding* the role of beliefs in teachers' choices, decisions, and actions; *setting goals, identifying* relevant topics using technology; *selecting* appropriate computer tools; and *planning* materials and strategies (in other words, teacher- or student-centered learning approaches) for infusing technology, and, finally, *reflecting* on *beliefs*, *decisions*, and *actions* in order to evaluate goals, processes, and effort.

These competencies are practiced using different TPCK tasks such as *comprehending tasks* and *lesson design*. Comprehending tasks involves analyzing and evaluating lessons prepared and taught by other participants, by focusing on lesson structure, student engagement, and student learning interactions. Designing teaching tasks reveals the teacher's understandings of how to promote their students' knowledge. These teaching tasks are complex and require higher order thinking, including synthesizing and creating learning activities for constructing TPCK (Zohar & Schwartzer, 2005). To perform these tasks, the teacher must be aware and active in deciding *What* (for example, what teacher- or student-centered learning pedagogical approach is appropriate), *When* (for example, when to use activities suggested in forum discussions—see below), *How* to engage students in these activities (for example, by requiring autonomous problem solving through simulations), and *W*hy to integrate activities into learning with technology (for example, with the aim of fostering self-construction of knowledge). All this requires strong self-efficacy beliefs linked to the merit of integrating TPCK in the classroom using the SRL cycle of planning, monitoring, and reflecting, although this is not easy to attain (Kramarski & Michalsky, 2010; Michalsky & Kramarski, in press).

Practical TPCK-SRL Training in a Hypermedia Environment

The goal of the TPCK-SRL model is to engage teachers (pre/in-service) actively in a web-based hypermedia environment. As a nonlinear, dynamic environment in the context of science teaching, the hypermedia environment offers preservice science teachers' new experiences, and allows them to learn and teach science topics using a constructivist approach. It does so by offering teachers access to information using as text, graphics, animation, and video, a virtual world of expertly designed lessons, which the teachers follow in real time (Azevedo, 2005; Jonassen, 2000; Kramarski & Michalsky, 2009, 2010). The hypermedia environment gives student teachers a chance to learn and teach, using autonomously self-constructed knowledge and collaborative modes of learning. According to the model, in the case of preservice teachers, it is important for them to experience the sharing of knowledge in a forum of their peers, because it provides them with insights into how other teachers design TPCK lessons, using student-centered pedagogies.

TPCK-SRL hypermedia practice involves group discussion (such as forums) and feedback exchange between peers with comparable expertise. The goal is to reinforce trainee teachers' beliefs about student-centered pedagogies, and to help them build their technology self-efficacy, by practicing the understanding and design skills, which are part of the TPCK task orientation. By explaining and justifying their thinking to peers and by challenging their peers' underlying reasons for their approach to TPCK, using the focal questions, What, When, How, and Why throughout the SRL cycle (See Appendix for screen shots and the method for elaboration), TPCK-SRL learners can examine their own thinking and improve their TPCK practice (Kramarski & Michalsky, 2010).

Study Design and Objectives

The study examined whether helping preservice teachers to apply SRL to TPCK, by using the *TPCK-SRL* model in a hypermedia environment, is more useful than using *TPCK* alone in the same hypermedia environment for:

(a) Developing two aspects of preservice teachers' beliefs:
   - Their pedagogical beliefs about student-centered learning, and
   - Their technology self-efficacy beliefs regarding the use of technology in the classroom using a constructivist approach; and

(b) Enhancing preservice teachers' TPCK-based lesson design using a constructivist approach.

The study predicted that the preservice teachers who practiced using the TPCK-SRL training model in a hypermedia environment would be affected more positively by the three variables tested than preservice teachers who practiced the hypermedia TPCK program only.

Method

The sample contained 96 Israeli student science teachers (60 % female, 40 % male) who attended a 12-week course on *Designing Web-Based Learning Activities* with a focus on hypermedia. The students had completed 2 years of their 3-year disciplinary training program (content knowledge—CK) and had just begun their 2 years of pedagogical training (PCK). Students were randomly divided into two groups, one receiving TPCK-SRL training ($n = 47$) and the other the TPCK training only ($n = 49$). There were no significant differences between the groups in terms of age, grade point average of major subject, demographic characteristics (gender, socioeconomic status, ethnicity, etc.), and any other study variable.

Course Structure and Curriculum for the TPCK-SRL and the TPCK Groups

Both groups received a one-semester course of 14 pedagogical workshop sessions of four academic hours each, giving a total of 56-h of training. They were exposed to the same pedagogies of teaching and learning (such as direct teaching, inquiry, cooperative learning, and the same comprehension tasks (analyzing video vignettes) and design tasks (planning lessons).

Group I: TPCK-SRL

The first workshop examined the complexity of constructing TPCK as a unique body of knowledge and stressed the added value of technology for student-centered learning approaches. Constructivist and traditional pedagogies were discussed in the context of teaching and learning environments, such as direct teaching, inquiry, cooperative learning, and discussions.

The TPCK-SRL framework, as a transformative approach, was presented to the group to discuss the role of SRL and IMPROVE prompts when used jointly. Throughout the workshops, the preservice teachers practiced TPCK comprehension and design tasks. For the comprehension tasks, the teachers analyzed seven video vignettes showing common classroom scenarios from the learner's perspective. For the design tasks, they needed to design seven web-based lessons from the teacher's perspective. IMPROVE question prompts guided participants in using hypermedia for autonomous learning aimed at incorporating TPCK in the classroom.

The IMPROVE prompts/self-questions were designed to support key aspects of self-regulated learning (Kramarski & Mevarech, 2003; Mevarech & Kramarski, 1997). IMPROVE was developed for use in math education, and was later modified to train teachers in the use of TPCK in different domains (such as science) (see Appendix 1). In order to encourage teachers to be proactive and self-regulated learners, the model used four categories of question prompts: *comprehension, connection, strategy*, and *reflection*.

- *Comprehension* prompts help teachers as learners to understand the goals or main idea of a task (for example, by asking "*What* is the task/goal?").
- *Connection* prompts help teachers to understand deeper relational structures of the task, by encouraging them to activate prior knowledge and articulate thoughts, beliefs, and explanations (for example, *What* are the differences/similarities between the tasks/pedagogy? *How* do I justify my conclusion?)
- *Strategy* prompts encourage teachers to plan and choose appropriate strategies, and then monitor and control their effectiveness (for example, *How* and *When* should I select/implement the strategy? *WHY*?)
- *Reflection* prompts help teachers to evaluate their problem-solving processes by encouraging them to think about their decisions, values, and beliefs (for example, Does the solution make sense? *What* is the added value of my plan? *How* can I adapt my plan to other needs?)

The participants shared their TCPK-based comprehension tasks and lesson design assignments in an online forum. They sent their responses to the IMPROVE prompts to a forum of peers, where they received feedback and gave others feedback on their answers to prompts, entering the forum whenever they wished to discuss their design process with a specific peer or with the general forum.

Appendix 1 displays a screen shot of the hypermedia environment showing a comprehension task in a teaching/learning situation, guided by IMPROVE question prompts, which ask *What, How, When*, and *Why* questions. Links to other resources (scripts, help screens, theoretical background) are also embedded in the screen.

Group II: TPCK

The preservice teachers in the TPCK group were exposed to the same pedagogical theories as the TPCK-SRL group, namely constructivist and traditional pedagogies, in the context of teaching and learning environments (i.e., in the context of teaching, inquiry, cooperative learning, and discussion). The TPCK group discussed the complexity of developing TPCK as a unique body of knowledge and experienced the added value of technology in the context of student-centered learning approaches in practice.

During their practice exercises, TPCK participants were asked to solve the same comprehension tasks (analyzing video vignettes) and lesson design tasks as the TPCK-SRL group in the same hypermedia environment. The TPCK group was encouraged to solve their tasks through group discussions or forums. They did not experience modeling of self-regulation in learning and did not work with IMPROVE prompts. Similarities and differences between the two groups are summarized in Fig. 1. Figure 1 shows that the only difference between the TPCK-SRL group and the TPCK group was exposure to SRL theory and SRL practice.

Measures

Three measures were used in the study: Pedagogical Beliefs, Technology Self-Efficacy, and TPCK-based Lesson Design.

Pedagogical Beliefs A pre/posttest instrument titled: Metaphors Describing Beliefs about the Ideal Teacher/Student (Michalsky & Kramarski, 2008) was used. The instrument included four metaphors, and participants were asked to choose one metaphor that they felt described the Ideal Teacher/Ideal Student, and then write a statement justifying their choice. The metaphors related to *teaching beliefs* about the *ideal teacher* and *learning beliefs* about the *ideal student.* The beliefs are positioned along a continuum from *teacher*-centered learning to *student*-centered learning.

Summary of course structure and curriculum for TPCK-SRL and TPCK groups

<table>
<tr><th></th><th>TPCK-SRL</th><th>TPCK</th></tr>
<tr><td>Structure and curriculum</td><td colspan="2">56 hours of training, including 14 pedagogical workshop sessions of 4 academic hours each.

Pedagogies of teaching and learning (such as, direct teaching, inquiry, cooperative learning.

The same comprehension tasks (analyzing video vignettes) and design tasks (planning lessons).</td></tr>
<tr><td>Access to technology environments</td><td colspan="2">Hypermedia and forum discussions</td></tr>
<tr><td>Theoretical/ conceptual framework</td><td colspan="2">TPCK-SRL as a transformative approach: TPCK as a unique body of knowledge; Stress on added value of technology for achieving learning goals;</td></tr>
<tr><td>SRL support</td><td>SRL as a tool for enhancing TPCK in the classroom.

Modeling self-regulation.

Using IMPROVE question prompts (What, How, When, and Why)</td><td>No explicit modeling of self-regulation and IMPROVE prompts.</td></tr>
</table>

Fig. 1 Summary of course structure and curriculum for TPCK-SRL and TPCK groups

The four metaphors also represent *four* types of knowledge construction (see Appendix 2):

A. *Metaphors describing the ideal teacher:*

   (a) *Transmission* type of knowledge—the teacher is conceived as a *funnel for knowledge*.
   (b) *Modeling* type—the teacher is conceived as a *tour guide*.
   (c) *Empowering* type—the teacher is conceived as a gardener nurturing the plants in his *garden*.
   (d) *Self-construction* type— the teacher is conceived as a provider of learning tools who watches students as they *construct knowledge*.

B. *Metaphors conceptualizing the ideal student:*

(a) *Transmission*— learner is conceived as an *empty vessel* to be filled.
(b) *Modeling*— learner is conceived as a *tourist*, who is taken on a *guided* tour.
(c) *Empowering*—learner is conceived as a plant, which can be *nurtured*, so that it grows and blooms.
(d) *Self-construction*—learner is conceived as an *independent* mountain climber.

Based on the participants' explanations of their choice of metaphor, two categories of justification were identified: (a) *learning center* justification, in other words, justification linked either to the teacher- or learner-centered teaching approach, and (b) learning *process* justification, in other words, justification linked to the students' *interest* in learning and teacher-student *relations*. Frequencies were calculated for each choice and justification. Participants received one point for any metaphor choice and any justification. Justification categories with examples of participants' justification for their metaphor choice include:

A. *Learning center*—refers to the *teacher/student role* in class, and whether the teaching approach is teacher-centered ("*This is an ideal method of teaching, because the teacher is in control and can transmit knowledge to the class*") or student-centered ("*In this kind of teaching, the student is active in the lesson, which is very important, because he will understand the material better.*")
B. *Learning process*—refers to *teacher–student relations* ("*This learning approach allows teachers to be empathic toward their students and make eye-contact with them, which helps to optimize student learning*"), and to the student's *interest* in learning ("*This learning approach increases the student's interest, which makes him or her more eager to learn*").

The validity and reliability of 20 % of the participants' answers were evaluated by two judges. The inter-reliability results showed a high correlation coefficient among the judges ranging from $r=.81$ for learning center justifications to $r=.97$ learning process justifications.

Technology Self-Efficacy Beliefs The preservice teachers' Technology Self-Efficacy Beliefs were assessed by a pre/posttest self-report questionnaire (11 items) prepared by Michalsky and Kramarski (2008). The questionnaire contained two factors. It examined teachers' beliefs regarding their ability to engage students actively in technology-based lessons (example of response: "*It allows me to engage students actively in forum discussions*") and about technology-based student learning (example of response: "*Inquiry-based technology actively engages students.*"). A confirmatory factor analysis (CFA) with orthogonal varimax rotation revealed the two factors with explained variance of 57.7 % (27.3 and 30.4 %, respectively). Cronbach's alpha values were 0.82, 0.88, respectively.

TPCK-Based Lesson Design Participants were asked to plan a two-lesson study unit (pre/posttest examination and intervention) involving web-based learning on the effects of global warming. The units were assessed using a TPCK coding scheme (Kramarski & Michalsky, 2010). Three criteria with a pedagogical constructivist orientation were used to assess the units (a) identifying learning objectives (for example, the objective of building students' scientific inquiry skills using laboratory simulations), (b) selection of activities (for example, students could take part in online peer discussions about the role of lungs aimed at increasing their understanding of the topic), and (c) teachers' performance in planning learning materials (for example, engaging students in a hypermedia inquiry project on the subject of photosynthesis).

The participants' performance on the three criteria were scored using a 4-point coding scheme: (a) Score of 4—Clear reference to the transformative approach of TPCK (in other words a unique body of knowledge), justifying the added value of the selected technology in constructivist terms; (b) Score of 3—The participant saw the student as the center, but did not clearly justify the unique value of using the technology in a constructivist way; (c) Score of 2—The participant did not place the teacher/student clearly at the center of learning and did not justify the use of technology; (d) Score of 1—The center of the technology-based learning lesson was the lesson content or the teacher.

Examples of Participants' Performance Scores with Reference to the Three Criteria (a) Score of 4—Building students' conceptual understanding of scientific inquiry skills, students will use laboratory simulations to identify the differences between dependent and independent variables (i.e., unique value of simulations with justification); (b) Score of 3—Producing graphs with the spreadsheet application will help students to present graphs in their summative project for the Malaria lessons (i.e., unique value of spreadsheet, no justification); (c) Score of 2—Summarizing the mechanisms of photosynthesis using information from the internet (i.e., place of the teacher/student is not clear, no justification); (d) Score of 1—Summarizing the main points of photosynthesis (i.e., teacher-centered learning).

Inter-rater reliability was calculated for the same 30 % of responses coded by both raters and yielded high Cohen's kappa reliability coefficients (identifying learning objectives: 0.90; selecting content: 0.85; and, planning didactic material: 0.86). Disagreements on scoring and coding of design skills were resolved through discussion.

Results

Beliefs About the Ideal Teacher/Ideal Student

A 3-step analysis of preservice teachers' beliefs was carried out: (1) Belief frequencies were calculated for the four metaphors (transmitting, modeling, empowerment, and self-knowledge construction) chosen by participants to represent the Ideal Teacher/Ideal Student (see Table 1); (2) The frequencies of participants' *justification* of metaphor choice in view of *learning center* (teacher/student centered), and (3) *learning process* (student–teacher relations and interest in learning) (see Table 2). Finally, a chi-square test was performed to examine whether a significant difference for the calculated frequencies existed between the TPCK-SRL group and the TPCK group.

Table 1 Frequencies (percentage) of preservice teachers' choices for the ideal teacher/ideal student metaphor (by group and time)

Metaphor: Ideal teacher								
	Construction		Empowerment		Modeling		Transmission	
	Knowledge constructor		Gardener		Tourist guide		Funnel	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
TPCK-SRL *n* = 47	9(19)	25(53)	18(38)	15(32)	9(19)	2(4)	11(23)	5(11)
TPCK *n=49*	7(21)	12(20)	16(38)	22(41)	10(17)	5(9)	12(21)	11(21)
Metaphor: Ideal student								
	Self-knowledge constructor		Plant		On a guided tour		Receptacle	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
TPCK-SRL *n* = 47	11(23)	26(56)	14(29)	10(21)	13(28)	7(15)	9(19)	4(8)
TPCK *n* = 49	13(21)	11(24)	11(25)	23(47)	16(23)	7(18)	12(21)	11(18)

Table 2 Frequencies (percentage) of preservice teachers' justifications for selecting the ideal teacher/ideal student by group and time

Teachers' justifications										
	Learning center				Learning process					
	Teacher-centered		Student-centered		Teacher–student relations		Interest in learning		Other	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Ideal teacher										
TPCK-SRL *n* = 47	24(29)	16(18)	6(11)	14(22)	23(29)	31(27)	18(23)	25(28)	3(8)	4(6)
TPCK *n* = 49	25(36)	25(36)	7(13)	7(14)	23(31)	29(35)	28(27)	17(28)	6(12)	7(10)
Ideal student										
TPCK-SRL *n* = 47	25(29)	16(17)	6(10)	15(16)	24(27)	32(29)	18(22)	27(32)	8(13)	6(7)
TPCK *n* = 49	27(33)	28(30)	5(6)	9(11)	22(29)	32(37)	18(25)	13(15)	9(14)	3(8)

Analysis of Metaphor Belief Choices

The chi-square test of the pretest frequencies for the Ideal Teacher metaphor *choices* (Table 1) showed no significant differences between the two learning groups in any of the four choices of metaphor *describing the Ideal Teacher* $3.7 < \chi^2_{(1,\,96)} < 5.2$, $p > .05$; Cramer's V < .03 and *Ideal Student* $2.4 < \chi^2_{(1,\,96)} < 3.9$, $p > .05$; Cramer's

V < .03. However, the posttest chi-square test revealed significant differences in the metaphors chosen by the TPCK-SRL and TPCK groups from among the four *Ideal Teacher* $15.2 < \chi^2_{(1,96)} < 20.4$, $p < .01$; Cramer's V < .03 and Ideal Student metaphors $19.3 < \chi^2_{(1,96)} < 25.3$, $p < .01$.

As Table 1 shows, *at the start* of the study, some 20 % of the preservice teachers in the TPCK-SRL group and the TPCK group held conflicting *teaching* and *learning* beliefs. They believed both in student self-knowledge construction (student-centered learning) and teacher knowledge transmission (teacher-centered learning). This finding shows that at this stage in their professional development, preservice teachers' beliefs about the Ideal Teacher/Ideal Student are not yet fully formed. However, by the end of the intervention, we identified striking differences between the beliefs of the two groups with regard to the Ideal Teacher/Ideal Student. More than half of the preservice teachers (56 %) in the TPCK-SRL group believed that the Ideal Student should construct knowledge and that the ideal teacher should facilitate this construction (53 %), a significantly higher percentage than the TPCK group participants who believed that the Ideal Teacher should construct knowledge (20 %) and the Ideal Student should construct knowledge (24 %). As noted before, self-knowledge construction beliefs underscore the importance of student autonomy for improving learning.

In general, the TPCK-SRL group was found to have a clear belief system. We can infer this from the hierarchical pattern found for the four Ideal Teacher metaphors: Metaphor 1 (53 %), Metaphor 2 (32 %), Metaphor 3 (14 %), Metaphor 4 (11 %), and the four Ideal Student metaphors: Metaphor 1 (56 %), Metaphor 2 (21 %), Metaphor 3 (15 %), and Metaphor 4 (8 %). The hierarchical pattern was especially marked for the teachers' choices for the Ideal Student metaphors: the highest percentage of teachers chose Metaphor 1 (56 %) representing self-knowledge construction beliefs, while the lowest percentage (8 %) chose Metaphor 4, expressing knowledge transmission beliefs.

The TPCK teachers, however, seemed to have no clear belief system underpinning their Ideal Teacher views: 20, 22, 9, 21 %, and Ideal Student views: 24, 47, 18, 18 %, respectively, for the four metaphors (1–4, respectively). An interesting finding was the high percentage (47 %) of preservice teachers in the TPCK group who chose the empowerment metaphor for the Ideal Student.

Analysis of Metaphor Belief Justifications

A chi-square test was conducted on the pretest frequencies (Table 2) of the metaphor choice justifications. No significant differences were found between the frequencies of the justifications in the TPCK-SRL group and the TPCK group for the Ideal Teacher $3.5 < \chi^2_{(1,96)}) < 5.3$, $p > .05$; Cramer's V < .03, and the Ideal Student $1.3 < \chi^2_{(1,96)} < 2.2$, $p > .05$; Cramer's V < .03. This was true both for the participants' justifications relating to *learning center* (teacher/student) and *learning process* (teacher–student relations and interest in learning).

However, the posttest analysis found significant differences in the frequencies of the justifications given by the two groups for the Ideal Teacher $18.3 < \chi^2_{(1,96)} > 22.6$,

$p<.01$; Cramer's V<.03, and Ideal Student $23.6<\chi^2_{(1, 96)}>20.4$, $p<.01$; Cramer's V<.03. This was true both for the participants' justifications regarding the *learning center* (teacher/student) and *learning process* (teacher–student relations and interest in learning).

At the end of the study (Table 2), participants in the TPCK group gave a higher percentage of teacher-centered justifications (36%) for their choice of Ideal Teacher and Ideal Student metaphor (30 %) compared with the TPCK-SRL group: Ideal Teacher: 18 % and Ideal Student: 17 %. Conversely, a significantly higher percentage in the TPCK-SRL group gave a student-centered justification for their choice of Ideal Teacher (22 %) and Ideal Student (16 %) metaphor compared with the TPCK group: Ideal Teacher (14 %) and Ideal Student (11 %).

Also, more participants in the TPCK-SRL group believed that creating an "*interest in learning*" characterized both the Ideal Teacher (28 %) and Ideal Student (32 %), compared to the TPCK group that believed that this factor relates more to the Ideal Teacher (28 %) and less to the Ideal Student (15 %).

In terms of the Ideal Teacher, the TPCK-SRL group placed less emphasis (27 %) on the teacher's role in the *teacher–student relationship* than the TPCK participants (35 %). These findings fit in with the end-of-study *reduction* (11 %) in the TPCK-SRL group's *teacher-centered* justification for the Ideal Teacher metaphor choice and the *increase* (10 %) in student-centered justification for the Ideal Teacher metaphor choice.

In sum, in the TPCK-SRL group, a high percentage of preservice teachers gave a *student-centered* justification for their Ideal Teacher (22 %) and Ideal Student (16 %) metaphor choice. This is indicated by their references to *teacher–student relations* (29 %), the emphasis on *interest in learning* (32 %), and the importance they ascribed to the student's role in these relations. In contrast, a high percentage of the TPCK group provided a *teacher-centered* (36 %) justification for their choice of Ideal Teacher and Ideal Student metaphor (30 %). This is indicated by their references to *teacher–student relations* (37 %), the importance they ascribed to the teacher's role and the fact that a lower percentage referred to *student interest in learning* (15 %).

Technology Self-Efficacy Beliefs

A one-way ANOVA for the pretest results indicated no significant differences between the two learning groups (*TPCK–SRL*: M =3.1; SD=1.8; *TPCK*: M=2.7; SD=1.6; F (1, 94)=2.7; $p>0.05$). A repeated measures ANOVA (2×2) conducted on the pretest and posttest data demonstrated a significant main effect of time F (1, 94)=8.1; $p<.01$; $\eta^2=0.19$ and a significant interaction between group and time for the technology self-efficacy beliefs F (1, 93)=10.3; $p<.01$; $\eta^2=0.09$. Cohen's d effect size indicated that the technology self-efficacy beliefs increased at the end of the study for the TPCK-SRL group (M=4.1; SD=1.9; $d=0.54$), whereas no improvement was found for the TPCK group (M=2.9; SD=1.6; $d=0.75$).

TPCK-Based Lesson Design

A one-way ANOVA (Table 3) for the pretest results showed no significant pre-course differences for the two groups in any of the coded design categories $F(1, 94) < 5.2$, $p > .05$. A two-way (Group X Time) MANOVA with repeated measures on time effect indicated that participants in both groups significantly improved in all lesson design categories. A significant interaction for Group X Time emerged for all three design categories at the end of the study. The TPCK-based lesson design of the hypermedia TPCK-SRL group improved significantly more than the TPCK group in the three design categories of using technology in the lesson: identifying learning objectives, selecting content, and planning didactical materials (Table 4 presents *F* values).

Correlations

Pearson correlations with Z scores were calculated on the TPCK-based lesson design (total score and three criteria) and technology self-efficacy in each group. Significant correlations were found in each group, on: TPCK-SRL group for the

Table 3 Student teachers' means, standard deviations, and Cohen's d[a] effect sizes for TPCK-based lesson design skills by time and group

	TPCK-SRL		**TPCK**	
	n = 46		*n* = 49	
Time	Pre	Post	Pre	Post
Identifying learning objectives				
M	1.2	2.9	1.6	2.1
SD	0.6	0.7	0.5	0.7
d	2.83		0.69	
Selecting content				
M	1.4	3.4	1.3	2.2
SD	0.8	0.8	0.5	0.6
d	2.50		1.32	
Planning didactic material				
M	1.7	3.4	1.9	2.3
SD	0.6	0.6	0.6	0.9
d	2.83		0.61	

Table 4 F and η^2 values of repeated measures for TPCK-based lesson design skills by time and group

	Identifying learning objectives		Selecting content		Planning didactic material	
	η^2	*F(1,94)*	η^2	*F(1,94)*	η^2	*F(1,94)*
Time	0.53	31.21[a]	0.36	53.22[a]	0.31	45.69[a]
Group	0.44	61.23[a]	0.52	45.28[a]	0.41	55.24[a]
Time*group	0.37	41.23[a]	0.43	39.54	0.52	47.39[a]

[a] $p < 0.001$

total score: $r = .68$, $p < 0.001$, and each of the components: identifying learning objectives, $r = .65$; selecting content $r = .54$, and planning didactic material, $r = .61$. All p's < 0.001, and on TPCK group for the total score: $r = .53$, $p < 0.001$, and each of the components: identifying learning objectives, $r = .49$; selecting content $r = .51$, and planning didactic material $r = .53$. All p's < 0.001.

However, the correlations of the TPCK-SRL group were higher than in the TPCK group on the total score, identifying learning objectives and planning didactic material than in the TPCK group.

Discussion

The study examined whether helping teachers to integrate SRL into TPCK using the TPCK-SRL approach (Kohen & Kramarski, 2012; Kramarski & Michalsky, 2010; Michalsky & Kramarski, in press) affected their belief system about student-centered pedagogy and self-efficacy in using technology in class, and whether this, in turn, enhanced their ability to design TPCK-based lesson in a constructivist way.

Preservice Pedagogical Beliefs

A pre-study assessment of the pedagogical beliefs of the two groups of preservice teachers showed that in general their beliefs were not significantly different. They apparently held both multiple views and conflicting beliefs (for example, they believed in both teacher vs. student centered learning). In particular, before the study, about 20 % thought that teachers were responsible for their students' knowledge (i.e., knowledge transmission), in the same way (about 38 %), they thought that teachers like gardeners have to "nurture flowers to make them bloom and grow" (Table 1). This supports other findings that prior to pedagogical training preservice teachers lack a coherent belief system regarding teaching and learning (Chen, 2008; Levin & Wadmany, 2006).

The study found that when preservice teachers practiced with hypermedia comprehending TPCK tasks (i.e., analyzing video vignettes) and design TPCK lessons in forum discussions, guided by SRL questions (TPCK-SRL model), their pedagogical beliefs about student-centered learning (self-constructing knowledge) changed, whereas the TPCK group's beliefs remained the same.

At the end of the study, the participants' choice of metaphor (Table 1) and justifications of their choice (Table 2) of Ideal Teacher/Ideal Student belief showed that the TPCK-SRL group believed *less* in teacher-centered learning (knowledge develops by transmitting and modeling) and *more* in student-centered learning (knowledge develops from students' self-construction). The belief in the self-construction of knowledge that the TPCK-SRL group acquired is an important belief for preservice teachers, as it supports them in making self-regulation decisions based on an understanding of the added value of TPCK (Butler et al., 2013; Kramarski & Michalsky, 2010).

Another interesting point relates to the high valued empowerment-type belief of the Ideal Teacher/Student held by both groups at the beginning and end of the study. Although this view focuses on the importance of nurturing students (a kind of constructivist view), the two groups saw this pedagogy differently (Table 1). TPCK participants saw it as a useful pedagogy from the perspective of the Ideal Teacher, who is responsible for his students learning and should control the learning process. The TPCK-SRL group, in contrast, saw it in terms of the Ideal Student and stressed the importance of increasing student autonomy and responsibility for the learning process. This interpretation is supported by statements found in the participants' justifications indicating that the student's role is to create "interest in learning" and to develop the "teacher–student relationship."

Furthermore, the high percentages found for the TPCK-SRL group's constructivist beliefs of the empowerment and self-knowledge construction support the conclusion that pedagogical beliefs change gradually, and that multiple conceptions can and do coexist in the transition to a new belief. It also supports the idea that by complementing one another, these multiple conceptions may be highly effective for bringing together the use of technology and constructivist pedagogy in the classroom (Levin & Wadmany, 2006).

These findings support the view that teachers' beliefs can be changed (Tillema, 1995; Levin & Wadmany, 2006), and, according to Jacobsen (2002), any change depends on the teacher's capacity to "*build new bridges*" through constructivist learning experiences. It seems that the learning processes arise when teachers are exposed to new goals using the TPCK-SRL model, which encourages them to modify their teaching styles and even their underlying beliefs about effective teaching. The benefits of the TPCK-SRL model are linked to the nature of the IMPROVE prompts. When preservice teachers use the IMPROVE prompts with the *What, When, How*, and *Why* questions, they update different pieces of knowledge and beliefs (for example, through the connection question) and also consider alternative pedagogies (for example, through the reflection question). This may have helped participants to understand the structure of TPCK relations and to improve their self-efficacy for applying it in class.

Technology Self-Efficacy Beliefs

When the preservice teachers practiced the TPCK-SRL model in a hypermedia environment, their self-efficacy beliefs (measured by the questionnaire) about engaging students by using learning-based technology in their lessons increased more than in the TPCK group. This is supported by their efficacy in providing well-explicated and well-justified plans for using technology in their TPCK lesson design (see Method for scoring scheme details). These plans included: defining goals for the specific science topic, mapping alternative technology tools, describing the unique added value of using the chosen technology in a constructivist environment (*Why* considerations).

Self-efficacy beliefs are important for motivating self-regulation (Zimmerman, 2000). Participants with high technology self-efficacy were better at translating their belief systems into constructivist behavior. This conclusion is supported by the significant correlations between technology-related self-efficacy beliefs and the TPCK-based lesson design components. This supports Bandura's (1997) argument that self-efficacy beliefs improve success in challenging tasks.

The findings show that exposure to the TPCK-SRL conceptual framework may have enabled participants to build a coherent belief system based on their constructivist views, that is, their self-constructing knowledge. This belief system is supported by participants' technology self-efficacy beliefs, which, in turn, helped them to connect their pedagogical beliefs with practice, as shown by their achievements in the TPCK-based lesson design.

TPCK-Based Lesson Design

The findings showed that participants who were exposed to the TPCK-SRL model improved significantly more than the TPCK group in all three of the TPCK-based lesson design categories: identifying learning objectives, selecting content, and planning didactic material.

The findings (Table 3) show that the TPCK-SRL group did better on the lesson design components than the TPCK group (mean score: 2.9–3.4, respectively). According to the coding scheme, high scores (3–4) point to constructivist pedagogical beliefs, which participants translated into student-centered learning activities for TPCK construction (Example of a planned task: "*Using simulations to engage students in problem solving, discussion, and debating their opinions in small groups*"). In contrast, the lower gains made by the TPCK group (mean scores of 2.1–2.3) reflected teacher-centered pedagogical beliefs, which the participants translated into teacher-centered learning for TPCK construction (Example of a planned task: "*Presenting activities using PowerPoint slides that help the teacher organize the teaching materials and provide examples and exercises*").

In sum, we can explain the positive findings (beliefs and TPCK-based lesson design) for the TPCK-SRL group as stemming from the differences in the instructions received by the two groups. The TPCK-SRL group was specifically told to focus on the SRL components (metacognition and motivation/affect) and to use IMPROVE prompts throughout the learning process for the purpose of discussion/reflection relating to the different aspects of TPCK (mapping, selecting, adapting, and reasoning "why"). The discussion and reflection of the TPCK-SRL group, guided by the SRL prompts, enabled them to build a coherent system of their constructivist pedagogical beliefs and shaped their technology self-efficacy. This, in turn, probably affected their ability to form a connection between their beliefs and the explicit requirements of TPCK.

Our findings also support previous findings that demonstrate that explicit support of SRL is necessary for the activation of SRL processes in any learning environment (Schraw, Crippen, & Hartley, 2006).

Practical Implications, Limitations, and Future Research

The results provide empirical support for the current TPCK approaches in technology education for trainee teachers (see Angeli & Valanides, 2009; Kramarski & Michalsky, 2009; 2010; Mishra & Koehler, 2006). They particularly underscore the importance of strengthening preservice teachers' student-centered pedagogical beliefs and technology self-efficacy beliefs in order to enhance the added value of teachers' TPCK practice in the classroom. Self-efficacy beliefs, which encompass a constructivist approach to integrating technology in the classroom, play an important role in teachers' decisions about *whether* they will use technology and *how* to make it work for learners (Chen, 2008).

Professional development programs should go beyond training that simply stresses basic technology skills, and, instead, aim to design programs that first identify teachers' beliefs about effective teaching and establish their technology self-efficacy and strategies for improved teaching and learning (Abitt, 2011; Kramarski & Michalsky, 2010).

The present study focused on preservice teachers during training. The next step would be to follow these preservice teachers during their first year of teaching and investigate how the training they received with TPCK-SRL support affected their classroom practice. It is important to continue investigating the link between teachers' beliefs and their TPCK activities by using larger samples and different TPCK approaches. Future studies should focus on the development of methods or instruments that can help in the rigorous identification and evaluation of different kinds of teacher beliefs, for example, by identifying epistemic beliefs. It is also important to gather data from observations and videotaping of actual classroom teaching. Studies like these would provide further insights into the effect of TPCK-SRL vs. TPCK on teachers' beliefs, and how their beliefs support them in coping with the complexity of working with TPCK in the classroom.

The hypermedia TPCK-SRL model has both theoretical and practical implications for the technology education of pre- and in-service teachers in different domains. Theoretically, the study leverages our conceptual understanding of teachers' beliefs as a key factor of SRL which can positively impact on the use of TPCK in the classroom. In the practical sense, that SRL question prompts (*what, when, how, and why*, based on IMPROVE) help teachers to reflect on their pedagogical beliefs and decision-making practices, which can help to improve their ability to construct TPCK and to enhance the added value of teachers' TPCK practice in the classroom. These prompts are also easily adaptable to different teacher training programs and technology environments.

In sum, the study supports the premise that preservice teachers should receive explicit extensive support when integrating technology in the classroom (TPCK). A salient finding was that although the self-efficacy in technology use of both groups was improved, adding the SRL model to TPCK practice carried significant added value for enhancing teachers' ability to transfer knowledge gained in training to the design of TPCK-based lessons (Table 3). Future studies should examine this conclusion in the context of other explicit training models for enhancing TPCK. It is also important to examine whether similar training for in-service teachers could be equally effective.

Appendix

Appendix 1: Screen Shot: TPCK-SRL Training Model

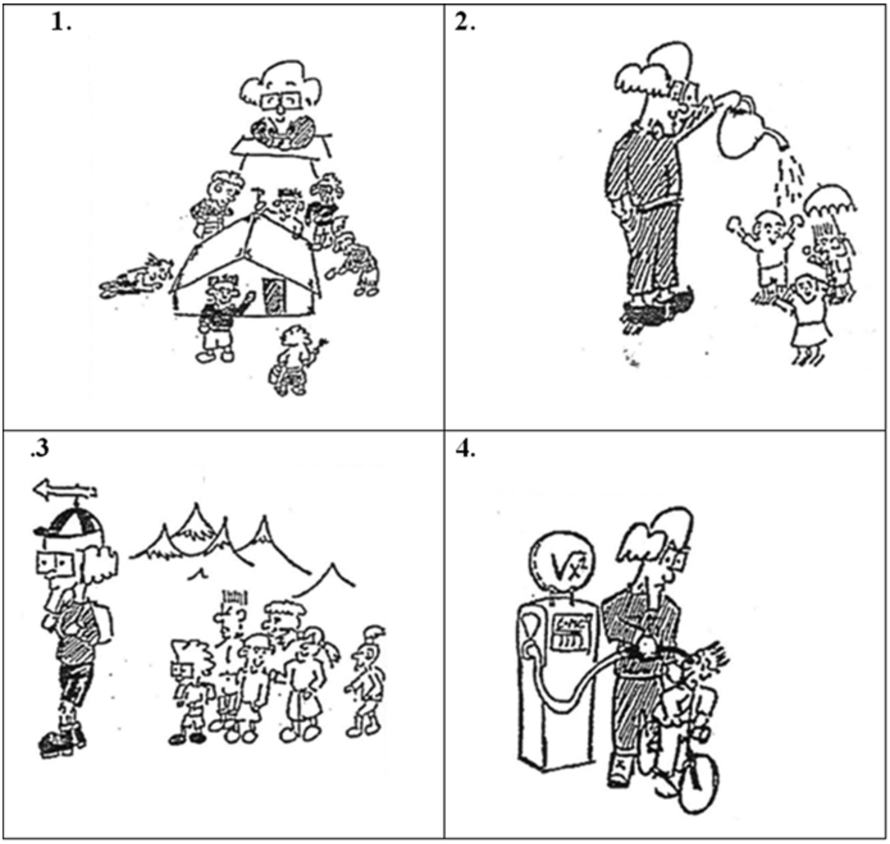
The screen-shot presents a comprehension TPCK task. Teachers are asked to CHECK THIS Analyze the task using the IMPROVE prompts. Focus on important events, goals, and processes. Identify difficulties in technology-based teaching/ learning while referring to the TPCK transformative approach. Suggest pedagogical approaches that can help you improve the lesson.

Teachers sent responses to the forum and received feedback from peers and provided peers with feedback on their responses to the prompts.

Appendix 2: Teaching and Learning Metaphors

A. *Metaphors conceptualizing the "Ideal Teacher"*

Here are four metaphors. Each metaphor represents a different *teaching process* model. Please examine the metaphors and then answer the question below:



In which metaphor do you think the student knows the material best? Explain and justify your choice.

B. *Metaphors conceptualizing the "Ideal Student"*

Here are four verbal metaphors. Each one represents a different *learning process* model.

1. The learner is like an *empty* vessel to be filled.
2. The learner is like a *tourist on a guided tour*.
3. The learner is like a seedling which has to be *nurtured* so that it grows and blooms.

4. The learner is like an *independent mountain climber.*

In which metaphor do you think the student knows the material best? Explain and justify your choice.

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Part III
The Development of TPCK in Teacher Development Contexts

Designing Effective Technology Preparation Opportunities for Preservice Teachers

Chrystalla Mouza and Rachel Karchmer-Klein

Introduction

As teacher educators, we spend much time in local schools, working alongside K-12 teachers as they integrate technology into their instruction. Often, however, the lessons we observe tend to reflect *technological* rather than *curricular* integration (Hutchison & Reinking, 2011). Technological integration corresponds to uses of technology that replicate conventional instructional goals (e.g., projecting text) and treats technology as separate from the curriculum. In contrast, curricular integration treats technology as integral to the curriculum, and corresponds to uses of technology that allow for transformed instruction and the adoption of new instructional goals with the potential to support students' twenty-first-century skills (e.g., multimodal writing).

Contemporary literature indicates that in order to prepare prospective teachers for curricular technology integration, teacher education programs must help them build knowledge of content, good pedagogical practices and technical skills, as well as an understanding of how these constructs interact with one another (Koehler & Mishra, 2008). These interactions among content, pedagogy, and technology form the core of what has been called Technological Pedagogical Content Knowledge (TPCK or TPACK; Angeli & Valanides, 2009; Mishra & Koehler, 2006; Niess, 2005). Despite the wide adoption of TPACK as a theoretical frame of teacher knowledge, recommendations on how to develop and assess this body of knowledge vary widely in the literature (Kay, 2006; Polly, Mims, Shepherd, & Inan, 2010; Tondeur, van Braak, Sang, Voogt, Fisser, & Ottenbreit-Leftwich, 2012).

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In the past decade, many teacher education programs have attempted to develop preservice teachers' TPACK through stand-alone educational technology courses (Polly et al., 2010). For example, a survey of 1,439 institutions with teacher education programs in the United States revealed that 85 % of them offer an educational technology course ranging from one to four credits (Kleiner, Thomas, & Lewis, 2007). While a stand-alone educational technology course can play an important role in developing preservice teachers' TPACK and helping them acquire a convincing rationale for using technology (Lampert & Gong, 2010), there is little evidence indicating that it can help new teachers engage in curricular technology integration. Instead, experts posit that technology courses are more effective, when they are directly connected to methods courses and encompass field placements that provide firsthand experiences on the ways in which technology can be effectively integrated into K-12 schools (Karchmer-Klein, 2007; Polly et al., 2010).

Utilizing TPACK as an instructional guide and a set of research-based principles on the preparation of preservice teachers, this chapter presents one approach to the design of stand-alone educational technology courses that addresses the challenge of curricular technology integration. It also presents insights from preservice teachers' reflections on the TPACK framework and their anticipated uses of technology in their student teaching placement and future classrooms.

Literature Review

TPACK Framework

TPACK is a theoretical frame of teacher knowledge without clear guidelines on how it can be weaved within teacher preparation. To facilitate the practical adoption of the TPACK framework, Harris and Hofer (2009) proposed a five-step curricular-based technology integration approach, consistent with the ways in which teachers plan lessons. Instead of focusing on technology, this approach places the emphasis on the students and the content they need to learn, thus having the potential to support curricular technology integration. The five steps embedded in this approach are consequently described:

- Step 1: Teachers begin by identifying the curriculum to be taught (content). This content is typically dictated by standards (e.g., Common Core State Standards in the United States), which describe what students are expected to learn.
- Step 2: Teachers make pedagogical decisions based on eight parameters illustrated in Fig. 1 that include: focus of the interactions, types of learning, student prior knowledge and skills, depth of understanding, amount of time required relative to the depth of understanding, amount and type of structure for the learning experience, learner configurations, and types of resources required for the learning experience. Each of these parameters is identified on a continuum based

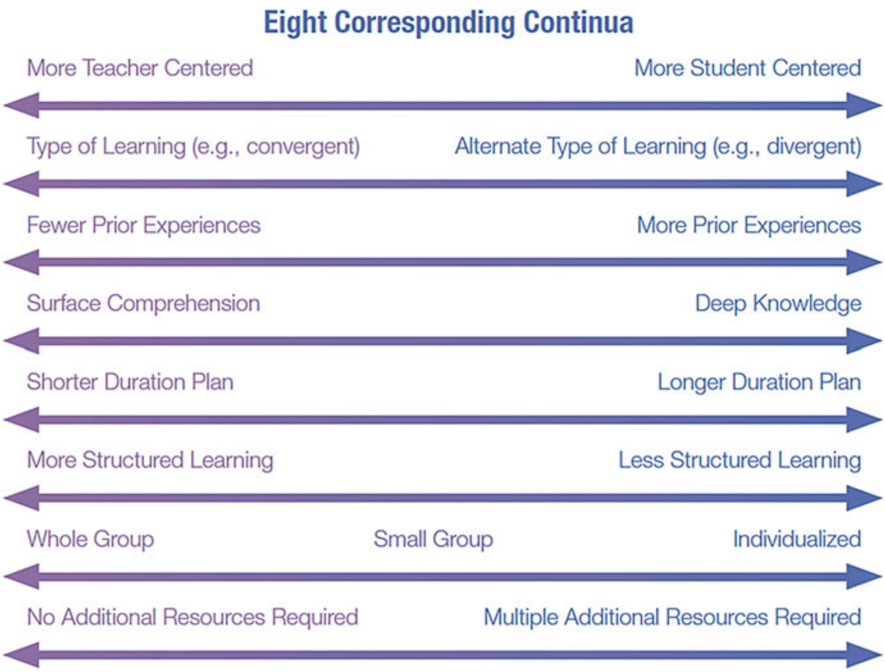

Fig. 1 Eight pedagogical continua by Harris and Hofer (2009)

on students' needs as well as the logistical realities of classrooms (see Fig. 1). When considering the first parameter, for example, it is important to realize that frequently lessons are a combination of teacher-centered and student-centered approaches. Often, teachers begin with direct instruction, transition to scaffolding, and gradually release students to work independently.

- Step 3: Teachers select activities that match specific learning goals and pedagogical decisions. According to Harris and Hofer (2009), technology-integrated learning tends to employ more than one activity type in order to foster deeper and differentiated learning.
- Step 4: Teachers select assessment strategies to measure student progress towards the identified learning goals. Such strategies should include both formative and summative assessment.
- Step 5: Teachers identify technology tools that can support selected learning goals, pedagogical decisions, and instructional activities.

In this chapter, we describe how we utilized the five-step approach described above in order to prepare preservice teachers for curricular technology integration consistent with the spirit of the TPACK framework.

Research Principles for the Design of Stand-Alone Educational Technology Courses

In a recent review of the literature, Tondeur et al. (2012) identified key strategies related to the preparation of preservice teachers to integrate technology into their lessons. These strategies, extrapolated through an ethnographic analysis of 19 qualitative studies reported in the literature, include the following:

- *Aligning theory and practice*. Effective approaches to preservice teacher preparation link conceptual and theoretical information to practice. Specifically, Tondeur et al. (2012) found that preservice teachers benefit when short lectures are combined with practical work.
- *Using educators as role models*. There is wide agreement in the literature that modeling of technology use is vital and that observations of teachers using technology serve as important motivators for preservice teachers.
- *Role of reflection*. Similarly, researchers agree that reflecting on the role of technology in education is key to learning, and that discussion groups, observations, and writing can encourage such reflection.
- *Instructional design*. Teaching with technology requires planning and preparation. Research indicates that preservice teachers benefit when actively engaged in the production of technology-enhanced materials.
- *Collaboration with peers*. Opportunities to collaborate with peers by discussing and sharing concerns were found to be important when learning about educational uses of technology. Online spaces can facilitate collaboration, though the composition of the group can also influence outcomes.
- *Authentic technology experiences*. Although observing uses of technology is important, research indicates that it cannot be a substitute for engaging in technology-enhanced experiences. Preservice teachers need opportunities to apply their knowledge in authentic technology experiences.
- *Continuous feedback*. Traditional tests are often inadequate in measuring preservice teachers' learning. Rather, alternative forms of assessment and feedback should be employed to document preservice teacher learning and practice over time.

In the following sections, we discuss how we redesigned an educational technology course over time to reflect best practices in the preparation of preservice teachers on the use of technology, as suggested by the research-based principles that were previously presented.

(Re)Designing the Educational Technology Course

Background

The Elementary Teacher Education (ETE) program at our university is accredited by the *National Council for the Accreditation of Teacher Education* (NCATE), a prominent accrediting organization in the United States. Graduates of the ETE program receive certification in kindergarten through fifth grade and either a middle school (Grades 6–8) content area (i.e., mathematics, social studies, science, or English) or special education. Consistent with contemporary research that advocates the necessity of field experiences in teacher education (Blue Ribbon Panel Report, 2010), the program curriculum is designed to provide preservice teachers with a range of practicum experiences in a variety of classroom settings. *Early field experiences* begin in the freshman year and provide preservice teachers the opportunity to observe experienced teachers and learn about the classroom environment, and how to interact with children. *Methods field experiences* are taken in conjunction with courses designed to develop teaching skills and provide preservice teachers with the opportunity to teach lessons to an entire class. Early and methods field experiences are designed to prepare preservice teachers for *student teaching*, where they gradually take over classroom responsibilities for a period of one semester.

When we started working at our current university, there was a technology block required in the ETE program. The block consisted of three one-credit courses that taught a variety of technology applications, such as Excel, Microsoft Word, and Dreamweaver, with no substantial connection to content-specific instruction. Gradually, the three one-credit courses were eliminated to reflect changes in preservice teachers' technology skills as well as advances in technology and were replaced by two other courses: a one-credit course titled *EDUC 286: Educational Technology Professional Tools* and a two-credit course titled *EDUC 387: Integrating Technology in Education*. EDUC 286: Educational Technology Professional Tools is taken in freshman year and is designed to prepare incoming preservice teachers to use basic educational technology techniques and methods in their own learning and their future teaching. *EDUC 387* is taken later in the program and is designed to help preservice teachers learn how to use technology to support content-area instruction. Nevertheless, initially the course remained loosely connected to a theoretical framework, to methods courses helping preservice teachers develop their teaching skills, and to field experiences in authentic classrooms.

Given the above limitations and our common interests, we decided to take the responsibility for the technology preparation of our ETE majors by supporting a reorganization of the two courses and a redistribution and focus of the content. Working within the constraints of the ETE program, we kept EDUC 286, but we eliminated coverage of outdated professional tools, and placed emphasis on contemporary collaborative tools (e.g., blogs) and ways in which they can be applied for personal and professional tasks. We also engaged in the redesign of EDUC 387 to focus on contemporary tools that support communication, content representation, collaboration, and professional planning (e.g., concept mapping, social networking, and electronic surveys), and ways in which these tools can be embedded within the context of content-area instruction.

Course (Re)Design

In this section, we discuss a three-fold approach to the redesign of the educational technology course that serves as the foundation of this chapter. We present a rationale for each decision based on our experiences from teaching the course over multiple years and our student course evaluations.

The first component of the course we redesigned was related to the delivery format. Initially, *EDUC 387* was offered in a face-to-face format in a computer laboratory. This environment, however, presented challenges to effective instruction, because computers were arranged in a traditional teacher-centered configuration, with large desktop computers blocking students' views of one another (Funkhouser & Mouza, 2013). The space constraints made peer–peer interactions difficult and provided few opportunities for creating the collaborative and constructivist learning that characterizes effective use of technology (Ertmer & Ottenbreit-Leftwich, 2010). Further, students expressed on their class evaluations the desire for moving portions of the class online. Given the focus of the course, it seemed natural to do this and, after much discussion, we decided that online delivery would allow us to effectively (a) model ways in which educators can use technology asynchronously, using contemporary technology tools (e.g., discussion forums, digital storytelling, and online posters); (b) promote discussion and reflection beyond the constraints of the classroom; and (c) provide opportunities to students to collaborate and learn from one another. As a result, the course was redesigned and offered in a hybrid format combining face-to-face and online sessions, facilitating easy access to technology and hands-on learning experiences.

The second component we sought to address was the alignment with the TPACK framework. Although the course always placed emphasis on curricular integration, it did not introduce a systematic way of planning with technology. TPACK was introduced to preservice teachers through presentations and examples at the beginning and throughout the course, but they were not required to utilize the framework as they completed course activities and assignments. As a result, frequently their assignments reflected technological rather than curricular integration, as they worked to design activities that utilized the technology tools introduced in the course. To address this challenge, we turned to the framework provided by Harris and Hofer (2009), which provided a practical approach to more systematic adoption of the TPACK framework consistent with the ways in which teachers plan lessons. Specifically, we redesigned our assignments in ways that explicitly engaged preservice teachers with the five-step approach presented by Harris and Hofer (2009). This strategy, essentially forced preservice teachers to always start their planning by first considering content and pedagogy, and then identifying the technology tools that could help their students learn that content.

The third, and final issue we addressed, was the placement of the course within the larger teacher education curriculum. Taking into account the literature on best practices in the preparation of preservice teachers, which highlights the necessity to connect theory and practice, *EDUC 387* was linked with methods courses and field experience. This connection allows preservice teachers to connect what they learn from the university classroom to the school classroom and vice versa. For example, in *EDUC 387* students learn how to use concept mapping software. Afterwards, they are required to develop a lesson using the software in a content-area of their choice, considering the characteristics of the students in their field placement. Finally, after consulting with their cooperating teacher, they are required to implement the lesson in their field placement, and prepare a reflective report documenting their experience and lessons learned.

Course Alignment with Research-Based Principles

In addition to explicitly weaving a practical approach to the adoption of the TPACK framework throughout the course, we have also directly aligned the course with research-based principles in the preparation of preservice teachers (Tondeur et al., 2012). Table 1 demonstrates the research-based principles exemplified in our course

Table 1 Course description and alignment with research principles

	Research principle	Course activities
Practical adoption of TPACK: five-step curricular-based technology integration	Theory to practice connection	Educational technology course offered in conjunction with *methods courses* and *field experience*
	Instructional design	Lesson critique: Preservice teachers are asked to choose a lesson and write a critique structured around the Harris and Hofer (2009) curricular-based technology integration prompts
		Lesson development: Preservice teachers are given repeated opportunities to design their own technology integrated lessons for their methods field experience classrooms. The lessons must reflect curricular-based technology integration organized around the Harris and Hofer (2009) framework prompts
	Role models	University faculty model uses of technology
		Cooperating teachers model uses of technology
	Authentic experiences	Opportunities to engage with technology including hands-on activities utilizing: interactive whiteboards, graphic organizers, Web 2.0 tools, and a learning management system
		Application of learning into practice through the implementation of curricular-based technology integrated lessons designed in the course into real classrooms
	Reflection	Case development: Preservice teachers design or identify a curricular-based technology integrated lesson, enact the lesson in a classroom setting, and write a reflective case on the implementation and outcomes of the lesson following a series of writing and reflection prompts

and the specific topics and assignments that correspond to each principle. In this section, we expand upon the specific ways in which such alignment was accomplished, while examples from student work and evaluation comments are cited to support our redesign.

Aligning Theory to Practice

There are three ways in which we ensure an alignment between theory and practice within our educational technology course. First, as noted, we have ensured *EDUC 387* is offered in the same semester in which preservice teachers enroll in *methods courses* and *methods field experience* in a local school. Methods courses are intended to prepare preservice teachers for their future classrooms and are accompanied by field experience in a local school. The methods courses and field experiences take place in the two consecutive semesters prior to student teaching. During that time, preservice teachers are in the field for 3 full weeks each semester, allowing them to observe and experience the daily routines of a classroom teacher, see growth in student learning, and develop strong relationships with cooperating teachers. These experiences also allow preservice teachers to put their knowledge into practice by designing and teaching lessons that prepare them to take over a classroom during student teaching. Second, we have developed recursive communication with the methods faculty, where we inform each other of the tools, strategies, and ideas that are emphasized in the courses. This approach allows us to provide unified content that supports learning in important ways. Third, in *EDUC 387,* preservice teachers are required to develop and implement curricular-based technology-integrated lessons specific to their current field placements. This is extremely beneficial, because field placements provide preservice teachers with a particular context to consider, as they identify learning goals, pedagogical strategies, and appropriate technology tools, as well as the opportunity to conduct their lessons within real classrooms.

Instructional Design

TPACK is a framework that emphasizes the importance of preparing teachers to make effective choices in their uses of technology, when teaching specific content to a particular student population (Tondeur et al., 2012). Towards this end, preservice teachers need repeated opportunities to examine instructional design, practice planning, and prepare materials that integrate technology tools. Our educational technology course takes a two-step approach to developing knowledge of instructional design: lesson critique and lesson development.

We begin the semester by defining curricular-based technology integration, providing examples and requiring preservice teachers to view lessons through that lens by completing a critique. We found that this explicitness in instructional design helps our preservice teachers conceptualize what we mean by curricular integration and allows them to analyze lessons prior to developing their own. To prepare for this assignment, we introduce *Thinkfinity* (http://www.thinkfinity.org), an award-winning educational resources portal with lesson plans spanning a range of content areas and grade levels. We spend time exploring the *Thinkfinity* partner sites and provide examples of effective curricular-based technology integrated lessons. Preservice teachers are then asked to choose a lesson and write a critique structured around the curricular-based technology integration prompts, which ask them to describe: (a) the learning goals of the lesson; (b) the pedagogical knowledge used in the lesson, using the eight corresponding continua described by Harris and Hofer (2009); (c) the activity types used in the lesson; (d) the assessment strategies used in the lesson; and (e) the technology used in the lesson. In conclusion, they are also asked to provide a qualitative assessment of whether the technology used in the lesson matches the identified learning goals and pedagogical strategies.

This is a challenging assignment, because it requires preservice teachers to think deeply about content, pedagogy, and technology, as well as how these three constructs are combined to develop effective instruction. They must draw upon knowledge gleaned in *EDUC 387*, in conjunction with the content and pedagogy learned in other courses. Perhaps most challenging for our preservice teachers is to think critically about the lessons they choose, recognizing that, although they were published on an award-winning website, the lessons may not always be good examples of curricular-based technology integration. In essence, this assignment marks the beginning of their understanding of curricular-based technology integration.

After spending considerable time critiquing published lessons, preservice teachers are given repeated opportunities to design their own lesson plans for their methods field experience classrooms. Utilizing a variety of technology tools and applications, including interactive whiteboards, concept mapping, electronic surveys, and Internet inquiry, the lesson plans must reflect curricular-based technology integration organized around the Harris and Hofer (2009) framework prompts. For instance, when learning about the pedagogical uses of concept maps, preservice teachers are asked to generate a lesson idea that utilizes electronic concept mapping software to support a learning goal, within a content area of their choice. Additionally, they are required to create a sample concept map that would help their students understand the task. We consequently present an example of a preservice teacher named Jaci and her approach to curricular technology integration using concept mapping.

Jaci, a junior ETE and special education major placed in a second grade classroom for her field experience, chose to develop her lesson around character point of view. Specifically, her learning goal focused on helping students "acknowledge differences in the points of view of characters, including speaking in a different voice for each character, when reading dialogue aloud" (Common Core State Standards, 2010). The lesson required the teacher to read the story, *The Pain and the Great One* (Blume, 1985) aloud to the class. Afterwards, students would work independently to develop two concept maps using *Kidspiration*. Each map would represent the point of view of one of the two main characters. Once the maps were complete, the

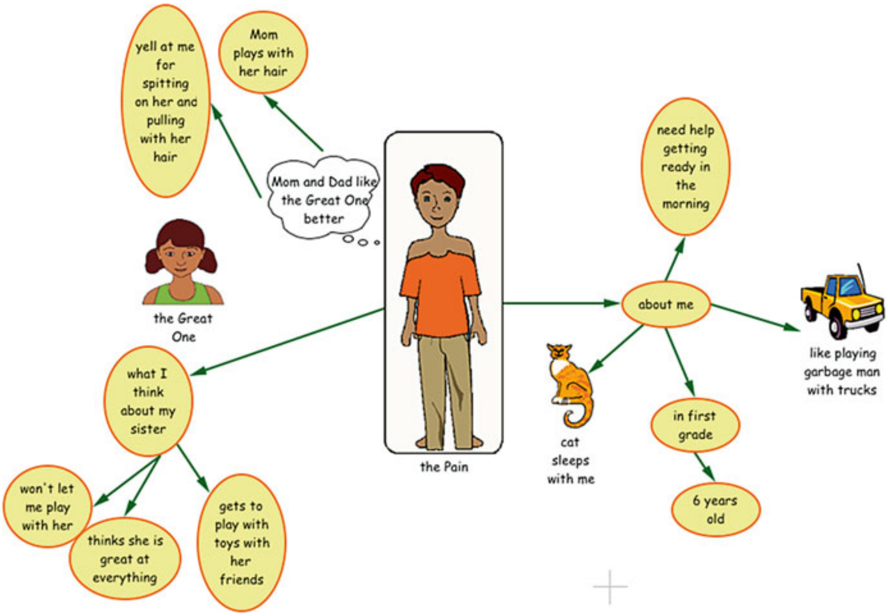

Fig. 2 A sample concept map created by Jaci, a preservice teacher in our course

students would be configured in small groups, where they would use the information they included in the maps to develop a dialogue between the two characters. The groups would then present their dialogues to the class. Figure 2 is an example of one concept map.

Jaci did an excellent job of creating a curricular-based technology integrated lesson. The content was well defined, the pedagogical decisions relevant to the content, the activities were systematic, and the assessment was appropriate. Her understanding, however, was most evident in her response to the final prompt of the assignment, asking her to explain how her use of technology supported the learning goal and pedagogical decisions she identified for the lesson:

> Kidspiration is helpful for visual learners and students who have trouble with handwriting. It also increases motivation because students are excited to use the software. Most importantly, students can think creatively and organize their map in a way that makes sense to them. It is necessary that students learn how to organize their thoughts and ideas, before they are expected to write more extensively in later grades. Thus, exposing second graders to pre-writing tools, like concept maps, will help them in the future. Creating concept maps that show ideas, thoughts and feelings from the perspective of each main character will make it much easier for students to see and analyze the story from different characters' points of view. When they move to small groups in this lesson, they are ready to think more critically and create dialogue with their group. Therefore, the technology supports how I suggest grouping students for each part of the lesson. Overall, the way I use Kidspiration in this lesson helps guide students through the process of identifying, organizing and interpreting details from the story.

Role Models

In their review of PT3 projects, Polly et al. (2010) found that preservice teachers, who had opportunities to observe the implementation of technology-rich units into methods courses, reported greater technological skills and more ideas on how to use technology with students. Finding technology-using teacher educators who are able to model effective technology integration, however, is challenging (Karchmer-Klein, 2007; Thompson, Schmidt, & Davis, 2003). Therefore, in designing our course, we look to a variety of resources to expose our preservice teachers to effective models of technology integration.

As the instructors for *EDUC 387*, we provide the most relative models of technology integration, since we choose the tools and applications preservice teachers will explore in our class. Therefore, for each tool and application introduced, we implement an activity requiring preservice teachers to learn about it and then apply it to an educational context. For example, since the class is delivered in a hybrid format, it is important for everyone to introduce themselves, so that all members of the classroom community become familiar with one another. To do this, we use *VoiceThread*, an online interactive tool that allows users to hold asynchronous conversations using video, audio, or text. Early in the semester, preservice teachers open a free *VoiceThread* account, watch several video tutorials, explore public VoiceThreads, and participate in their first *VoiceThread*, by introducing themselves on the class *Introduction* site. These basic steps expose preservice teachers to the tool and allow them to practice the technical skills necessary to effectively engage with it. A few weeks later, when we complete a unit on the unique characteristics of digital texts, we ask preservice teachers to read a related article and then participate in *VoiceThread* discussions, following a set of guiding questions where they use text, audio, or video, to share their ideas as well as comment on their peers' views. This process provides them with an explicit use of the technology tool within the context of learning about reading and writing digital texts.

In addition to our own modeling, each year more and more methods instructors incorporate technology into their teaching practices. This, in turn, provides our ETE majors with increased models of technology integration beyond their educational technology course. An end of the semester survey, asking preservice teachers to describe a specific episode where a professor effectively modeled curricular-based instruction illustrates how as a unit, the ETE faculty model curricular-based technology integration:

- EDUC 387 was the class in which I used the most technology. I learned many new technologies, such as, Glogster, VoiceThread, and Inspiration. We had a nice balance of learning how to use the software and completing an assignment that required us to use the software to learn content.
- During my social studies teaching course, we had a videoconference with someone who worked in a museum in Washington DC. He talked to us about what artifacts were available for teaching purposes.
- In my Mathematics class, the instructor effectively used Geometer Sketchpad and Google images/shapes to show the divisions of geometrical figures and

different ways to cut the shapes to count the vertices and lines. This visual was extremely helpful.

Besides observing technology-rich lessons in their teacher education program, it is important for preservice teachers to have opportunities to observe effective use of technology in their field placements. In fact, research indicates that preservice teachers greatly benefit from experiencing effective technology integration in the field and tend to disregard practices taught at the university, if these are not used in real classroom settings (e.g., Korthagen & Kessels, 1999).

Field placements are identified by the ETE program clinical coordinators and are dictated by many factors including proximity to the university, willingness to accommodate preservice teachers, diversity of the host school population, cooperative teachers' reputations, and their years of experience. Given these constraints, effective technology use by cooperating teachers and access to current technology tools are often not priorities when identifying field placements. This is a challenge we confront each semester, as several of our preservice teachers are placed in classrooms with little to no technology use. Yet, those preservice teachers, who do observe technology integration frequently, report effective modeling and support from the cooperating teacher. One preservice teacher shared the following example on his end of the semester survey:

> My cooperating teacher most effectively demonstrated the use of technology in a social studies lesson, where students were learning about aerial maps. To introduce the lesson, she projected Google Earth onto the Smart Board, and zoomed into our town and elementary school. The students were fascinated by the images she showed them. Visually connecting the social studies lesson to the students' lives and places they are familiar with helped engage them throughout the rest of the lesson.

Another preservice teacher explained:

> My cooperating teacher used iMovie to help teach poetry concepts. Students were analyzing tone and mood, and their assignment was as follows: take an assigned mood/tone and create an iMovie presentation, using pictures and music to convey that mood/tone. Students really enjoyed using this technology and the lesson successfully taught students meaningful content, and could also be used as an effective form of assessment. Students were taught how to use the iMovie software before the lesson, and thus all had the background knowledge to complete the project.

Although we recognize that the quality of the instruction greatly varies, we believe the mere exposure to technology integration is beneficial, because it facilitates thoughtful discussions about what our preservice teachers observe and how they may consider modifying it for use in their own instruction.

Authentic Experiences

According to Tondeur et al. (2012), many teacher education programs emphasize the importance of providing preservice teachers with authentic technology experiences, including increased opportunities for hands-on work. In our course, preservice teachers have repeated opportunities to engage with technology, including hands-on activities utilizing an interactive whiteboard, graphic organizers, Web 2.0 tools, and a learning management system. Additionally, preservice teachers apply their learning into practice by implementing curricular-based technology-integrated lessons, designed in our course, into their field practicum. This exercise enables them to first hand witness use of technology with their own students. When asked to describe an episode where they effectively demonstrated curricular-based technology integration, preservice teachers shared a variety of examples:

- I taught a lesson where the students first examined a variety of 3-D shapes, then created a web on Inspiration showing which 3-D shapes were made from what 2-D shapes (what shapes were on the faces of the 3-D shapes). It was meant to help show students the relationships of different 3-D shapes (for example, all prisms have rectangles as faces).
- In my methods course, our social studies lesson had to integrate technology. We decided to use a camera to document our experience, as we took the students on a tour of their neighborhood. On this tour, we took the students and walked up and down the blocks highlighting key parts of a neighborhood, such as, the library, the police station, the art museum, the post office, a college, etc. The technology enhanced the lesson, because we were able to document our experience and the pictures helped students create their own photos as an assessment after the lesson.
- Teaching a mathematics lesson, I had the opportunity to use electronic spinners and dice on the interactive whiteboard. During whole class discussion of probability, I was able to show the students, using spinners and dice, the probability they would get. This helped the students with the questions they were asked (for example, what is the probability that you spin a 1 on the first spinner, and then roll a 2 on the 6 sided die), because the students could come to the board and try it on the spinner and dice, and see how it compared to their calculated answer.

The requirement to teach a curricular-based technology-integrated lesson emphasizes to our preservice teachers the importance of *doing* rather than *observing* in teacher preparation (Tearle & Golder, 2008).

Reflection

An essential factor influencing effective use of technology rests with the pedagogical and personal beliefs of teachers (Ertmer, 2005). The highly personal nature of beliefs makes them resistant to change, but when teachers see value in a specific pedagogical strategy, they are more likely to incorporate it into their teaching practice (Zhao & Cziko, 2001). In turn, adoption of new teaching practices can help confirm existing beliefs or lead to the creation of new or reconstructed beliefs (Haney, Lumpe, Czerniak, & Egan, 2002; Mouza, 2009). As a result, helping preservice teachers examine and reflect upon their beliefs, in relation to the use of technology in teaching, is critical for their learning.

Despite its importance, detailed reflection is challenging and requires action or an underlying experience (Birmingham, 2004). In our course, we make it possible for preservice teachers to reflect on their ideas, beliefs, and experiences with respect to technology, through a case development process (Mouza & Karchmer-Klein, 2013). The process of case development progresses incrementally throughout the semester and is divided in various stages where preservice teachers design or identify a curricular-based technology-integrated lesson, enact the lesson in their field practicum, and write a reflective case on the implementation and outcomes of the lesson. To facilitate the process of reflection, a series of writing and reflection prompts are provided that help preservice teachers engage in systematic and detailed analysis of their practice.

Perhaps the most interesting component of the reflection requires the preservice teachers to identify challenges encountered during the implementation of their lesson, followed by modifications they would make the next time they taught the lesson to a group of students. This section encourages preservice teachers to critically examine their instruction and think deeply about change based upon their actual experience teaching the lesson. Although the challenges range from major to minor, preservice teachers seem to equate them, since they affect their own teaching. For example, Ellen was a junior ETE and special education major placed in a third grade classroom with a technology savvy teacher and a Smart Board. She used the Smart Board to engage her students in an interactive lesson on currency, requiring the students to manipulate graphics to represent different amounts of money. Ellen wrote:

> I would consider everyday in the classroom to be filled with challenges for a teacher. In particular, I was faced with one challenge in the middle of my lesson. When starting the lesson, the Smart Board I found was not calibrated and a random object appeared on the board that I could not figure out how to delete it. These challenges were relatively minor, however they still delayed the lesson a few minutes until the issues were resolved. In the future, when planning a technology lesson, I would consider students' opinions in fixing the issue, because they might know more about the Smart Board than me!

Laurie, a junior ETE and special education major, dealt with a content challenge during her mathematics inquiry lesson. Her learning goal focused on engaging students in real-world mathematics by solving percentage problems. She wrote, "When I found the Math at the Mall game online, I thought it was the perfect tool to use. It effectively connects mathematics, specifically percentages, to real life experiences and even gives math help when needed." However, during the implementation, Laurie quickly realized that the students did not have as much prior knowledge about percentages as she thought they had. She explained, "While they knew how to convert percentages to decimals, they didn't understand the operation and how to actually take a percentage of a number." Laurie quickly changed directions and modeled the activity several more times, until the majority of students understood. She reflected, "Next time, I will conduct my own assessment of the students' knowledge rather than assuming where the students are at with their understanding of math."

Results from our research (Mouza & Karchmer-Klein, 2013) indicate that case development provides a fruitful context for helping preservice teachers bring together different knowledge bases to design and implement effective curricular-based technology-integrated lessons. Further, results indicate that analyzing and reflecting on technology-integrated classroom experiences helps preservice teachers identify important lessons related to technology, reconsider their ideas on the motivational role of technology, and witness firsthand ways in which use of technology can engage students in learning challenging materials.

Lessons Learned from Student Reflections

To examine the impact and effectiveness of our course design, every semester we ask preservice teachers to reflect upon their learning in the course, considering three key questions: (1) Why is it important to align technology with content and pedagogy? (2) How do you plan to use the TPACK framework to develop curricular-based and technology-integrated lessons in your future classroom? And (3) In what ways, if any, do you anticipate using technology in your student teaching placement and future classroom as a full time teacher? This section reports on key insights that emerged from analyzing reflections collected over the past 4 years.

Reflections on the TPACK Framework

Review of our preservice teachers' reflections indicated that they uniformly acknowledge the importance of using technology that is aligned with content and pedagogy. All preservice teachers acknowledged that in today's day and age, when modern technology has penetrated people's everyday lives, it is critical to extend its use in the classroom in an appropriate way. As one student noted in her reflection, "students these days are heavily reliant on technology, and it is important to key into that and show them that the Internet is useful for more things than social networking and chatting with friends." Similarly, other preservice teachers reflected on the importance of using technology to connect with students' worlds, but emphasized the need to do so in pedagogically appropriate ways. Many noted how it is easy to focus on technology in order to make learning more "fun," but cautioned against getting off track and engaging in activities that are not likely to foster student learning. In fact, all preservice teachers spoke highly about the importance of focusing on content first, by identifying important learning goals aligned with standards, and then selecting pedagogical strategies and technologies that match those goals. As one preservice teacher explained:

> Technology tools can open doors to previously unavailable or impossible content explorations, but teachers must be careful when using these tools. Teachers must avoid using technology just for the sake of using technology, because, as Harris and Hofer explain, "techno-centric learning experiences rarely help students meet curricular-based content standards."

More importantly, all preservice teachers appreciated the curricular-based approach to technology integration introduced throughout the semester. They found it relevant to the planning of all lessons, not just the ones integrating technology. As one preservice teacher stated, the curricular-based approach provided a good model to keep in mind for all lesson planning: "setting learning goals, deciding upon teaching strategies, selecting activities, assessment strategies and resources, are things that teachers should always take into consideration." Further, all preservice teachers found the eight corresponding pedagogical continua very helpful in thinking critically about how they will teach their lessons to reach the desired outcomes. One, in particular, summed up those sentiments pretty well when stating:

> The curricular-based technology integration approach is almost like a cheat sheet for making quality, well thought out technology-integrated lessons. This approach and the TPACK framework as a whole serve as a guide to help you craft quality lessons, and maintain the correct levels of pedagogy and content.

Future Uses of the TPACK Framework

EDUC 387 is the first course in which preservice teachers are specifically asked to plan, enact, and reflect upon the implementation of technology-integrated lessons. This approach enables them to witness the benefits of systematic planning to technology integration for both themselves and their students. When asked to reflect upon TPACK and how it would influence lesson planning in the future, one preservice teacher explained:

> I can understand how easy it is for many teachers to first choose the technology outlet, and then try to match it to their lesson goals and pedagogy, because that seems like the way to go about it. After taking this class and learning about the TPACK framework, I can see why this is not the correct way to plan a technology-integrated lesson. I already used the TPACK framework when I created a review game for my seventh-grade students, and I will continue to use it in the future. In the classroom this semester, I first decided that I wanted the students to review previously targeted learning goals, when I realized they were having trouble. Considering the success of this lesson, I will refer back to it, when planning lessons for my own future classroom.

Some preservice teachers reported observing their cooperating teachers matching technology tools to learning goals and pedagogical strategies; the opposite of what was taught in their educational technology course. Interestingly, many preservice teachers admitted they found this to be an acceptable approach, before they learned the importance of organizing their instruction around content. For example, one preservice teacher characteristically noted:

> Prior to this course, I thought it would be perfectly acceptable for a teacher to choose a website first and then plan a lesson around it. However, from the curricular-based approach to technology integration, I learned how important it is for teachers to follow the TPACK framework and appropriately integrate technology into lessons, instead of starting with technology and attempting to build a lesson around it.

All preservice teachers indicated that they plan to use the TPACK framework as a guide to the future design of technology-integrated lessons. In their reflections, they often described the steps they would follow to do so, consistent with the curricular-based approach they adopted throughout the semester. For many preservice teachers, this was an important insight acquired through the course. One preservice teacher explained:

> This framework really hits every major point that needs to be discussed before implementing a lesson. Furthermore, using this framework will assist me in finding lessons that match my learning goals. The five-step approach to technology integration really explained this misconception to me, and I am excited to implement technology in more sound ways in my future classroom.

Further, many preservice teachers drew again on their experience enacting their technology-integrated lesson in their field placement to justify the importance of placing technology in the context of learning goals and sound pedagogical strategies. One preservice teacher elaborated on this by writing:

> Basically, it is really important to first use the content that you are teaching to find technological opportunities in the classroom. If the integrated lesson really matches the curriculum and the learning goals, the students will take a lot more away from the lesson. For example, in my field placement, I implemented an inquiry-oriented online activity with my seventh-grade students. However, the content that I focused on was not related to what students were learning in social studies at the time. I think that the students found the activity fun and resourceful, but if it had matched the current curriculum, then the students would have taken a lot more away from the activity. Therefore, next time, I would first look at the curriculum and my learning goals for the lesson, and then create a technology-integrated lesson based on this information. This would ensure that the students are achieving relevant learning goals through the lesson.

Interestingly, preservice teachers also reflected on the importance of their own professional development and its relation to successful technology integration. Many realized the need to keep up with their own knowledge of technology, content, and pedagogy, in order to continue planning successful technology-integrated lessons using the TPACK framework. They acknowledged that knowing and understanding the content to the best of their ability would help their students reach the identified learning goals. They also acknowledged the need to develop further pedagogical knowledge in regard to classroom management and instructional techniques that would help their students succeed. One preservice teacher succinctly summarized these points in his statement:

> In order for technology to be successfully integrated into the classroom, it must be placed into the context of the TPACK framework. Alignment is just one part of the TPACK framework that I will use in my future classroom to ensure that content knowledge is being applied. The other parts of the framework will require me to become familiar with the latest technology, which fits into the technological knowledge area of the framework. In order for me to develop my technological knowledge, I will need to engage with new tools on my own time. Further, I will also need to keep myself updated with the latest research-based pedagogical practices through professional development courses. The combination of developing my own content knowledge, technological knowledge and pedagogical knowledge, will allow me to successfully develop technology-integrated lessons using the TPACK framework.

Anticipated Future Uses of Technology

When asked to reflect upon the ways in which they anticipate using technology in their student teaching placement and in their future classrooms as full time teachers, all preservice teachers reiterated the importance of using technology, expressed desire to have technology tools in their future classrooms, and reported on expected uses. The expected uses of technology were often described, in conjunction with anticipated pedagogical strategies but not in conjunction with learning goals to be achieved, such as: “I will use a Smart Board when I teach” or “I will use technology to present information to students as well as online activities.” In other words, preservice teachers tended to describe generic uses of technology and their potential to align with specific pedagogical strategies.

By far, most preservice teachers hoped to have and expected to use an interactive whiteboard in their student teaching and future classroom. Interactive whiteboards have gained increased popularity in K-12 schools in the United States and other countries. They have the potential to enhance demonstrating and modeling through objects that can be manipulated, improve the quality of teacher–student interactions, facilitate planning, and increase the pace and depth of learning (British Educational Communications and Technology Agency [Becta], 2003). Henessy, Deaney, Ruthven, and Winterbottom (2007) found that interactive whiteboards assist in providing classroom conditions that can guide student participation in more challenging activities. Despite those benefits, research indicates that mere use of interactive whiteboard does not automatically create the conditions required for interactive and deep learning (Hall & Higgins, 2005). Hall and Higgins (2005), for example, have conjectured that the primary reason behind the wide adoption of interactive whiteboards lie with their ability to support whole class teaching consistent with traditional teaching methods.

Our preservice teachers’ emphasis on interactive whiteboards can be attributed to two variables. First, the majority of the preservice teachers had opportunities to observe uses of interactive whiteboards in their field placement, thereby becoming more familiar with this technology. Second, preservice teachers had the opportunity to observe an experienced teacher utilizing an interactive whiteboard in an authentic setting during a course scheduled field trip to a local school. The teacher modeled effective use of the interactive whiteboard and demonstrated examples and student work completed while using the board. Thus, it appears that increased exposure to the use of interactive whiteboards enabled preservice teachers to witness the benefits of using these tools in the classroom. It is also possible that preservice teachers felt pressure to utilize these tools in their future teaching given their wide availability. One preservice teacher characteristically noted: “During my middle school placement, I expect to use the Smart Board almost daily. The students can engage with the Smart Board in order to enhance their learning.” Other preservice teachers indicated that they plan on using a Smart Board to “project student work, model examples and encourage movement in the classroom” and to use “time management tricks, countdown clocks and review games.”

Other expected uses of technology included the use of digital content (e.g., online videos and inquiry-oriented online activities), use of content specific software (e.g., graphic organizers), use of collaborative tools (e.g., wikis), and use of communication software to facilitate interaction with parents. One preservice teacher noted: “I plan to use various online mathematics tools to keep students engaged with the material and create a variety of ways for them to participate in the learning process.”

Discussion and Future Steps

In this chapter, we have presented one approach to the design of educational technology courses that is aligned with research-based principles on the preparation of preservice teachers, while utilizing the TPACK framework as an instructional guide. We have also presented insights from preservice teachers’ reflections on the TPACK framework, and their anticipated uses of technology in their student teaching placement and future classrooms.

Analysis of preservice teachers’ reflections indicated that key components of the course were beneficial in fostering a greater appreciation of technology in the context of content and pedagogy. Many preservice teachers appreciated the opportunity to learn about new technology tools, observe the application of technology in classroom teaching, and engage in instructional design and reflection. Despite that, one course alone may not be sufficient in fostering depth of understanding, as it was evident by preservice teachers’ responses on their future uses of technology. This might be particularly true among preservice teachers who lack pedagogical expertise and experience in key aspects of the TPACK framework, such as content standards and pedagogy. For example, frequently our preservice teachers were surprised at their students’ prior knowledge with respect to technology. Specifically, preservice teachers often overestimated what their students knew about technology, thus designing lessons that took longer than expected to implement or presented unexpected challenges. As a result, enactment of technology-integrated lessons was often an eye opening experience for preservice teachers that reinforced the need to assess student prior knowledge, not only of content but also of technology. Future iterations of the course might place more emphasis on the connection between lesson design and the targeted student population.

Another challenge we witnessed throughout our experiences from teaching the course is still related to technology access. Despite the increase of technology in USA schools, the move from traditional paper and pencil testing to computerized testing has resulted in limited access to technology for purposes outside testing. Future iterations of the course might address such practical challenges, when thinking and designing curricular uses of technology.

What is key to the redesign of the course is that it shifts emphasis from the technology to the curriculum. The activities, as well as the five-step approach to the practical adoption of the TPACK framework, are not specific to certain types of technologies. Rather, these could be used with a variety of technologies and instructional activities, thus making our approach fairly resilient amidst rapid technological changes. In fact, over the years, we did change the tools introduced in the course to reflect advances in technology but kept the activities intact. More recently, for example, we placed increased emphasis on the use of mobile educational apps and assigned each preservice teacher a tablet computer they could use for their planning and instructional needs. Amidst this shift, we continued to rely on the TPACK framework and the five-step approach to curricular technology integration, as preservice teachers design lessons that combine content knowledge, pedagogy, and mobile educational apps.

In terms of future steps, it appears that it is important to continue documenting the impact of our instructional practices and the stand-alone educational technology course, in particular, on preservice teacher learning of technology, content, and pedagogy (Mouza & Karchmer-Klein, 2013; Shinas, Yilmaz-Ozden, Mouza, Karchmer-Klein, & Glutting, 2013). Such efforts should utilize more comprehensive approaches that move beyond preservice teachers' perceptions and anticipated uses of technology through written descriptions. Future efforts should also include more direct methods of data collection, such as observations and interviews to draw richer descriptions of preservice teachers' learning and practice. Although much has been written about it, it is critical that we provide preservice teachers with opportunities to observe successful uses of technology in their field placements. Studies documenting preservice teachers' learning in technology-rich field placements reported promising outcomes, including positive attitudes towards technology, frequent use of technology, and more instances of preservice teaching using technology to support student learning (Strudler, Archambault, Bendixen, Anderson, & Weiss, 2003). Along the same lines, we as teacher educators must also continue to model uses of technology that are well aligned with content and pedagogy. Such models should move beyond the use of simple presentation technologies. In combination, these practices have the potential to help preservice teachers realize that effective use of technology is not a simple matter, but rather a complex process that requires thoughtful consideration of content and pedagogy.

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The Framework of TPACK-in-Practice: Designing Content-Centric Technology Professional Learning Contexts to Develop Teacher Knowledge of Technology-enhanced Teaching (TPACK)

Kamini Jaipal-Jamani and Candace Figg

Introduction

Developing teacher knowledge about teaching with technology has shifted from delivering training in sessions, or courses, centered on how to use the tool—an approach that Papert (1987) described as techno-centric, to content-centric approaches, where the focus is on how to teach content with the tool (Figg & Burson, 2011; Fisher, Dwyer, & Yocam, 1996; Harris, 2005; Harris, Mishra, & Koehler, 2007, 2009; McKenzie, 2001; Means & Olson, 1997; Roblyer, Edwards, & Havriluk, 1997). Traditional skill training workshops focus on technical skill development, which are "often learned out of context, seem remote from classroom practice and leave many teachers wondering about their utility and worth" (McKenzie, 2001, Weakness of Past Efforts and the Training Model, para. 22). Koehler et al. (2011) explained that "such learning is often de-contextualised, lacking connection with broader issues of technology integration with actual classroom practice" (p. 151). Research also shows that proficiency with the tools does not appear to impact teacher use of the tools in daily instructional practices with their students (Angeli & Valanides, 2009; Becker, 1994; Hadley & Sheingold, 1993; Schrum, 2005).

Content-centric approaches emphasize developing "the rich connections between technology, the subject matter (content), and the means of teaching it (the pedagogy)" (Koehler & Mishra, 2005, p. 95) in collaborative professional learning contexts. Teacher knowledge representing these rich connections is referred to as Technological Pedagogical and Content Knowledge (TPACK). The TPACK model,

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as described by Koehler and Mishra (2008), is increasingly being used to design professional learning contexts to develop teacher knowledge of technology-enhanced teaching. (Figg & Jaipal, 2012; Harris, 1998; Harris & Hofer, 2009; Harris et al., 2010; Jaipal & Figg, 2010b; Mueller, 2010; Niess, 2005b; Voogt et al., 2010). The aforementioned examples of professional development contexts included in-service teachers attending additional qualifications and master's courses, preservice teacher courses, and master's level technology courses in which professional learning occurred over long periods of time.

Additionally, a widely used approach to prepare in-service teachers and higher education faculty to teach with technology is through short, one-time intervention workshops, since these are most convenient in terms of preparation, logistics, and teacher workload (Darling-Hammond, Chung Wei, Andree, Richardson, & Orphanos, 2009; Figg & Jaipal, 2012; Garet, Porter, Desimone, Birman, & Yoon, 2007; Owston, Wideman, Morbey, & Murphy, 2004; Sugar, Crawley, & Fine, 2004; Wei, Darling-Hammond, Andree, Richardson, & Orphanos, 2009). Many of these workshops are currently implemented in ways that focus on learning skills to use the tool and promote a techno-centric approach of learning how to teach with technology (e.g., many workshops presented at conferences, such as the Texas Computer Education Association and Florida Educational Technology Conference, as well as those offered by Smart Technologies and Apple Training and Certification). How can professional learning contexts, such as short intervention workshops or a series of short professional sessions, be designed to promote content-centric approaches of learning how to teach with technology? There is a lack of information in the literature on how professional learning contexts can be designed to effectively develop "teacher knowledge required for technology integration in pedagogy" (Mishra & Koehler, 2006, p. 95). The purpose of this chapter is to introduce and explain the *Framework of TPACK-in-Practice*, and illustrate the *Framework's* usefulness in designing content-centric technology professional learning contexts for teachers and higher education faculty.

Why TPACK-in-Practice?

Mishra and Koehler (2006) proposed a "conceptually based theoretical framework about the relationship between technology and teaching" (p. 1019). This model presented the following pairs of knowledge intersections in relation to technology: technological content knowledge (TCK); technological pedagogical knowledge (TPK); and the intersection of technology, pedagogy, and content (TPCK), called technological pedagogical content knowledge (TPCK or TPACK) (Fig. 1).

Their model built upon Shulman's (1986, 1987) theory of teacher knowledge, where teacher knowledge encompasses a number of categories of knowledge specific to the act of teaching (e.g., pedagogical content knowledge, knowledge of learners and their characteristics, and knowledge of educational contexts). The knowledge required for successful technology-enhanced teaching (TPACK) is situ-

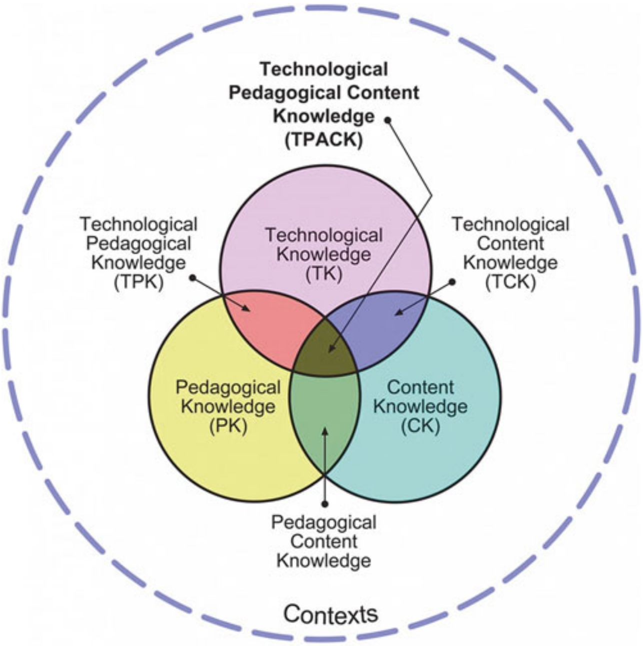


Fig. 1 Technological Pedagogical and Content Knowledge (Mishra & Koehler, 2006)

ated within pedagogical content knowledge (PCK), which relates to "that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (Shulman, 1987, p. 8).

Angeli and Valanides (2005, 2009) also built on Shulman's (1986) theory of teacher knowledge and proposed a model that included three contributing knowledge bases, namely, subject matter knowledge, pedagogical knowledge, and technology (restricted to ICT in this case), and two additional elements, namely, knowledge of students and knowledge of the context within which learning takes place. Angeli and Valanides (2009) particularly highlighted the intersection of the three knowledge bases (referred to as ICT-TPCK) as a distinct knowledge component, and they explicitly stated that "teachers need to be explicitly taught about the interactions among technology, content, pedagogy, and learners" (p. 158).

These models (Angeli & Valanides, 2009; Mishra & Koehler, 2006) of teacher knowledge for teaching with technology (TPACK) are beneficial in that they provide a theoretical foundation for framing research investigating teaching with technology. However, these models do not illuminate what the theoretical constructs might look like in practice. To bridge the gap between the theoretical constructs of TPACK and the actions that demonstrate the TPACK knowledge components in practice, we developed the *Framework of TPACK-in-Practice* (Figg & Jaipal, 2012; Jaipal & Figg, 2010a, 2010b, 2012).

Development of the *Framework of TPACK-in-Practice*

The *Framework of TPACK-in-Practice* emerged from the results of a set of four consecutive studies of teachers' decisions and actions in teaching practice (Figg & Jaipal, 2009, 2012; Jaipal & Figg, 2010a, 2010b, 2012). Participants in these mixed methods studies were preservice teachers and in-service teachers in the field. Data collection methods included classroom observations of technology-enhanced lessons with field notes, pre- and post-individual interviews with preservice and in-service teachers, focus group interviews, questionnaires about technology skills, knowledge and attitudes, and examination of lesson plans/resources and student artifacts for technology-enhanced lessons.

In the first study, a cross-case analysis of four preservice teachers' decisions and actions, made in the context of their teaching practice, led to the development of a *Taxonomy of TK, TCK, and TPK Characteristics*, in which characteristics supporting successful implementation were identified (Jaipal & Figg, 2010b). Student achievement of learning goals through informal observations during the lesson, and the teachers' formal assessment of student artifacts, provided evidence of successful implementation of technology-enhanced lessons. To explore whether the explicit teaching of the characteristics identified in the *Taxonomy of TK, TCK, and TPK Characteristics* would influence the development of TPACK knowledge in preservice teachers, the taxonomy was used to redesign a technology methods course for preservice teachers.

The second study involved administering a survey to participants in four sections of the redesigned technology course to assess preservice teachers' knowledge of the technology components of TPACK. Survey results indicated there was evidence of TPACK knowledge gain by preservice teachers (Figg & Jaipal, 2011).

A third study was conducted in which eight preservice teachers, who had completed the TPACK-based technology methods course, were observed teaching during their practicum. Findings of this study showed that participants were implementing technology more effectively in their lessons and sequencing a larger variety of technology-enhanced activities in one lesson (Jaipal & Figg, 2010a).

To examine whether in-service teachers would benefit from explicit teaching of TPACK knowledge, and specifically the characteristics and actions identified in the *Taxonomy of TK, TCK, and TPK characteristics*, a fourth study was conducted with four in-service teachers. 'Just in time' professional development for integrating blogs in teaching practice was provided by the researchers to build TPACK knowledge (Figg, Jaipal, & Mueller, 2011). Findings of the fourth study also indicated that the explicit teaching of the characteristics of TCK, TPCK, and TPK to experienced teachers was also necessary. Particularly, the TPACK knowledge components of TCK and TPK emerged as important, when supporting in-service teachers in learning to teach content with technology. The explicit teaching of: (1) TCK knowledge about different types of activities and models of teaching that are appropriate for using blogs to enhance student learning, and (2) TPK knowledge about how to scaffold

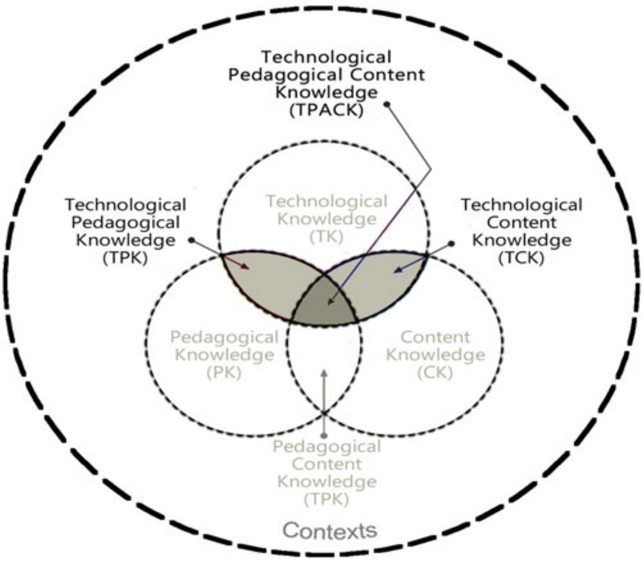


Fig. 2 Three knowledge intersections of TPACK (TPCK, TCK, and TPK) in the *Framework of TPACK-in-Practice* that influence successful technology-enhanced teaching

teaching of technical skills, while teaching content, were essential for successful implementation of technology-enhanced lessons by experienced teachers.

Data from the preceding studies were analyzed to develop the *Framework of TPACK-in-Practice.* A comprehensive cross-case analysis of the 12 preservice and 4 in-service teachers' decisions and actions made in the context of their teaching practice, which led to successful implementation, was performed (Figg & Jaipal, 2009; Jaipal & Figg, 2010a, 2010b). Feedback from technology educators and external reviewers in the field, and survey feedback from preservice teachers was used to inform the development of the framework. The *Framework of TPACK-in-Practice* identifies the characteristics and actions demonstrating TPACK knowledge that teachers use in practice associated with the knowledge intersections, where technology is infused (TPCK, TCK, and TPK). Knowledge of these characteristics and actions are necessary foundations for successful teaching with technology in elementary classrooms. These intersections are illustrated in Fig. 2.

In the *Framework of TPACK-in-Practice*, we highlight TPK, TCK, and the intersection of TPK and TCK, which is TPACK knowledge as denoted in the Mishra and Koehler (2006) model. In our framework, we refer to the intersection of TPK and TCK as TPCK-in-Practice to distinguish the subset of specific actions within the TPACK knowledge domain that we have identified in practice. Hence, Table 1 presents a description of the knowledge components of TPACK-in-Practice.

The *Framework of TPACK-in-Practice* (Fig. 3) illustrates identified practice-based characteristics and actions representing TPCK-in-Practice, TCK-in-Practice,

Table 1 Components of TPACK-in-Practice

TPCK-in-Practice	Knowledge about how to design technology-enhanced instructional experiences for different models of teaching (e.g., Direct Instruction, Problem-based Learning, Inquiry-based Learning) to meet content learning goals
TCK-in-Practice	Knowledge about content-appropriate technologies (knowledge of tools of a discipline and ability to appropriately repurpose tools across disciplines) and teachers' ability to use the tool (personal attitudes, skills, and comfort level with these technologies)
TPK-in-Practice	Knowledge of practical teaching competencies (use e.g., classroom management, differentiated support, and assessment) to plan and implement technology-enhanced lessons

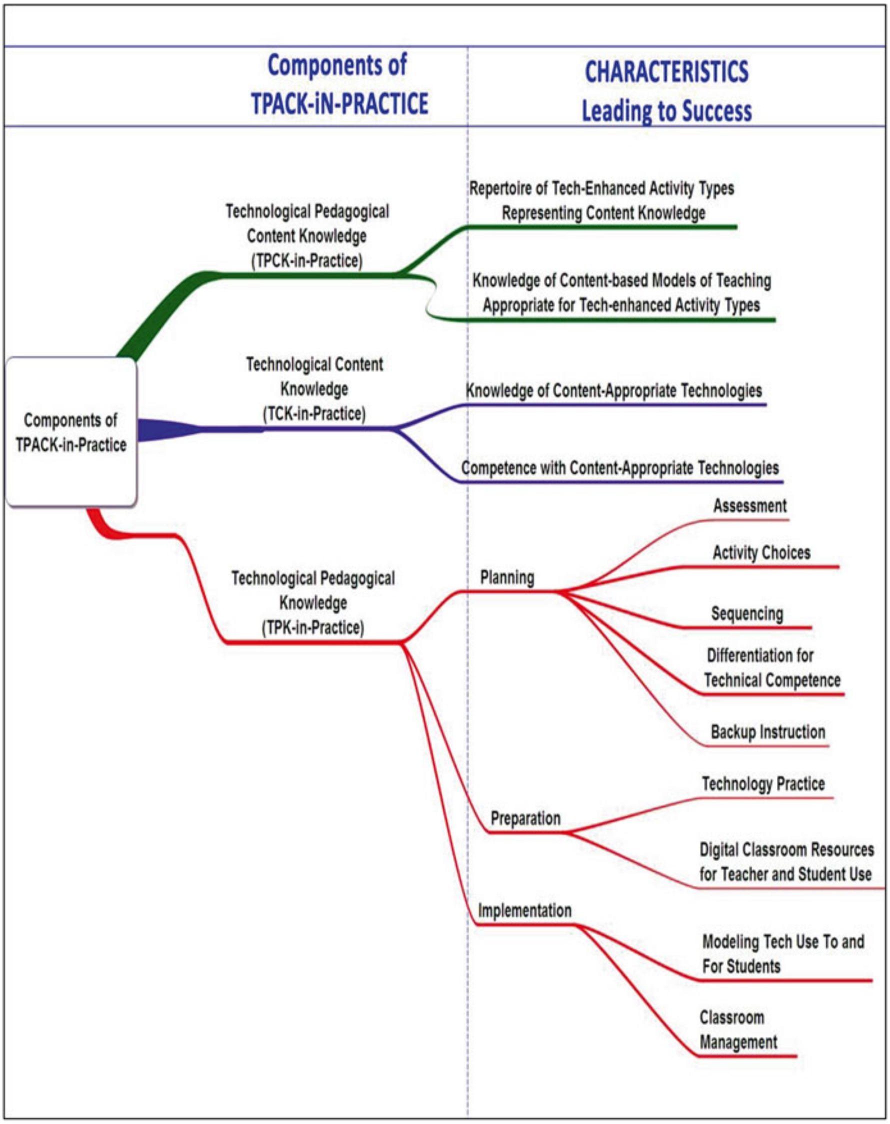


Fig. 3 The Framework of TPACK-in-Practice

and TPK-in-Practice. These specific skills and knowledge can be explicitly taught in a variety of professional learning contexts (i.e., teacher education technology courses, in-service workshops) to develop teacher knowledge of technology-enhanced teaching.

The *Framework of TPACK-in-Practice*

A large body of research (Harris & Hofer, 2009, 2011; Hughes, 2005; McCrory, 2008; Niess, 2005a, 2005b, 2006; Suharwoto & Niess, 2001) presupposes that TPACK is developed within specific subject matter areas, and these findings contribute to understanding and informing technology integration in a specific subject area. However, elementary classroom teachers often teach interdisciplinary lessons that integrate subject matter content; therefore, there is a need to identify characteristics of TPACK that are similar across disciplines. Our *Framework of TPACK-in-Practice* (Fig. 3) highlights general characteristics supporting successful technology-enhanced lessons and is consistent with recent literature (Kereluik, Mishra, & Koehler, 2010) that rethinks conceptualization of content as "trans-disciplinary." Kereluik et al. (2010) explain this "trans-disciplinary" knowledge as including the ability to "creatively move across, synthesize across, two or more disciplines, and be able to use technologies for gathering information, conducting analysis and communicating … ideas effectively" (p. 3895). Hence, descriptions of TPACK characteristics that apply across subject matter disciplines are important as guides for teachers teaching discipline-based or cross-curricular lessons.

TPCK-in-Practice

Mishra and Koehler (2006) explained that "quality teaching requires developing a nuanced understanding of the complex relationships between technology, content and pedagogy, and using this understanding to develop appropriate, context-specific strategies and representations" (p. 1029). Based on Fig. 2, TPCK-in-Practice is knowledge that emerges from the infusion of Technological Knowledge (TK) into PCK. TPCK-in-Practice is conceptualized as knowledge about how to design technology-enhanced instructional experiences for different models of teaching to meet content learning goals. For example, a science teacher has a repertoire of "the most powerful analogies, illustrations, examples, explanations, and demonstrations" (Shulman, 1986, p. 9) and understands how to use them to teach science concepts (PCK). When the teacher teaches these science concepts using technology tools, there is a need to rethink ways to "[represent] *and* [formulate] *the subject that make it comprehensible to others*" (Shulman, 1986, p. 9).

Table 2 Characteristics and actions of TPCK-in-Practice

Characteristics leading to success	Samples of teacher actions in practice
Repertoire of technology-enhanced activity types representing content knowledge	Analyze structure of technology-enhanced activity type
	Select most effective technology-enhanced activity type
Knowledge of content-based models of teaching appropriate for technology-enhanced activity types	Analyze type of knowledge to be learned
	Select appropriate Model of Teaching for technology-enhanced instruction

The two broad characteristics of TPCK-in-Practice that influence teacher decision-making, with samples of teacher actions observed in practice (Figg & Jaipal, 2009; Jaipal & Figg, 2010a, 2010b) are summarized in Table 2.

For both characteristics, the generic processes of analysis and selection emerged as significant actions in teachers' thinking, during planning of technology-enhanced instruction.

Characteristic: Repertoire of Technology-Enhanced Activity Types Representing Content Knowledge

TPCK-in-Practice includes knowledge about a repertoire of technology-enhanced activity types (such as those suggested by Harris & Hofer, 2009) that are appropriate to teach the content. An activity type is the structure, or framework, of an activity that can be adapted for content and grade level (Figg & Burson, 2012). Harris and Hofer (2009) further described an activity type as "what is most essential about the structure of a particular kind of learning action, as it relates to what students do when engaged in that particular learning-related activity" (p. 101). For example, *creating a journal entry* is an activity type. The structure of the activity is to have the students complete a writing entry, post, or reflection, expressing their knowledge about a specified topic or related to a specific purpose. In kindergarten, the activity may take the form of having students complete their 'journal' post by drawing a picture or telling their thoughts to a classroom aide, who writes it down for them. In middle and high school, the activity can be structured, so that journals may be completed by students online through blogs, wikis, or twitter posts. Furthermore, *creating journal entries* is an appropriate activity for a variety of subject areas. For example, we see journals used in math classes for recording decisions about problem-solving, or in science classes for documenting experiential learning.

As teachers think about planning a technology-enhanced lesson, they make decisions about technology-enhanced activity types in relation to its effectiveness to teach and represent the content learning outcome. The thinking process involves: (1) analyzing the structure of technology-enhanced activity types to assess its appropriateness for developing desired content learning outcome, and (2) selecting the most effective technology-enhanced activity type. For example, teachers, who have knowledge of a variety of technology-enhanced activity types appropriate for developing problem-solving skills, such as WebQuests, Web Inquiries, and Spreadsheets, understand that to develop problem-solving skills in a math probability lesson, the most effective technology-enhanced activity type would be a spreadsheet for visual representation of relationships on graphs.

Knowledge of Content-Based Models of Teaching Appropriate for Technology-Enhanced Activity Types

Knowledge of *Models of Teaching* (Joyce, Weil, & Calhoun, 2004) is an important component of teacher knowledge. In technology-enhanced lessons in different content areas, teachers need knowledge about which technologies match content-appropriate *Models of Teaching*. Two specific actions of this characteristic were identified as: (1) analyzing the content learning outcome for types of knowledge to be learned (i.e., factual, conceptual, metacognitive, or procedural), and (2) selecting the *Model of Teaching* appropriate for technology-enhanced activity types leading to the desired lesson learning outcome.

For example, in a science lesson, where the content learning outcome is for students to gain understanding of factors affecting particle motion, the teacher makes a decision (analysis) about which technology-enhanced representations, or activity types, would be appropriate to facilitate learning of conceptual knowledge of particle motion. In our example, an online particle motion simulation or a static particle motion animation could be selected. Then, the technology-enhanced lesson needs to be structured using an appropriate *Model of Teaching* that is consistent with specific learning outcomes. If the learning outcome is for learners to visually experience the effect of variable manipulation on particle motion, then the Scientific Inquiry *Model of Teaching* is appropriate for structuring a lesson using an online particle motion simulation, where individual students engage in the simulation in a computer laboratory. On the other hand, if the learning outcome is for students to merely gain an understanding of how particles move, then viewing a static animation in a lesson structure based on the Direct Instruction *Model of Teaching* would be appropriate.

TCK-in-Practice

TCK is conceptualized as knowledge about technologies appropriate for content (also referred to as content-appropriate technologies) and includes teachers' personal attitudes, skill, and comfort level with these technologies (Jaipal & Figg, 2010b). Additionally, within the TPACK literature, content knowledge is reconceptualized as interdisciplinary, characterized by skills of "being able to creatively move across, synthesize across, two or more disciplines, and be able to use technologies for gathering information, conducting analysis and communicating ideas effectively"

Table 3 Characteristics and actions of TCK-in-Practice

Characteristics leading to success	Samples of teacher actions in practice
Knowledge of content-appropriate technologies (see section called knowledge of content-appropriate technologies)	Matching discipline-specific tools to content
	Repurposing tools of other disciplines to match content
Competence with content-appropriate technologies (see section called competence with content-appropriate technologies)	Identifying technical skills needed for discipline-based tool use
	Identifying personal skill levels of tool use

(Kereluik et al., 2010, p. 3895). Our definition of TCK-in-Practice incorporates this interdisciplinary, or cross-disciplinary, view of CK and includes the ability to transfer skills and knowledge learned in one discipline to other disciplines and contexts. Hence, TCK-in-Practice is teacher knowledge about how to use content-appropriate technologies, or cross-disciplinary technologies, in instruction, and their personal competence to use these technologies. We summarize the characteristics and actions from teachers' practice that represent TCK-in-Practice in Table 3.

Knowledge of Content-Appropriate Technologies

The characteristic includes the following actions.

Matching discipline-specific tools to the content. There are different technologies that facilitate the achievement of learning goals more effectively in different disciplines. For example, understanding how to use calculators is a knowledge requirement for conducting mathematical computations. Successful technology-enhanced instruction requires that teachers be familiar with specific tools that are appropriate for teaching content in different disciplines.

Repurposing tools of other disciplines to match content. "Most technologies are not designed for educational purposes" (Kereluik et al., 2010, p. 3896). Therefore, teachers need to be able to repurpose tools, "where a tool designed for one purpose is "re-seen" in a new pedagogical light" (p. 3896). Such an envisioning involves knowing how a blog could be used in instruction in different disciplines. This knowledge also includes understanding how to repurpose tools from one discipline to another, such as using a calculator in geography to do map calculations.

Competence with Content-Appropriate Technologies

The characteristic includes the following actions.

Identifying technical skills needed for discipline-based tool use. Operational procedures for using technology tools range from simple to complex. To be able to recognize the different skill levels for content-specific tool use is an essential characteristic of TCK-in-Practice. Teachers should be able to identify which skills are basic and should be acquired first, which skills are more complex, and which skills are too difficult to be included in initial, or secondary, skill-learning situations. For example, math teachers introduce basic calculation skills in simple math problems before proceeding to using calculators for exponent or algebraic calculations.

Identifying personal skill levels of tool use. As a part of TCK-in-Practice, teachers develop a general awareness of the limitations of their personal technical skill and comfort level with content-appropriate tools. This awareness is necessary, so that teachers can select technology tools, that they will be able to use competently in classroom instruction.

TPK-in-Practice

TPK is envisaged as the knowledge emerging from the infusion of Technological Knowledge (TK) with Pedagogical Knowledge (PK). Pedagogical Knowledge (PK) is described by Shulman (1987) as "those broad principles and strategies of classroom management and organization that appear to transcend subject matter" (p. 8). Mishra and Koehler (2006) describe PK as:

> A generic form of knowledge that is involved in all issues of student learning, classroom management, lesson plan development and implementation, and student evaluation. It includes knowledge about techniques or methods to be used in the classroom; the nature of the target audience; and strategies for evaluating student understanding. (pp. 1026–1027)

We view TPK-in-Practice as including these practical teaching competencies during the planning, preparation, and implementation phases of instruction (Jaipal & Figg, 2010a). The following sections explain, and Tables 4, 5, and 6 summarize, the characteristics and actions from teachers' practice that represent TPK-in-Practice knowledge for these three phases of instruction. Although, we present these categories and actions in a specific order, our findings indicate that the processes of planning, preparation, and implementation are dynamic, nonlinear, and complex (Jaipal & Figg, 2010b).

TPK-in-Practice: Planning Characteristics

In the planning category of TPK-in-Practice, we identified five characteristics of planning (Figg & Jaipal, 2009; Jaipal & Figg, 2010a, 2010b) that emerge as necessary for designing successful technology-enhanced lessons. These characteristics are: assessment, activity choices, sequencing, differentiation for abilities and skills, and backup instruction (See Table 4).

Table 4 Characteristics and actions of TPK-in-Practice: Planning

Characteristics leading to success	Samples of teacher actions in practice
Assessment	Match assessments to technology-enhanced learning activities
	Create assessment instruments using technology
	Use technology to conduct assessments
Activity choices	Select activities based on subject matter learning outcomes/goals
	Incorporate a variety of technology-based activities
	Refine activities through collaborative review
Sequencing	Build technology and content skills within lesson and unit
	Develop technical skills in increments through content activities
Differentiation for technical competence	Introduce few technical skills in a lesson
	Chunk technical skills into simple procedures
	Adapt lesson or online activities for students
	Create specific learning objects for students
	Use of technology-enhanced activities with multiple modes
Backup instruction	Plan alternate lesson activities
	Plan for alternate technologies

Table 5 Characteristics and actions of TPK-in-Practice: Preparation

Characteristics leading to success	Samples of teacher actions in practice
Technology practice	Practice with technology tools in instructional settings
	Obtain peer feedback
Digital classroom Resources for teacher and student use	Collect online resources in linklist or Diigo site

Table 6 Characteristics and actions of TPK-in-Practice: Implementation

Characteristics leading to success	Samples of teacher actions in practice
Modeling technology Use To and For Students	Model best practices for technology tool use
	Model generic functions across applications
	Use teacher-created exemplars
	Have students model technical skills
Classroom management	Use grouping techniques to support technical skill and content development
	Use appropriate demonstration techniques in technology-enhanced lessons
	Use techniques for engaging students with technology during lessons

For each of these characteristics, samples of teacher actions and how they are enacted in practice are described in the following paragraphs.

Assessment Knowledge of how to plan assessment of technology-enhanced lessons includes actions, such as:

- *Match assessments to technology-enhanced learning activities*: This involves having the knowledge to select an assessment instrument that appropriately assesses learning goals of the technology-enhanced activity (Zhou, Varnhagen, Sears, Kasprzak, & Shervey, 2011). For example, a checklist could be selected as an appropriate assessment for documenting student completion of a technology-enhanced multimedia product, assigned as a culminating activity in a lesson or unit; the quality of that end product (which includes technical aspects, such as media elements as well as the content) would be assessed using a rubric (Jonassen, Howland, Marra, & Crismond, 2008).
- *Create assessment instruments using technology*: Knowledge about how to create various assessment instruments using technology tools is embedded within planning actions. An example of the creation action would be to use an online tool, such as *Google Forms* or *Survey Monkey,* to create a survey or quiz to assess student learning of content.
- *Use technology to conduct assessments*: An example of using technology to conduct an assessment is selecting Classroom Response Clickers to conduct a multiple choice assessment.

Activity Choices Knowledge of how to select technology-enhanced activities includes actions, such as:

- *Select activities based on subject matter learning outcomes/goals*: This involves having the knowledge to select the learning activity based on content learning outcomes or goals, instead of technical skill outcomes or goals. Planning technology-enhanced lessons should begin with the curriculum standards/documents and learning outcomes of subject matter content areas in mind, before selecting technology-enhanced activities. For example, a teacher is teaching a lesson in science, where students are introduced to the human skeletal system. Once the content learning goals are established, the teacher selects a technology-enhanced core learning activity—having students research questions about the skeletal system, using a blog linked to a site called 'Ask the Scientist.'
- *Incorporate a variety of technology activities*: Incorporating a variety of technology-enhanced activities within the lesson involves using several technology-enhanced activities within a single lesson in order to meet the learning goals. For example, introducing the content with a Jeopardy Game (PowerPoint), followed by a core learning activity that engages students working in pairs to design a concept map of the content being taught, and concluding with students contributing to a Google Drive page to collaboratively report what they learned. Teachers need to develop a repertoire of appropriate technology-enhanced activity types (Hofer & Harris, 2010) to use during planning.

- *Refine activities through collaborative review*: Our research showed that collaborative planning with associate teachers, or peers, provided opportunities for reflection, review, and refinement of lesson plans. Inclusion of the review and refinement process with a peer, or associate teacher, during planning improved technology-enhanced implementation of lessons.

Sequencing Knowledge of how to sequence technology-enhanced activities includes actions, such as:

- *Build technology and content skills within lesson and unit.* When planning a lesson, teachers should be able to sequence activities within a lesson to build technical skills and content knowledge. Similarly, lessons in a unit should be designed, so that technical skills are scaffolded. For example, in a Language Arts unit on forms of media, a comic strip is to be discussed as a form of media that is produced for specific audiences. *ComicLife* could be used to create comic strips over a series of lessons as one of the forms. To be successful in creating the final product, a Manga comic strip, students would be taught both the necessary language and technical skills in the series of lessons.
- *Develop technical skills in increments through content activities*: Rather than teaching technical skills in isolation, the focus of a technology-enhanced lesson should be on learning the content. However, technical skills are necessary to facilitate effective use of the technology to learn the content in these lessons. An effective way to develop technical skills in content-based lessons is to teach technical skills in increments, from simple to complex, through a series of content tasks. For example, in the Language Arts unit on media literacy, in a first lesson, students would learn how to complete a one-frame comic to illustrate one idea or thought, where simple features of the tool (e.g., Comic Life) are introduced. In the next lesson, the content task could be creating a comic with a storyline that involves more than one idea or thought. As part of this second task, students would learn advanced or additional features of the tool. A final task could be creating a short Manga comic strip with several frames and a storyline, using the technical skills already introduced or with a few additional technical skills.

Differentiation for Technical Competence Knowledge of the following actions supports differentiated instruction of technical competence in a classroom.

- *Introduce few technical skills at a time*. Technical skills in a lesson could be thought of as a form of 'just in time' training. Only the relevant skills needed to complete the learning task are taught. For example, in creating a slideshow, it is more effective to introduce one skill, such as *Slide Design*, rather than teach all the skills needed to build a slideshow (Jaipal & Figg, 2010b). Such an approach scaffolds the learning for students at different stages of technical competence and minimizes the number of new technical skills introduced, so that the focus remains on learning the content of the lesson and not on learning the tool.
- *Chunk technical skills into simple procedures.* For example, a procedure for *Slide Design* could be developed to aid learning of technical skills in the creation

of a slideshow. There are basic technical skills related to designing a slide. These skills include: creating a slide, adding and formatting text on the slide, adding and manipulating images on the slide, and adding a background to the slide. Because these skills are related, they could be chunked together and taught in the same content-based lesson. Techniques used to support this chunking process include (a) using a mnemonic to assist students in remembering the skill set associated with designing a slide, and (b) providing simple, brief tutorials (print or electronic) that illustrate the steps of the procedure.

- *Adapt lesson/online activities for students*. Resources from any source, including the Internet, must be adapted to support the diverse learning needs of students. For example, many online resources are not appropriate for specific grade levels, but include valuable information. Teachers would rewrite the information to suit reading levels and align with curriculum.
- *Create specific learning objects for students*. In many cases, learning objects must be created for specific learning needs, and how to create these using technology tools is important. Examples of learning objects that can be created include virtual field trips to specific sites, creating Graphic novels to use in a group discussion with students, creating a timeline to depict a chronological concept, and creating a Glog that represents information needed for the lesson.
- *Use tech activities with multiple modes*. Consistent with effective differentiation practices, technology-enhanced lessons provide an additional opportunity to differentiate instruction by affording opportunities to use multiple modes. For example, in a lesson on the Canadian Railroad, a Graphic Novel could be used to introduce the topic to students, in which images that display art examples of the railway could be displayed to guide discussion. As well, the "Canadian Railroad Trilogy," a music video by Gordon Lightfoot, which addressed the issues surrounding the Canadian Pacific Railway, could be shown and discussed. A video documentary depicting real and reenacted footage of the actual construction process of the railway could conclude the lesson.

Backup Instruction Planning for all technology-enhanced lessons should include alternate lesson activities and technologies should there be technical difficulties with the technology being integrated into the lesson.

- *Plan alternate lesson activities*. Alternate lesson activities that do not include technology should be selected prior to a technology-enhanced lesson, so in the event that all technology fails, backup activities could be substituted quickly, so class time is not wasted.
- *Plan for alternate technologies*. Often, selected technologies to support lesson activities may not be available during lesson time. For example, an online tool, such as Webspiration, is selected for the lesson and at the time of instruction, the tool is not available. The teacher should be aware of alternate technologies, such as Inspiration and Smart Ideas, that provide the same type of function.

TPK-in-Practice: Preparation Characteristics

In the preparation category of TPK-in-Practice, we identified two characteristics (Jaipal & Figg, 2010a, 2010b; Figg & Jaipal, 2009) that contribute to successful implementation of technology-enhanced lessons. These preparation characteristics of TPK-in-Practice are: technology practice and digital classroom resources for teacher and student, as summarized in Table 5.

For each of these characteristics, samples of teacher actions, and how they are enacted in practice, are described in the following paragraphs.

Technology Practice The following actions were identified as important features of practicing with the technology in order to prepare for implementation of a technology-enhanced lesson:

- *Practice with technology tools in an instructional setting*. It is not sufficient to practice technical skills necessary for teaching technology-enhanced lessons on a personal computer or other computers not in the instructional setting. Practicing in the instructional setting ensures that the teacher becomes aware of constraints and affordances (both physical and technical) that may be encountered during instruction. Some examples include teacher awareness that accessing programs on school servers may be different for teachers and students, availability of equipment, such as headphones for use and setup, and availability of software on school computers.
- *Obtain peer feedback*. While this may not be practical for all teachers and all technology-enhanced lesson implementation, getting feedback on lesson ideas and practicing in front of a peer in the instructional setting provide opportunities for refinement of technology teaching strategies.

Digital Classroom Resources for Teacher and Student Use An important part of preparation is developing the digital resources to be used in a technology-enhanced lesson by teachers for instructional purposes and students for learning purposes. For example, building a digital resource repository, in the form of a DIIGO bookmark site or linklist, provides easy access to resources and minimizes class time spent searching for images, sounds, or video clips during the lesson.

TPK-in-Practice: Implementation Characteristics

In the implementation category of TPK-in-Practice, we identified two characteristics of teacher actions (Figg & Jaipal, 2009; Jaipal & Figg, 2010a, 2010b) that supported successful implementation of technology-enhanced lessons. These implementation characteristics of TPK-in-Practice are: modeling technology use to and for students, and classroom management, as summarized in Table 6.

For each of these characteristics, samples of teacher actions, and how they are enacted in practice, are described in the following paragraphs.

Modeling Technology Use to and for Students This characteristic involves several modeling actions that teachers can incorporate into their instructional practices.

- *Model best practices for technology tool use*. While teaching the tools within a content-based lesson, teachers model correct use of tools. For example, when designing slides in a slideshow, the teacher models how to select an appropriate color and size for the font, so that it contrasts with the background color and can be seen at a distance.
- *Model generic functions across applications*. Knowledge of some of the generic features that are found in multiple applications can facilitate use of technology. For example, the teacher introduces a new tool by showing functions that are similar to other more familiar tools, such as, introducing the Symbol Palette in Inspiration and comparing that to the Gallery Toolbar in Smart Ideas.
- *Use teacher-created exemplars*. Teachers provide examples of completed technology-enhanced products similar to those students will be expected to create. For example, the teacher provides students with an example of a completed flowchart, so that students can visualize the final product they create.
- *Have students model technical skills*. Teacher knowledge about how to engage students in modeling their own technical skills was found to be important. Our research indicated that teachers used various techniques, including asking student helpers to set up the technology or assist throughout the lesson, to engage students with the technology used in the lesson. For example, assigning student helpers to calibrate the SMART Board prior to the lesson, or use the SMART Board throughout the lesson to demonstrate how to activate commands, was an effective strategy for students to model technical skills.

Classroom Management Teaching with technology requires that teachers adapt knowledge of general pedagogical strategies (Shulman, 1987) for technology-enhanced lesson implementation. These management strategies may vary from regular classroom management strategies. Findings from our research (Figg & Jaipal, 2009; Jaipal & Figg, 2010a, 2010b) point to knowledge of the following, as classroom management techniques that can be adopted in technology-enhanced lessons:

- *Use grouping techniques to support technical skill and content development.* The current content-centric approach to technology-enhanced teaching promotes learning of technical skills and content skills concurrently. Hence, knowledge about how to group students, particularly designating group members to support technical skill and academic content development, is needed for successful group work in technology-enhanced lessons. For example, the teacher assigns students to groups, so that each group has members who are technically competent with the tool being used and members who can support content learning.
- *Use appropriate demonstration techniques in technology-enhanced lessons*. While teacher demonstrations in the classroom are common pedagogical practice, effective demonstrating techniques in technology-enhanced lessons require knowledge about how to conduct demonstrations using a technology tool in ways that minimize classroom management issues. Specific techniques can

include using a computer lab 'monitoring' software, such as NetSupport, where the teacher is able to control student monitors, or using an LCD Projector or SMART Board to conduct a whole class demonstration in the classroom prior to individual computer use.

- *Use techniques for engaging students with technology during lessons*. Jonassen et al. (2008) stated that "Meaningful learning requires learners who are actively engaged by a meaningful task in which they manipulate objects and parameters of the environment they are working in and observe the results of their manipulations" (p. 3). In a technology-enhanced lesson, teachers need to provide students with opportunities to interact with and use the technology during the lesson to construct knowledge. An example of an activity that engages students with the technology is using a SMART Board, where students collectively create a Word Web that highlights vocabulary to be used in a content-based task.

The *Framework of TPACK-in-Practice* (See complete *Framework* in Appendix) identifies teacher characteristics and actions that lead to successful technology-enhanced instruction and can be applied across grade levels for both novice and experienced teachers. It should be noted the characteristics of TPCK-in-Practice and TCK-in-Practice are not reflected in concrete teacher actions, as they illustrate teacher thinking processes that occur as the teacher plans and implements technology-enhanced instruction. We now illustrate how this framework can be applied to design and/or be incorporated into technology-enhanced professional learning contexts.

Using TPACK-in-Practice to Design Technology Professional Learning Contexts

The *Framework of TPACK-in-Practice* provides a foundation for designing professional learning contexts, such as a workshop that promotes the shift from techno-centric pedagogy (acquisition of skills approach) to a content-centric pedagogy (develop understandings about teaching content with technology). It provides actions that can be explicitly incorporated into the professional context to develop TPACK knowledge.

The pilot implementation of a preservice technology course (Figg et al., 2011), where characteristics from the *TPACK-in-Practice Framework* were implemented, revealed four stages of professional learning that contributed to teacher development of TPACK knowledge. These four stages (referred to as the TPACK based Professional Learning Design Model-TPLDM) are presented as a guide for designing professional learning contexts for teacher development of TPACK knowledge and are sequenced as they would be incorporated in the professional learning context.

(a) *Modeling a technology-enhanced activity type (learning WITH the tool).* The type of modeling we propose involves having each participant act as a learner in a technology-enhanced activity. Workshop participants experience learning with a specific technology to meet content learning outcomes; this also provides a context for participating in follow-up activities in which they will be learning technical skills needed to teach similar content with the tool. This particular approach provides a learning context in which the technology is seamlessly integrated with the content. Knowledge of the technical skill is secondary at this point.

For example, in a workshop designed to teach educators how to teach with wikis, the workshop would begin with participants completing a wiki-based virtual field trip in a particular content area. This opening activity incorporates the use of the specific tool, the wiki, which is the technical focus of the workshop. The modeled activity emphasizes content learning goals as the focus of the workshop, and TCK-in-Practice knowledge is highlighted through the modeling of the use of technology that is appropriate for meeting content learning outcomes. Participants are also given an opportunity to see how the tool is used in an authentic classroom learning activity for students. Participants also see examples of how to match models of teaching content to technology (using wikis to record findings in an inquiry-based lesson), experiencing knowledge of TPCK-in-Practice.

(b) *Integrating 'pedagogical dialog' in a modeled lesson.* A discussion period in which participants build their knowledge about how the tool is used in practice is critical to promote growth of knowledge of how to teach with technology. The inclusion of a dialog with other participants about the pedagogy, content, and technology being modeled is essential (Angeli, 2005). The *Framework of TPACK-in-Practice* highlights teacher actions that a discussion should elicit. For example, in-service teachers may require more in-depth discussion about implementation strategies and techniques (TPK-in-Practice), whereas, for novice teachers, the connections between the modeled activity and the decisions teachers make in the planning and implementing of technology-enhanced lesson should include aspects of TPK-in-Practice, TCK-in-Practice, and TPCK-in-Practice. Without this conversation, teachers are merely seeing or participating in the modeled technology-enhanced activity and not making connections between pedagogy, content, and technology.

(c) *Developing activity-specific technical skills (TK in context) through short tool demonstrations*. In the example of the Virtual Field Trip workshop, the facilitator would instruct participants in the technical skills required to develop their own Virtual Field Trip (e.g., setting up a wiki or blog with links) in this third stage of the workshop. The *Framework* of *TPACK-in-Practice* indicates that the tool demonstration activity should include acquisition of a few technical skills (just in time training) needed to use the tool in instruction, as well as provide examples of how other teachers are using the tool.

Research suggests that 'just in time' training (short, frequent training sessions) sustained over time is most effective for the development of teacher knowledge and competence to integrate technology into their instruction (Carlson, 2002; Gavrin, Porter, Desimone, Birman, & Yoon, 2004; Grunwald & Associates, 2010; McKenzie, 2001; Rosen, 2005); hence, this portion of the workshop should incorporate minimal skill instruction.

(d) *Applying TPACK-in-Practice to design an independent task*. Selecting a design task that parallels the preparation that teachers do before technology-enhanced lesson implementation, allows participants to practice their new-found knowledge in an authentic context, and also reinforces and consolidates TPACK knowledge. The same task may be provided for each participant, or participants are asked to design their own task using the tools, depending upon the learning needs and comfort level of the participants. For example, participants in the Virtual Field Trip workshop can use the TPACK knowledge learned in the workshop to design a Virtual Field Trip to be implemented with students in their own classrooms.

Discussion

The *Framework of TPACK-in-Practice* is a model that is derived from and situated in the practice of teaching. It is a model in progress, and we expect that other characteristics and actions will emerge in different teaching contexts. However, the *Framework* is useful to technology teacher educators, as it presents practice-based guidance for the design of technology professional learning contexts. As described in this chapter, the characteristics and actions presented in the framework were used to redesign a technology course for preservice teachers and to provide professional development to in-service teachers; four distinct stages of how to optimize teachers' professional learning experiences emerged. These four TPACK-in-Practice-based design stages, identified in the preceding section, develop the knowledge explicitly highlighted in the *Framework*; this knowledge can be translated into teacher actions in practice. Therefore, the *Framework of TPACK-in-Practice* and the TPACK based Professional Learning Design Model promote the shift from the traditional, technical skill emphasis, to a content-centric approach, where teachers are taught how to teach with the tool to meet content learning goals rather than how to use the tool (Harris, 2005; Harris et al., 2007, 2009; Niess, 2005b).

The stages of the Professional Learning Design Model tap on the situated knowledge of participants gained from practical experiences with teaching; beliefs about teaching and learning; and influences of curriculum content, pedagogy, classroom, school, and community contexts (Brown, Collins, & Duguid, 1989; Moallem, 1998; Shulman, 1987). The literature suggests that situated learning enhances the development of technology-enhanced decision-making and instructional design (Angeli & Valanides, 2009; Figg & Burson, 2011; Jaipal & Figg, 2010b). Workshops and other professional learning contexts designed to promote TPACK-in-Practice characteristics provide practical experiences, or situated learning opportunities, for learning how to teach with technology. For example, teachers begin a TPACK based workshop by participating in an authentic learning activity that models the use of the technology in a classroom situation, and then engage in pedagogical dialog about TPK-in-Practice, TCK-in-Practice, and TPCK-in-Practice; hence, they draw on situated knowledge about teaching to inform their learning. Modeling the characteristics of TPACK in teacher technology professional learning contexts is essential for teachers learning how to teach with technology (Carlson & Gooden, 1999; Cooper & Bull, 1997; Kinslow, Newcombe, & Goss, 2002; Teclehaimanot & Lamb, 2005).

The pedagogical dialog stage brings to the forefront relationships among the pedagogy, the content, and the technology being modeled. This dialog, following a modeled activity, serves to build cognitive thinking processes around designing and implementing technology-enhanced teaching. Angeli (2005) explained that modeling alone was not sufficient; it is necessary to explicitly explain:

> the pedagogical reasoning that guided the design of instruction with technology, so that student teachers can experience these new visions of learning with technology and examine how the teacher's role changes, how the subject matter gets transformed, and how the learning process is enhanced. (p. 395)

Using pedagogic discourse, to explicitly illuminate the actions teachers use to successfully teach with technology, allowed novice teachers, or those new to teaching with technology, to engage in this pedagogical reasoning (Figg & Jaipal, 2009). Study participants who engaged in these processes reported increased confidence in teaching technology-enhanced lessons, development of positive attitudes toward teaching with technology, and acknowledged that, because they were more aware of the planning and implementation needs for teaching with technology, they could design and implement technology-enhanced lessons (Figg & Jaipal, 2009; Friel et al., 2009; Trachan & Moorman, 2001).

This Professional Learning Design Model encourages the development of TPCK-in-Practice by providing teachers with opportunities to build up a repertoire of activity types (Harris & Hofer, 2009) that are adaptable for disciplinary and cross-disciplinary purposes and to develop *Models of Teaching* (Joyce et al., 2004) that match their philosophies of teaching and their comfort level. Harris et al. (2010) suggested that identifying learning activity types is a "*logical approach to helping teachers to better integrate technologies in their teaching* [by] *directly link*[ing] *students' content-related learning needs with particular content-based learning activities and related educational technologies that will best support the activities' successful implementation*" (p. 575). Workshops that emphasize how to use activity types as "mental design tools that help us to think concretely about students' learning processes" (Harris, 2000–2001, p. 53), within various instructional structures, promote foundational knowledge building about the design process of technology-enhanced teaching. As well, incorporating "simple, practical activities that required participants to brainstorm ways these techniques would apply to specific teaching situations" (Teclehaimanot & Lamb, 2005, section 8, para 6) promotes transfer of knowledge about technology-enhanced teaching to the different contexts and content areas.

Finally, the TPACK based Professional Learning Design Model (TPLDM) incorporates characteristics of TPK-in-Practice, which are particularly salient to successful implementation of technology-enhanced lessons for not only preservice teachers, but also in-service teachers (Figg et al., 2011). For example, giving participants time to practice new technical skills and apply "*their* [teaching] ideas to technology-rich instructional situations" (Teclehaimanot & Lamb, 2005, section 7, para 3) promotes the development of TPK-in-Practice. Research related to providing workshop participants with time to practice indicates that as much as 50 % of the workshop time should be devoted to hands-on activities (Chamberlin & Scot, 2002). Professional workshops based on the Framework of TPACK-in-Practice provide much of the time for exploring tools in an instructional context (as a learner in a learning situation) as well as providing time for personal skill development.

Conclusion

The notion that technical competence is not sufficient to develop teaching competence with technology is widely agreed upon in the field (Angeli & Valanides, 2009; Figg & Burson, 2011; Fisher et al., 1996; Harris, 2005; Harris et al., 2007, 2009; McKenzie, 2001; Jaipal & Figg, 2010a, 2010b; Means & Olson, 1997; Roblyer et al., 1997). As McKenzie (2001) succinctly stated:

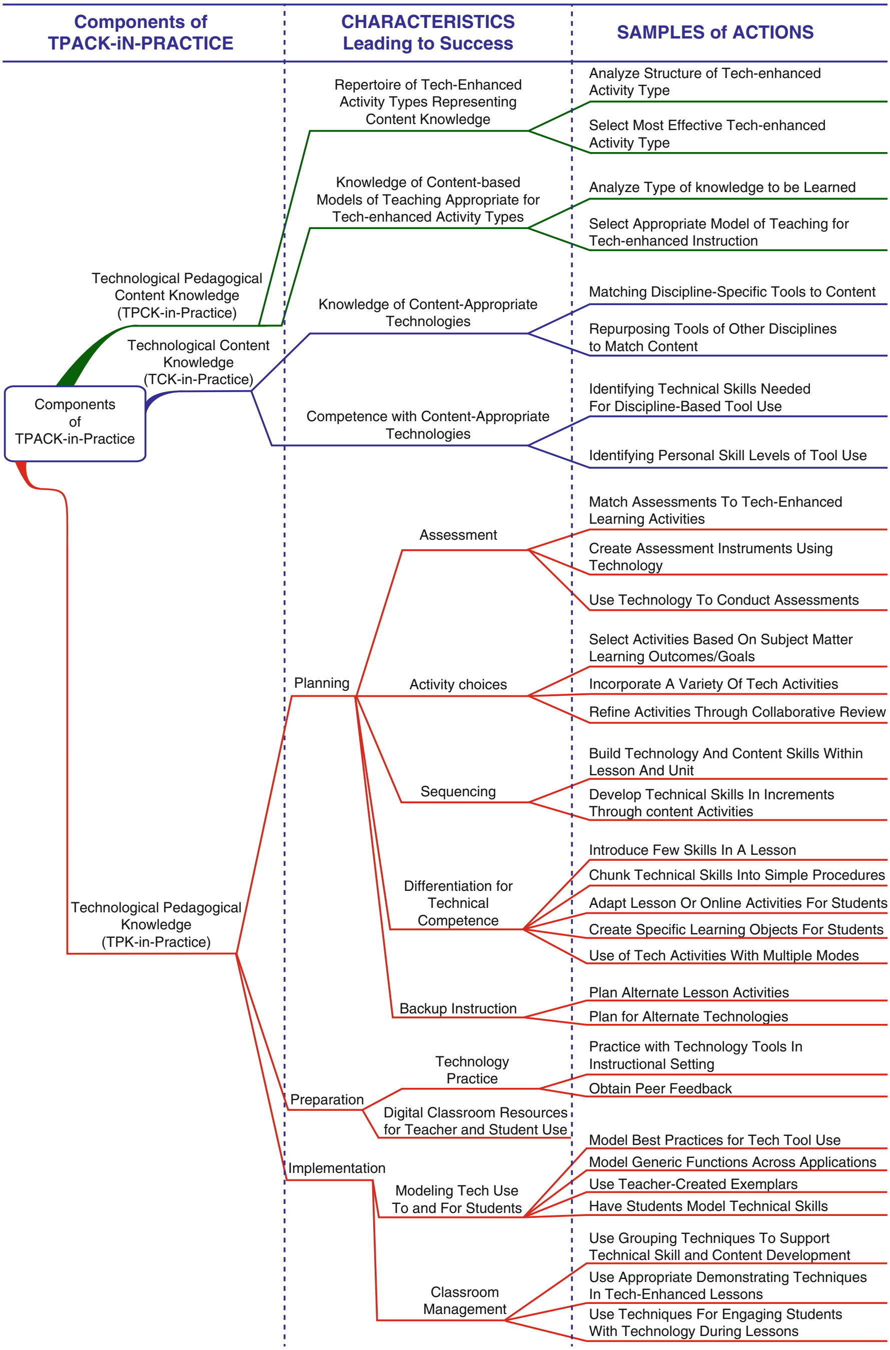
> [Teacher professional development] *should be about using new tools to help students master the key concepts and skills embedded in the science, social studies, art and other curriculum standards. It is not so much about powerpointing, spreadsheeting or word processing.* (section 1, para 9)

Hence, for technology teacher educators, teaching technical skills in professional learning contexts is not sufficient to develop teaching competence with technology; the focus should instead be on building the knowledge that becomes teacher actions in practice. A significant contribution of *The Framework of TPACK-in-Practice* is that it identifies teacher actions that characterize teacher knowledge essential for successful technology-enhanced teaching, specifically the knowledge components of TCK-in-practice, TPK-in-practice, and TPCK-in-practice.

Overall, the *Framework of TPACK-in-Practice* emphasizes the notion that technology is an integral part of teaching and learning that occurs in twenty-first century classrooms. Teacher knowledge is never stable, but always changing based on the technologies of the discipline; the technology's influence on learners; and when, where, and how learners choose to learn. Therefore, designing professional learning contexts grounded in the *Framework of TPACK-in-Practice,* which promotes teaching with technology as a process of developing knowledge that becomes teacher actions in practice (TPACK-in-Practice), supports the development of content-centric pedagogies for teaching with technology.

Appendix

Framework of TPACK-in-Practice (with characteristics and action examples) (Retrieved from http://unpackingtpack.wikispaces.com/Taxonomy)


Components of
TPACK-iN-PRACTICE
CHARACTERISTICS
Leading to Success
SAMPLES of ACTIONS
Components
of
TPACK-in-Practice
Technological Pedagogical
Content Knowledge
(TPCK-in-Practice)
Repertoire of Tech-Enhanced
Activity Types Representing
Content Knowledge
Analyze Structure of Tech-enhanced
Activity Type
Select Most Effective Tech-enhanced
Activity Type
Knowledge of Content-based
Models of Teaching Appropriate for
Tech-enhanced Activity Types
Analyze Type of knowledge to be Learned
Select Appropriate Model of Teaching for
Tech-enhanced Instruction
Technological Content
Knowledge
(TCK-in-Practice)
Knowledge of Content-Appropriate
Technologies
Matching Discipline-Specific Tools to Content
Repurposing Tools of Other Disciplines
to Match Content
Competence with Content-Appropriate
Technologies
Identifying Technical Skills Needed
For Discipline-Based Tool Use
Identifying Personal Skill Levels of Tool Use
Technological Pedagogical
Knowledge
(TPK-in-Practice)
Planning
Assessment
Match Assessments To Tech-Enhanced
Learning Activities
Create Assessment Instruments Using
Technology
Use Technology To Conduct Assessments
Activity choices
Select Activities Based On Subject Matter
Learning Outcomes/Goals
Incorporate A Variety Of Tech Activities
Refine Activities Through Collaborative Review
Sequencing
Build Technology And Content Skills Within
Lesson And Unit
Develop Technical Skills In Increments
Through content Activities
Differentiation for
Technical
Competence
Introduce Few Skills In A Lesson
Chunk Technical Skills Into Simple Procedures
Adapt Lesson Or Online Activities For Students
Create Specific Learning Objects For Students
Use of Tech Activities With Multiple Modes
Backup Instruction
Plan Alternate Lesson Activities
Plan for Alternate Technologies
Preparation
Technology
Practice
Practice with Technology Tools In
Instructional Setting
Obtain Peer Feedback
Digital Classroom Resources
for Teacher and Student Use
Implementation
Modeling Tech Use
To and For Students
Model Best Practices for Tech Tool Use
Model Generic Functions Across Applications
Use Teacher-Created Exemplars
Have Students Model Technical Skills
Classroom
Management
Use Grouping Techniques To Support
Technical Skill and Content Development
Use Appropriate Demonstrating Techniques
In Tech-Enhanced Lessons
Use Techniques For Engaging Students
With Technology During Lessons

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Between the Notion and the Act: Veteran Teachers' TPACK and Practice in 1:1 Settings

Lisa G. Hervey

Introduction

The availability of educational technology has prompted recent scholarly discourse about how Shulman's (1986) well-established construct of pedagogical content knowledge (PCK) can be augmented to help describe the type of knowledge teachers need to effectively enhance student learning with technology. Building on the intent of Shulman's work, Mishra and Koehler (2006), among other researchers (e.g., Angeli & Valanides, 2005, 2009; Niess, 2008), developed a twenty-first century transformation of the PCK framework. In their framework, as shown in Fig. 1, adding teachers' technology knowledge to teachers' existing PCK created three new constructs: (a) technological content knowledge (TCK), (b) technological pedagogical knowledge (TPK), and (c) technological pedagogical content knowledge (TPACK).

Shulman (1986) defined PCK as "that amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (p. 8). According to Shulman (1986), teachers' enactment of their PCK during instruction is as follows:

> It 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)

Teachers need to master two types of content knowledge: (a) deep knowledge of the subject itself, and (b) knowledge of appropriate curricular scope and sequence. Teachers' pedagogical knowledge is concerned with choosing the most useful forms of representing and communicating content, combined with their knowledge

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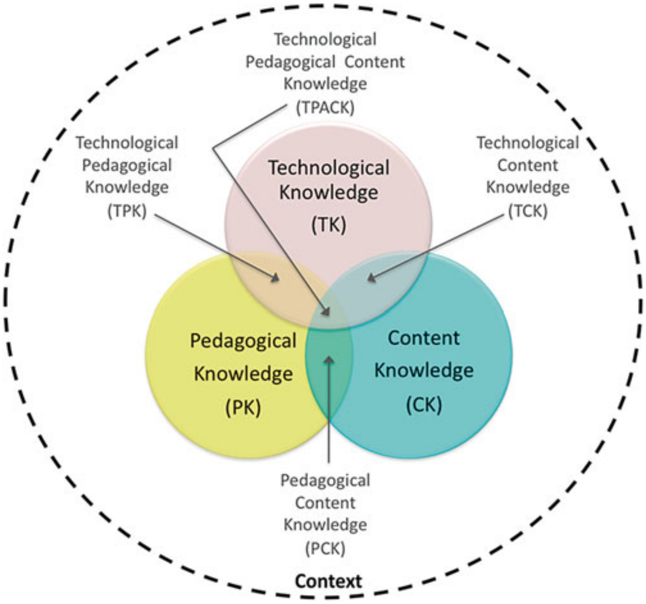

Fig. 1 Technological pedagogical content knowledge framework (Adapted from Mishra & Koehler (2006). Copyright by the Teachers College, Columbia University)

of how students best learn the specific concepts and topics of a subject (i.e., scope and sequence).

Applefield, Huber, and Moallem's (2001) study found that teachers' pedagogical understandings have considerable influence on their decisions regarding lessons using technology. Teachers' professional knowledge takes root over time, as they develop ideas about what it takes to be an effective teacher and how students best learn. Therefore, teachers who were taught in a traditional manner may hold on to traditional pedagogical practices when attempting to integrate technology. In fact, Webb and Cox's (2004) review on computer-related pedagogy suggested that most in-service teachers fail to explore many of the affordances of computers and technology and create more engaging and constructivist-oriented pedagogy. These teachers either may not see the affordances of technology or may take up only the affordances that are consistent with their preexisting professional knowledge. More often than not, teachers just attach new approaches on top of existing practices without really altering instruction to effectively integrate technology. Teachers' efforts to integrate technology into their school curricula are often limited by barriers fundamentally rooted in their professional knowledge about teaching and learning (Wang, Ertmer, & Newby, 2004). Thus, innovation is less likely to be adopted by experienced teachers, if it deviates greatly from their knowledge base.

Realizing that successfully integrating technology is no small feat, Mishra and Koehler (2006) provocatively refer to teaching with technology as a "wicked problem" to emphasize the novel and dynamic nature of this phenomenon.

Fully understanding constructs in the twenty-first century, teachers' professional knowledge, such as TCK, TPK, and TPACK, is an emerging and meticulous undertaking across all educational contexts.

Conceptual Distinctions for TCK, TPK, and TPACK

TCK conceptualizes teachers' understanding of how the application of technology can directly support student skill development in a given discipline; teachers firmly grasp the reciprocal relationship between a selected technology and their students' content learning (Mishra & Koehler, 2006). That is, teachers must be intimately familiar with their content, as well as have the capacity to effectively choose and appropriately leverage technology to support their students' learning and achievement. Therefore, TCK could be described as *using technologies best suited for addressing content learning*. Every technology choice made by teachers "affords and constrains the types of content ideas that can be taught" (Koehler & Mishra, 2008, p. 16). According to Cox (2008), teachers' selection of technology should be based on the imperatives of a particular content area. As emerging technologies make available a wider array of technologies for teachers to choose from, they must first consider *how* and *if* their choice is appropriate for the specific content to be taught. Niess (2008) offers a matrix for a process that teachers go through when "clarifying their ideas about content" (p. 233), while developing a lesson with technology: (a) declarative, (b) procedural, (c) schematic, and (d) strategic. At the declarative level, technology may be used to help students identify (not necessarily simulate) with the targeted content. At the procedural level, teachers choose technology to help their students think about how to use their content knowledge. At the schematic level, teachers may select technology to guide their students in understanding why and when they might use their new content-related knowledge. At the strategic level, teachers may pick a certain technology to afford their students the opportunity to synthesize their new knowledge; students might either create a product, or performance, that demonstrates their specific content learning.

Another conceptual distinction in the TCK construct is *using technologies that best simulate or represent content domain knowledge*. Kohler and Mishra (2008) contended that technology "has placed a greater emphasis on the role of simulation in understanding phenomena" (p. 15). Technology provides extensive representational opportunities for teachers to display content to their students. For example, science teachers can actually show their students how blood flows through a pumping heart in many Web 2.0 simulations or even in a video. Content can be represented via video, audio, and still images presented electronically (LCD, SmartBoard, class website, etc.), and by Internet/Web 2.0 tools or applications. These representations exist independent of the teachers' knowledge about their use in a pedagogical context; knowledge of how their choice of technology facilitates content representation is their TCK.

TPK conceptualizes knowledge about how technologies may be used to meet teachers' pedagogical aim(s) in the classroom (Koehler & Mishra, 2008).

Specifically, TPK requires teachers to have "forward-looking, creative and open-minded seeking of technology, not for its own sake, but for the sake of student learning and understanding" (p. 17). In other words, teachers deeply consider how technologies influence, or are influenced, by their own pedagogical style and their students' learning styles. As such, the TPK construct is *using technology as part of a pedagogical strategy*. TPK is widely considered to be independent of a specific content, or topic, not because it does not involve content, but it can be applied in any content domain (Cox, 2008; Koehler & Mishra, 2008). Hughes (2005) emphasized that TPK refers to the use of technology "as a general pedagogical tool" (p. 279). For example, teachers may use a wiki as a delivery system to provide handouts and rubrics to their students, or to make an assessment. These practices meet *general pedagogical aims*. Koehler and Mishra (2008) emphasized that teachers need to "develop skills to look beyond the immediate technology and 'reconfigure it' for their own pedagogical purposes" (p. 17). Teachers may ignore the fixed functionality of a given technology (e.g., MSWord or blogs) and leverage these technologies for another pedagogical reason or intention. Koehler and Mishra (2008) also posited that teachers must understand how "learning changes when particular technologies are used" (p. 16). Thus, teachers' TPK might include knowledge of how using technology can better motivate or better engage their students in activities, such as cooperative learning. Further, Niess (2008) asserted that teachers with TPK bear in mind students' learning style when choosing a particular technology. For example, teachers may use a video to augment a lesson, while supporting visual learners. Therefore, TPK may include: (a) a teacher simply using technology for instruction and classroom management, (b) repurposing particular technologies, and (c) considering student learning when selecting a technology.

TPACK illustrates teachers' ability to engage in a transactional negotiation among their content, pedagogy, and technology knowledge domains (Mishra & Koehler, 2006). Teachers implement new skills and understandings, when they combine these knowledge domains, while teaching with technology. Koehler and Mishra (2008) also claimed that individual components of TPACK (content, pedagogy, and technology) are difficult to tease out in teachers' practice. Further, they asserted that "teaching successfully with technology requires continually creating, sustaining, maintaining and re-establishing a dynamic equilibrium between each component" (p. 20). Therefore, the TPACK construct includes *using pedagogical techniques that constructively and continuously incorporate technologies to teach content.* Ultimately, when teachers' gain a sense of balance, they are able to *better facilitate* students' *mastery of content* while using *technology*.

Experienced Teacher Pedagogy in a New Education Era

Experienced teaching is a complex phenomenon. Experienced or *veteran* teachers' professional knowledge, once developed, remains stable (Gess-Newsome, 1999). Efficaciously weaving new knowledge base, in this case technology knowledge, into their preexisting professional knowledge base is often a daunting task for veteran teachers (Bebell & Kay, 2010; Harris, 2008; Hughes, 2005; Hughes & Scharber, 2008). Veteran teachers have to *unlearn* some established practices and to *learn* new techniques and pedagogical skills that continually evolve with each new advance of technological innovation.

Much of the early research only used survey studies to identify variables that may have influence over experienced in-service teachers' use of technology in the classroom (Becker & Ravitz, 1999). Specifically, these studies used self-report methodologies to capture teachers' computer skills, frequency of their technology use in the classroom, and what technologies were available to them (Anderson & Ronnkvist, 1999; Puma, Chaplin, & Pape, 2000; Smerdon et al., 2000). Although valuable in their own right, these studies ignored the complex and messy process veteran teachers navigate, as they develop professional knowledge for effective technology integration (Lim & Chai, 2008; Windschitl & Sahl, 2002). When integrating technology to transform their instructional practices, veteran teachers must make substantial additions and adaptations to their professional knowledge base, not just their *technology use*.

Purpose of Study

Veteran teachers need to deeply and flexibly understand educational technology applications, so they can better help students meet curricular driven learning outcomes alongside tacit twenty-first-century skills, such as collaboration, play, and problem-solving (Pink, 2006). Ultimately, these teachers need to see how technology can create connections between content area learning and their students' everyday lives.

A surge in 1:1 computing initiatives in K-12 education across the United States further adds to the complexity of the current educational landscape for veteran teachers. Thirty-seven percent of US public school districts are currently engaged in at least one laptop initiative (National School Board Association, 2010). One to one (1:1) instructional environments are characterized as each student having at least one internet-connected wireless computing device for use in the classroom. The constant access to technology and information in 1:1 settings creates a "new learning ecology," where teachers' professional knowledge must make a "pedagogical shift to accommodate learning that is continuous, changing, and above all exponential" (Spires, Wiebe, Young, Hollebrands, & Lee, 2009, p. 10). Clearly, 1:1 settings will influence how veteran teachers approach curriculum development and student participation during instruction. The TPACK framework helps researchers study both the disparate and combined domains of content, technology, and pedagogy knowledge veteran teachers' possess and display in ubiquitous computing settings.

To my knowledge, after conducting extensive research, veteran teachers have not been the target population for current TPACK research. Specifically, findings from valid and reliable measures of secondary veteran teachers' TPACK knowledge, and observations of their practice in 1:1 classrooms, have not been made available in the literature. How experienced teachers integrate technology during their instructional practice is tactical, strategic, and epistemological: the integration of technology results from the kinds of TCK, TPK, and TPACK they possess. I believe it is necessary to research secondary veteran teachers' TPACK and their practices in 1:1 settings.

As we move further into the twenty-first century, there is little doubt that veteran teachers' instructional practices will undergo a metamorphosis (Graham, 2011; Koehler et al., 2011). We also know that the 1:1 setting will become commonplace in public education, both in the United States and internationally. To better support these global shifts, educational stakeholders need to know how veteran teachers' TCK, TPK, and TPACK impact their execution of instructional practices in 1:1 settings. The research question guiding this study was: How are veteran teachers' technological pedagogical content knowledge (TCK, TPK, and TPACK) reflected in their instructional practices implemented in 1:1 settings?

Methods

To gain an in-depth understanding of veteran teachers' TCK, TPK, and TPACK in 1:1 settings, I employed a mixed methods sequential design (quantitative → qualitative). Each aspect of this study's design is discussed in the sections that follow.

Participants

Participant recruitment was conducted through a 1:1 learning collaborative housed in a university located in the southeastern United States. The macro participant pool was a subset of a larger study (Hervey, 2011), where 156 in-service secondary teachers had completed an adapted *Survey of Preservice Teachers' Knowledge of Teaching and Technology* (Schmidt et al., 2009).

For this study, veteran teachers were defined as having 8 or more years of experience. Many attempts were made to rationalize this benchmark by looking at statewide teacher attrition rates in North Carolina that may have been correlated to veteran teachers choosing to leave the profession, as technology requirements increased. Data indicated that high numbers of beginning teachers are leaving, and then declines with each year of service (Corbell, 2009) are observed. As such, a simple algorithm of doubling the number of years required (e.g., 4 years) to achieve tenure in North Carolina was applied to select "veteran teacher" participants. Only 81 of the 156 teachers met this criterion and were considered as "veterans" for this study. Table 1 provides their results on the adapted *Survey of Preservice Teachers' Knowledge of Teaching and Technology.*

Table 1 Mean, standard deviations, and skewness for participants' TCK, TPK, and TPACK subscale scores ($n = 81$)

	M^a	*SD*	Skewness
TCK	3.89	0.71	–0.59
TPK	3.98	0.56	–0.03
TPACK	3.98	0.50	–0.20

[a]Note: Means are based on the following five-point Likert scale: (1) strongly disagree, (2) disagree, (3) neither agree nor disagree, (4) agree, and (5) strongly agree

From the 81 eligible participants, I created potential pools of 10 veteran teachers per construct (e.g., TCK, TPK, and TPACK). I transformed the individual participants' raw scores for TCK, TPK, and TPACK to z-scores to locate results that differed from the normal distributions for each subscale. To identify the most illuminating case for each high and low case for TCK, TPK, and TPACK, the entry point for pool formation was determined by the subscale that yielded the largest z-scores above ±1.00. As such, pool formation began with the TCK subscale, where the largest z-score of –2.39 was found. The "low" TCK participant pool was formed using the five largest negative z-scores ranging from −2.39 to −1.53, and the "high" pool was formed using five participants who all had the highest z-score of 1.49. I then used the next biggest z-scores from the TPACK subscale, −1.64 to −1.29 and 1.15 to 1.46, to form the "low" and "high" pool of five participants each, while eliminating any duplicates already taken in the TCK pools. Finally, the "low" (−1.39 to −1.02) and "high" pool (all 1.21) for TPK was formed, with participants not already included in the TCK and TPACK pools.

I contacted (via email) the identified secondary veteran teachers from each pool. From those willing to participate, three cases were formed with two teachers per construct (e.g., TCK, TPK, and TPACK; $n=6$). For example, the TCK case was comprised of one veteran teacher who self-reported high TCK and one teacher who self-reported low TCK, in their responses on the adapted *Survey of Preservice Teachers' Knowledge of Teaching and Technology*.

Cases

The TCK case included Sheila and Rachael (pseudonyms are used in every instance). The TPK case was compromised of Yasmine and Mike. Liam and Sophie were in the TPACK case.

Self-reported high "TCK" teacher – Sheila: Shelia taught seventh-grade language arts at a rural school on a traditional calendar. She held a Master's of Education in Middle Grades Education/Language Arts and a National Board Certification. She had 13 years of teaching experience; she spent 10 years teaching sixth-grade language arts, at a different middle school located in a nearby county. Her current school, one of four middle schools in the local school district, was located at the foot of the Blue Ridge Mountains in northern North Carolina. Based on the most current public statistics, this school served, approximately, 650 students, 71 % White, 24 % Hispanics, 4 % Black, in grades 6 through 8.

Self-reported "low" TCK teacher – Rachael: Rachael taught seventh-grade language arts in a small, rural community in northern North Carolina, one of four middle schools in the local school district. She held a Bachelor's in Nutrition, Master of Arts in teaching, and National Board certification. She had 18 years of teaching experience; all teaching language arts in various middle school grades. Based on the most current statistics, this public school served, approximately, 500 students, 89 % White, 7 % Hispanics, 3 % Black, in grades 6 through 8.

Self-reported "high" TPK teacher – Yasmine: Yasmine taught Biology, Honors Biology, and Library Science in a large public high school located in the county seat of a metropolitan area in eastern North Carolina. She held a Bachelor's degree in teaching and had 11 years of teaching experience in various middle school grades. Her school, one of three high schools in the local school district, served 836 students, 51 % Black, 38 % White, 11 % Hispanics in grades 9 through 12.

Self-reported low "TPK" teacher – Mike: Mike taught ninth- and tenth-grade English at a public high school set within an historic community, located in eastern North Carolina. He held a Bachelor's in Education and a National Board Certification. He had 13 years of teaching experience; all teaching English in various high schools in his district. His school, one of five high schools in the local school district, served, approximately, 750 students, 89 % Black, 29 % White, 6 % Hispanic, in grades 9 through 12.

Self-reported "high" TPACK teacher – Liam: Liam taught AP Physics, Honors Physics, and Honors Earth Science, in a sizeable public high school situated in the county seat of metropolitan area in eastern North Carolina. He held a Bachelor's in teaching and had 11 years of teaching experience; all teaching various high school sciences. His school, one of three high schools in the local school district, served, approximately, 830 students, 51 % Black, 38 % White, 11 % Hispanics, in grades 9 through 12.

Self-reported "low" TPACK teacher – Sophie: Sophie taught seventh-grade language arts and held a Master's of Education in Middle Grades Education/Language Arts and a National Board Certification. She had 10 years of teaching experience. Her school, one of four middle schools in the local school district, was located in a rural county in northern North Carolina. Based on the most current public statistics, this school served, approximately, 430 students, 86 % White, 12 % Hispanics, 2 % Black, in grades 6 through 8.

Procedures and Data Sources

Videotaped Classroom Observations I used an HD Flip camera to videotape a single lesson in each teacher's classroom. The average length of each lesson was 55 min. Observations enable researchers to see things that participants themselves are not aware of, or they are unwilling to discuss (Patton, 2002). Specifically, videotaped observations can capture the illusive qualities of teaching that separate one teacher from another (Rosenstein, 2000). Videotaped observations become permanent records that can be analyzed multiple times, yielding opportunities for new insights, and confirmation of coding and emerging themes. The videotaped observations were used to triangulate emerging findings from the study; they were used in combination with interview data and field notes to substantiate findings.

Stimulated Recall Interviews I asked teachers to participate in stimulated recall interviews (SRIs), as soon as possible after their videotaped classroom observations. The video files were downloaded and then played on my password-protected computer. I gave directions to the teachers prior to viewing a video (e.g., "Please provide me with your objectives and intentions for the lesson, and comment on any ideas, beliefs or theories that you can identify that influenced your planning and teaching approach" (based on Lyle, 2003). While viewing the taped lesson, teachers were directed as follows: "As you view the videotape, please walk me through the lesson and tell me what was going on in your mind at the time. Try to distinguish between any thoughts you had at the time, and thoughts you're having now as you watch the tape and make me aware of those differences. You can stop the video as often as you like and for as long as you need to explain your thinking" (based on Kane, Sandretto, & Heath, 2004).

Since thinking aloud during teaching is rather difficult, SRIs offer one way to capture teachers' thinking during instruction (Ethel & McMeniman, 2000; Lyle, 2003). In SRIs, video or audio of a lesson is immediately played after the lesson to stimulate the revival of thoughts the teacher had prior and during teaching. Studies have shown that SRIs are useful for tapping into the implicit knowledge teachers' possess (2000; 2003; Meade & McMeniman, 1992). Moreover, joint viewing of the video footage can deepen a researcher's understanding of teachers' practice and thinking through reflective dialog (Rosenstein, 2002). The SRIs helped me glean profound insights into what aspects of TCK, TPK, and TPACK guided teachers' pedagogical choices prior to and during instructional practices that I captured on video.

Semi-structured Interviews Semi-structured interviewing utilizes open-ended questions that allow for individual variations of interpretations of their reality. Follow-up questions were an important part of this study's process to capture the complexities veteran teachers' experience, when they teach and learn with technologies within their 1:1 classroom and school. Their experiences are part of their practice. For this study, immediately following their SRI, I engaged each teacher in a semi-structured interview to elicit additional information, feelings, or thoughts, about their 1:1 environment. These interviews were guided by a set of questions and averaged 10–15 min.

Analysis

The analysis that was conducted in this study was intended to support the discovery of new information about how veteran teachers' technological pedagogical content knowledge (TCK, TPK, and TPACK) is reflected in their instructional practices implemented in 1:1 settings.

With-in Case Analysis

Yin (2003) recommended "analytic generalization … in which a previously developed theory is used as a template with which to compare the empirical results of the case study" (p. 31). Storberg-Walker (2008) claimed that, "From a qualitative research perspective, each analytical component must be unique. It is necessary to define/specify each component, so there is no overlap in definitions. Unique elements require explicit definitions and distinctions in order for researchers to code data" (p. 567). Therefore, *a priori* codes, using *analytic components* and *markers,* were created based on conceptual distinctions among TCK, TPK, and TPACK.

TCK Codes The first analytic component in the TCK construct was *using technologies best suited for addressing content knowledge* (see Table 2). The markers for this analytic component were: (a) declarative, (b) procedural, (c) schematic, and (d) strategic (Niess, 2008). The second analytic component for the TCK construct was *using technologies that best simulate or represent content knowledge* with four markers to delineate the actual type of technology used in the lessons.

TPK Codes The TPK construct attempts to conceptualize teachers' knowledge when they use technologies to meet their pedagogical aims in the classroom (Koehler & Mishra, 2008). As seen in Table 3, the analytic component for the TPK construct was *using technology as part of a pedagogical strategy* and the markers were: (a) general pedagogical aim, (b) repurposing, and (c) considering student learning.

TPACK Codes The analytic component in the TPACK construct was using *pedagogical techniques that constructively and continuously incorporate technologies to teach content* (see Table 4). The singularity of this analytic approach, with no markers, was based on Koehler and Mishra's (2008) claim that the smaller grain size components (e.g., content, pedagogy, and technology) are difficult to tease out individually, when teachers are truly actualizing TPACK during the learning and teaching process.

Before within-case coding began, the ATLAS-ti memo feature was employed to record critical events in each teacher's video to serve as a point of reference for subsequent coding (Powell, Francisco, & Maher, 2003). Any time that the teacher used technology, while teaching or directed students to use technology, was considered to be a critical event. These memos helped me organize and refine how the video data were later coded, in relation to the TCK, TPK, and TPACK *a priori* coding as previously was described. In an effort to triangulate the video data, the same code used on the teacher's SRI transcript (where they clearly referred to a segment or activity in their videotaped lesson) was applied to the video and related field note data where applicable.

Table 2 TCK analytic components and markers

TPACK domain	Analytic component	Markers
TCK	*Using technologies best suited for addressing content knowledge:* teachers understand the affordances and constraints of the technology as it relates to content ideas (Koehler & Mishra, 2008)	*Declarative*: technology may be used help students identify (not necessarily simulate) the content knowledge
		Procedural: technology to help students think about how to use the content knowledge
		Schematic: technology to guide students in understanding why and when they might use the content knowledge
		Strategic: technology that affords their students the ability to synthesize their content knowledge to create a product or a performance that demonstrates that content knowledge (Niess, 2008)
TCK	*Using technologies that best simulate or represent content knowledge*	Content was represented via video
		Content was represented in audio
		Content was represented by images (LCD, SmartBoard, website, etc.)
		Content was represented directly by Internet/ Web2.0 tool or application

Table 3 TPK analytic components and markers

TPACK domain	Analytic component	Markers
TPK	*Using technology as part of a pedagogical strategy*	General pedagogical aim (Hughes, 2005)
		Repurposing: "develop skills to look beyond the immediate technology and "reconfigure it" for their own pedagogical purposes" (Koehler & Mishra, 2008, p. 17)
		Considering student learning: "learning changes when particular technologies are used" (Koehler & Mishra, 2008, p. 16)

Table 4 TPACK analytic component and markers

TPACK domain	Analytic component
TPACK	*Using pedagogical techniques that constructively and continuously incorporate technologies to teach content*: "teaching successfully with technology requires continually creating, sustaining, maintaining and re-establishing a dynamic equilibrium between each component" (Koehler & Mishra, 2008, p. 20)

Cross Case

Through an inductive process, the semi-structured interview data were open coded using the constant comparative analysis method; before adding a new quote to a category, it was compared to each of the other quotes that were part of that category and reasoned through its inclusion or the initiation of a new initial category (Patton, 2002). Six categories were revealed: leadership stance, professional development experiences, help with technology, being a veteran teacher, teachers' attitude towards 1:1 initiative, and teachers' self-efficacy for using technology. During a second reading, subcategories were created to highlight the various dimensions within each initial category. Next, the coded data was clustered into themes based on their relevance to this study. In all, 14 codes were established and 3 interpretive themes emerged from the data.

Findings

Summaries of these findings are offered in two sections: (a) within-case findings and (b) cross-case findings.

Within Case Findings

Video and SRI data were interpreted using the a priori codes, as described in the previous sections.

TCK Case Shelia's seventh-grade language arts lesson required students to use higher level thinking skills when identifying, analyzing, and evaluating the mood and tone, when reading a selected text. Rachael's seventh-grade language arts lesson was a review of vocabulary, characterization, and plot associated with *Rikki-Tikki-Tavi*, a story from Kipling's *The Jungle Book.* Both Shelia and Rachael demonstrated vibrant, active, and diverse examples of the ways in which their TCK guided them in making decisions, when facilitating a technology-infused lesson. SRI, video, and field note data revealed that both teachers confidently made strategic technology choices. First, their technology choices supported their students' content knowledge development. Second, their choices represented, or simulated, the content knowledge understudy. The declarative, procedural, schematic, and strategic markers, as described earlier, surfaced largely in the teachers' videos and comments. Figure 2 synthesizes the findings from the TCK case to highlight similarities and differences between Sheila and Rachael's practice.

TPK Case Yasmine's tenth-grade biology lesson centered on dominant, recessive, and intermediate traits associated with genetic disorders. Mike's lesson was a review

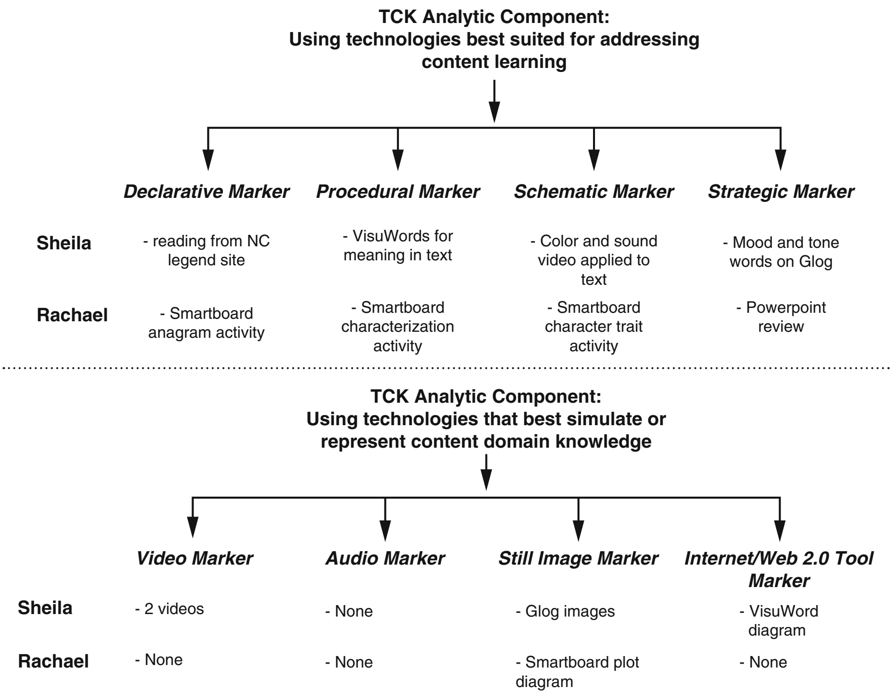

Fig. 2 TCK case findings by analytic components and markers

of the following grammar elements: punctuation, subject–verb agreement, sentence fragments, and run-on sentences. Yasmine and Mike's TPK was evidenced in their pedagogical strategies employed during their lessons. Existence of their TPK, as a general pedagogical aim, was evidenced by their explicit value of assessment via technology; the phrases "immediate feedback" and "bench marking" came up more than once in their SRIs. Yasmine and Mike also described the ways in which they considered student learning when using technology. For example, in efforts to deepen their students' learning they both provided "more engaging" and "collaborative" activities supported by technology. Neither Yasmine, nor Mike, repurposed technology during their individual lessons: this topic of repurposing is examined further in the discussion. Figure 3 provides a graphic snapshot of the TPK case findings.

TPACK Case Liam's lesson centered around the Law of Conservation, specifically examining inelastic collisions through measuring velocity and height to determine kinetic energy. Sophie's seventh-grade language arts lesson was the culmination of creating a cookbook, applying second person point of view, where all students were contributing a family recipe. The data, in this case, illuminated stark differences in the complexity involved in observing teachers' balanced negotiation among their content, pedagogical, and technology knowledge. Quite simply, Liam demonstrated sustained TPACK and Sophie did not. Figure 4 provides a graphic representation of the TPACK case findings.

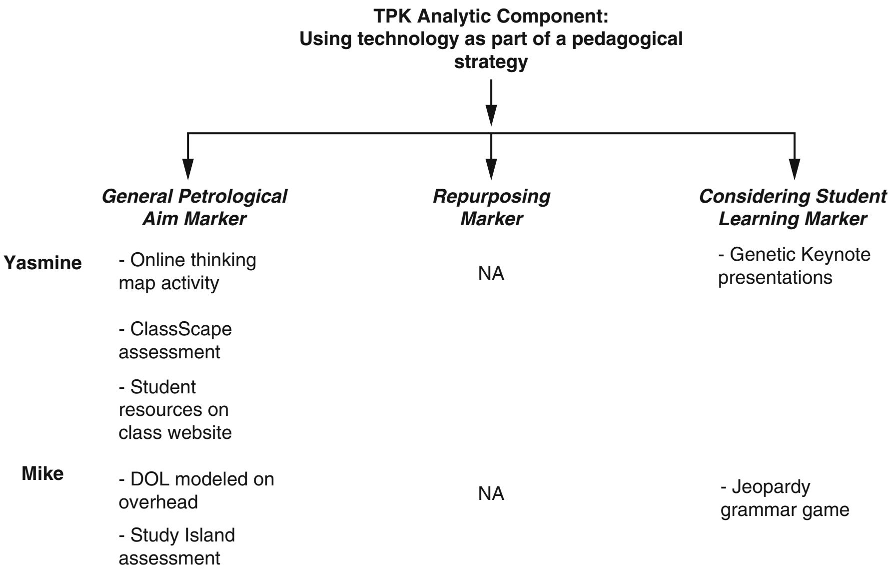

Fig. 3 TPK case findings by analytic components and markers

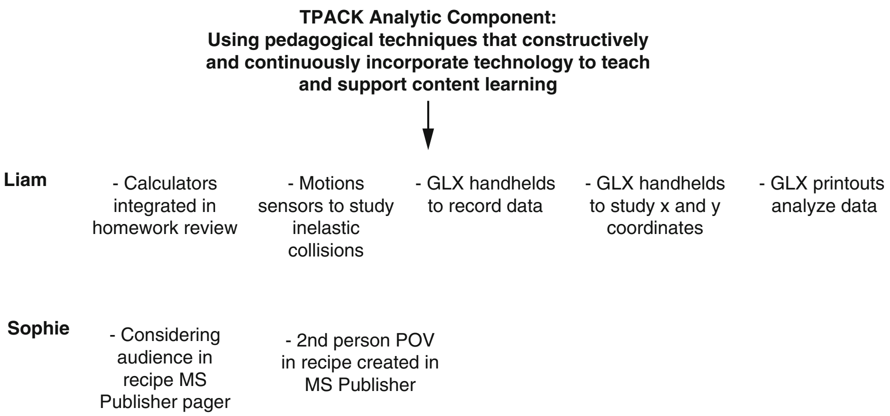

Fig. 4 TPACK case findings by analytic components and markers

Cross Case Findings

As previously discussed, 14 codes and 3 themes emerged from teachers' semi-structured interviews. The interpretative themes that developed from my cross analysis were: (a) Helping us Help Ourselves: "My school will find a way to make that happen for me." (b) Help Us Help Students: "I'm able to identify specific objectives that I need to focus on." and (c) Help Us Help Each Other: "We get to practice together."

Help us help ourselves: "My school will find a way to make that happen for me." Many teachers alluded to wanting freedom to bolster their own capacity for effectively leveraging technology, while teaching in their 1:1 environments. Sheila made it clear in how she has helped herself in this way: "So all of our training is differentiated, I can choose the level that I feel I am at and go to workshops I feel I can handle." Liam shared a similar experience about the professional development offerings at his school: "We're able to choose. I get to ask myself 'Do I want to focus on this particular area or do I want to learn about that technology?'"

Several teachers emphasized that their schools provide them with the latitude to better manage their own technology choices. Sophie described how her school's culture enabled her to help herself:

> If we deem a website or video to be appropriate, then we can use it. We have to preview it, but we can use our professional judgment. If we can find it and feel like it's worthy, then we have this freedom to use it.

Rachael enjoyed a similar freedom to help herself in her 1:1 setting. She shared: "If a site is blocked. You e-mail your facilitator, and then they'll unblock the site. They trust us here." School cultures that help teachers help themselves should not be underestimated. Veteran teachers practicing in 1:1 settings should be encouraged to trust their abilities to appropriately select technologies that they deem necessary to further student learning. It was evident from my data analysis that having this type of freedom was directly related to teachers' personalization of their own learning and bold selections of technology to support and enhance student learning.

On the other end of the continuum, however, several teachers, who were satisfied with general professional development opportunities, expressed frustration in not being helped in more personalized ways. Mike was the most animated:

> I've actually never had someone in the course of my professional development say, 'Hey, look, you're a mid-career teacher; you are facing a dichotomy between your pedagogical knowledge and your technological proficiency. Are there things that you would like to do in the classroom that you feel like you're not able to?'

Sophie explained her frustration this way:

> I need to see more literacy-based technology applied in an actual classroom. I haven't had any professional development that was designed to help me develop my own language arts lessons using technology in our Web 2.0 environment.

Many of these teachers felt empowered to freely make technology choices that they felt best improved learning and teaching processes. However, many of these teachers appeared to want more personalized and content related opportunities to learn how to effectively teach with technology.

Help us to help students: "It's a really wonderful thing to see kids get what they need." Several of the teachers shared how their school helped them to help students improve their achievement and meet learning goals. Yasmine shared that at her 1:1 school:

> We've had training on how to use ClassScape. They taught us how to read the data, so I'm able to identify specific objectives that I need to focus on with my students. It helped to raise their scores and proficiency levels.

Several teachers shared the benefit of exposure to new understandings about how specific technologies could make learning goals achievable by their students with differing abilities. Sheila shared how her school helped her help her students:

> A few weeks back, they [the school] brought somebody in to teach us about VoiceThread. I got to see how I could use it for different learning styles. I hadn't thought about that, but VoiceThread is great for visual and auditory learners. Now, I will try to use it more.

Many teachers felt free to, and were successful in, advocating for technologies that allowed their students to thrive, as well as supported instructional differentiation. Purposefully helping these teachers help their students capitalize on the availability of laptops and effectively increase student learning, when using technology, was invaluable.

Help us help each other: "We get to practice together." Sustaining and realizing the benefit of ubiquitous computing requires a strong sense of school community. Many teachers in this study were provided opportunities to seek help from each other to better their technology integration. Yasmine shared how her 1:1 school helps its teachers help each other:

> We have staff development on Tuesdays and Thursdays. We gain some type of new technological skill. We get to talk with each other about how we can use these in our classroom and how to use the new cameras or whatever the technology may be. I think that's the best part.

Some teachers in this study were also encouraged to recognize their colleagues' expertise. Rachael explained that, "About once a month, you have to do a lesson. You plan a lesson, you go into a class and you teach it. Everybody gets to watch you. If you're the expert, you get to share that." Liam shared a similar practice in his school, "So people will come back from a conference and share things that they've learned. They're really empowered to share it, and that definitely helps." Mike described his experience this way, "Sometimes during our PD we're encouraged to talk to each other: 'Tell me what you're doing in your classroom.' or 'Have you thought about this?' 'What are the barriers to trying this?'"

Teachers have long been working closely with each other to further develop their skills and better facilitate effective learning for their students. This ongoing collaboration appeared to take on new life, when these teachers were provided ubiquitous technology in their 1:1 classrooms. Part of this new life, however, appeared to include a perceived chasm between teachers of different generations. Unprompted by me, some of the teachers in this study expressed concern that their collaborative efforts with colleagues are hindered by their veteran status. Mike makes this clear:

> The newer teachers, in my own English department, believe there is a lapse of technology use in my classroom. I am seen as a veteran teacher. Therefore, I can't possibly be a leader or a pioneer in this particular area.

Sophie shared a similar experience that raised the same feelings in her:

> I felt like the younger teachers make a big deal on how they use technology versus how I use it. At lunch the other day, another teacher told me that I was of a 'different technological generation' than they were. They were only 3 or 4 years younger than me. I said, 'That is not true! I Facebook!' It was just a superficial conversation, but it was an interesting perspective. How do I stay current and try technologies that are completely new to me that I may not be using in my daily life, and then bring them into my classroom?

Similarly, Liam shared:

> I think as a veteran teacher, it's a preparation thing. If you iron out the kinks [of technology] by doing a test or doing it yourself, that of course takes time. It would be nice if the younger teachers would step up more and share their skills.

These teachers are certainly facing challenges that may be brought on by generational differences between them and their peers that are further exacerbated by the availability of technology.

Discussion

Two concluding themes emerged from synthesizing findings across both the qualitative phases: (a) Illuminated TCK, TPK, and TPACK, and (b) The Veteran Teacher, TPACK, and the 1:1 Setting. In the first section, use of *a priori* within-case analysis approach better illuminated these veteran teachers' TCK, TPK, and TPACK, and thus added to the TPACK theoretical model and related findings. Recommendations for future TPACK research are offered where appropriate. In the second section, findings are elevated from the cross-case analysis that provided unique insights into the challenges veteran teachers' experience, while practicing in 1:1 settings. Finally, future research recommendations are made that may enable researchers, administrators, and policy makers to address these challenges that veteran teachers face, as they strive to transform their practices, including their TPACK, for the twenty-first century.

Illuminated TCK, TPK, and TPACK

Groth, Spickler, Bergner, and Bardzell (2009) posited that teachers' classroom instruction, when observed through the lens of the TPACK framework, could identify important theoretical constructs in their practice. This study's findings support their claim. The use of *a priori* coding, based on the TPACK conceptual framework, significantly illuminated the participating teachers' respective TCK, TPK, and TPACK during practice in a 1:1 setting and will be discussed in the following sections: (a) Explicit TCK, (b) Repurposing TPK, and (c) Illusive TPACK.

Explicit TCK TCK is defined as a teacher's knowledge of appropriate technologies for representing concepts associated with a specific content area. In general, Sheila and Rachael were readily able to discuss the relationship between technology and their content. For example, Sheila recalled her thoughts about technologies she used to teach language arts:

> I used different technologies to present the different parts of mood and tone. Sometimes technology can help me to teach part of it [content], sometimes the technology is right for the whole thing. For example, when reading with the kids, I can stop right where a word is, I can just click and, BOOM! I can put VisuWords on the screen. I can show the kids all of the different relationships and meanings of the word. Then, I get them re-read that sentence with an understanding that is in context. That's using technology and connecting it to content immediately.

She added humorously, “It’s about what the tool can do for you, I mean, there’s no use in using a spoon if you’re eating French fries.” Rachael had similar thoughts:

> Doesn’t the SmartBoard scream “language arts” to you? I use it so that I can check their [students] use of their content knowledge quickly and move on.

The very nature of TCK, however, makes it difficult to adequately identify teachers’ tacit knowledge during practice. Rather, teachers’ knowledge of the relationship between technology and their content is situated in their thought processes. The *declarative* (knowing the content knowledge), *procedural* (knowing how to use content knowledge), *schematic* (knowing why to use content knowledge), and *strategic* (knowing when and where to use content knowledge) markers proved helpful in parsing out TCK evidence in both teachers’ lessons. These markers brought a greater clarity to how Shelia and Rachael’s TCK impacted their practice with technology. Indeed, the marker matrix better helped highlight both Shelia and Rachael’s actions and reasoning that formed their TCK. Rachael and Sheila both exhibited knowledge of how to guide their students’ content learning, through transformational and appropriate technologies. The matrix makes clear that both teachers know how to use technologies to teach their content and scaffold students’ content knowledge to the highest evolution (e.g., strategic level). Overall, I assert that the marker matrix recommended by Niess (2008) was munificent in providing the best means of analyzing these teachers’ TCK. Moving forward, this matrix of markers may enable researchers to cross content area boundaries, deepening their insight into all teachers’ TCK. Moreover, this marker matrix may prove to be the best lens to make TCK “observable” as researchers continue to try to better understand the construct. More evidence is needed to either support or refute these claims.

Repurposing TPK TPK refers to a teacher’s knowledge of how technologies can aid general pedagogical aims and impact student learning. As seen in Fig. 3, Yasmine and Mike were adept at using technologies for general pedagogical purposes. During their interviews, both teachers made clear how they take time to think about how technology influences their students’ readiness for learning. For example, Yasmine shared, “Before I plan something, I have to think of a way to make sure that every student is engaged. I want to make sure the technology is the right choice.” Mike shared a very similar thought process, when reflecting on his Web 2.0 Jeopardy game:

> They’re [students] drawing off of each other in terms of engagement. That was what I was hoping to achieve through the use of that particular technology. I wanted an activity that was collaborative, and a little bit more fun and engaging. I think that the online Jeopardy does achieve that.

However, Mishra and Koehler (2009) insisted that a key competency associated with TPK required teachers to go beyond their fixed and traditional knowledge of particular technologies and repurpose them in creative ways that are well suited to their setting and students. That is, veteran teachers need to be skilled at repurposing, because many of the available technologies were not originally designed for educational purposes. For example, blogs, wikis, and GPS systems were not specifically designed for educational use; therefore, teachers must repurpose them for use in their instructional practices. Such repurposing requires deep experiential understanding of the technology and deliberate practice with those technologies in the repurposed manner (Mishra & Koehler, 2009). The TPK markers helped to highlight that neither Yasmine nor Mike demonstrated "repurposing" or redesigned or even subverted the original intentions of the technologies used in their lessons. This is significant because teachers' TPK is not completely developed until they acquire "flexible knowledge" of technologies (Koehler & Mishra, 2008, p. 17). As such, a worthwhile objective of the TPACK research agenda is to better understand how to help secondary veteran teachers' fully develop their TPK, where repurposing of technologies to support and enhance their students' learning is a central aim.

Illusive TPACK TPACK describes teachers' perpetual balancing of their technological, pedagogical, and content knowledge while teaching. According to Mishra and Koehler (2006), seeing a teacher's TPACK is "an analytical act and one that is difficult to tease out in practice" (p. 1029). The combination of collecting both observational and interview data proved useful in better examining and identifying Liam and Sophie's TPACK. Mishra and Koehler (2006) also explained that "teaching and learning with technology exists in a dynamic transactional relationship between the three components in the framework; a change in any one of the factors has to be 'compensated' by changes in the other two" (p. 1029). Further, to teach well with technology, teachers must constantly create, maintain, and *reestablish* the equilibrium among all three TPACK factors (Koehler & Mishra, 2008). To date, there is little evidence reported in the literature that captures this unique TPACK phenomenon. Liam's stimulated recall interview provided ample evidence of this complex transaction. Specifically, he explained:

> I want to do an activity, use a technology and get to the principles. It's like you are on a roller coaster ride, when you're mixing all of these things together. You get on and when the ride is going on, you are constantly catching your breath. When you go on this roller coaster ride, it's great fun and it's exhilarating, and it's awesome. That's what happens when you have the kids engaged and learning with technology and I am teaching. Does that make sense?

He continues with his rollercoaster analogy to shed light on how he *reestablishes* his TPACK:

> Okay, just like when you get off the roller coaster, you're like, "Wow, that was fun, let's do it again." It [TPACK] exists for a certain bit of time, but then it comes and goes. You know it when you've got it. You have all these things going, you know you've got that match. Oh, it's such a fragile thing because it comes and it goes and you know when it's over.

The *a priori* coding use captured how a veteran secondary teacher uniquely and actively weaved together the factors associated with TPACK. Liam's testimony allowed a privileged peek into how he actualized and articulated his fluid maneuvers within the space defined by his technology, pedagogy, and content knowledge. In fact, it also brings greater clarity to findings in Spires, Hervey, and Watson's (2013) study, where they investigated how an inquiry learning project (ILP) model scaffolded TPACK development in 20 in-service English/language arts (ELA) teachers. One of the teachers in their study reported, "I can feel my brain changing" (np) when attempting to articulate her newly constructed connections within her TPACK. Future research should include extended observations paired with interviews directly aimed at exploring teachers' thoughts and feelings that support their actions, when using technology during instruction viewed through a TPACK theoretical lens.

The Veteran Teacher, TPACK, and the 1:1 Setting

How the generational related characteristics teachers' possess impact their approach to technology in 1:1 settings has received limited attention in the literature. It was not until 2001, when Prensky (2001) posited that two groups of technology users exist: (a) digital natives or (b) digital immigrants, with digital natives being born during the age of technology. In other words, digital natives have spent their entire lives surrounded by computers, videogames, MP3 players, cell phones, and all the other ubiquitous tools of the digital age. Oblinger and Oblinger (2005) claimed that technology users who fall in the digital native camp have an elevated ability to: (a) read visual images, (b) shift attention and provide fast response, and (c) learn better through inductive discovery. Their analysis suggests that digital immigrants may experience a transitional period before their skills match those of digital natives. Dwyer, Ringstaff, and Sandholtz (1990) found that "new patterns of teaching and learning" occurred when teachers had unprecedented ubiquitous access to technologies, like those in 1:1 settings (p. 4). In fact, many veteran teachers have reported having difficulty maximizing the access to 1:1 laptops to facilitate complex and enriching instructional activities (Bebell & Kay, 2010; Dunleavy, Dexter, & Heinecke, 2007). This makes sense, since Koehler and Mishra (2008) claimed that thoughtful use of technology is largely based on a teacher's ability to intertwine their pedagogical, content, and technological knowledge. They suggested that best practice with technology involves "knowledge of the existence, components and capabilities of various technologies, when used in various teaching and learning settings, and knowing how teaching might change as the result of using particular technologies" (p. 1028). Taken together, this interrelated body of research suggests that teachers across all generations will face challenges in developing their TPACK in 1:1 settings. This study has provided a small portal into the secondary veteran teacher experience in 1:1 schools. The two major generational struggles these veteran teachers perceived are better described in the next sections as: (a) Generational Struggle: Getting the help we want and need, and (b) Generational Struggle: Us versus them.

Generational struggle: "Getting the help we need and want." In general, teachers in this study reported that they were satisfied with professional development that has been offered at their schools, especially when it was self-selected. This type of autonomy helped them to improve their confidence and ability to effectively use technology in more relevant ways. This is similar to what Bebell and Kay (2010) found in their 2-year assessments of teacher preparedness in a Boston area 1:1 laptop initiative. However, some of the teachers in this study felt they could be better supported, when it came to how professional development was managed and delivered. Mike commented:

> Our county uses a 'top-down' approach, when it comes to professional development. It feels like, 'These are some objectives that we want to achieve, this is how we're going to achieve them. These are some needs that we perceive you have, and so this is what we're going to do to fill those needs.' There has been less of, 'Hey, what do you need? What can we do to help you?' There is a 'disconnect' between what we need and what we've been provided.

Like Mike, it was apparent that Rachael felt she was not receiving the type of help and support she really wanted when she shared:

> I just wish they [Administration] would ask what I needed. We're in this meeting, and we're in that meeting. We need time to just sit and play with our equipment. Just give us the time we need.

Sophie illustrated her experience with professional development at her school in this way:

> In terms of professional support, there are two things I've noticed. First, our county has a real emphasis on us just getting the hours of professional development. Second, they don't care what it is in, they just want to make sure we have the professional development.

These findings further demonstrate how differentiated and personalized professional development might aid these teachers in better leveraging technology during instruction, as well as simultaneously stimulating TPACK growth and development.

Generational struggle: "Us versus them." The National Education Technology Plan (NETP) (2009) calls for teachers to "tap into experts and best practices for just-in-time learning and problem solving, and design and develop resources and share them with their colleagues" (p. 46). It appears that several teachers in this study were experiencing roadblocks in achieving this important twenty-first century goal. This is unfortunate, because Silvernail and Lane (2004) reported that teachers rated "receiving informal help from colleagues" (p. 16) highest across all forms of professional support in Maine's 1:1 initiative. That is, these collegial relationships improved their willingness to attempt similar innovations in their own classrooms. However, Prensky (2001) asserted, "those of us who were not born into the digital world, but have, at some later point in our lives, become fascinated by and adopted many or most aspects of the new technology are, and always will be compared to… digital immigrants" (p. 2). This sentiment echoed throughout many of the teachers' reflections on their experiences and interactions with peers in their 1:1 settings. Rachael shared her perspective:

> There are teachers, mostly the younger ones, who feel they are at the top of the pyramid. They look down at those who don't have as much knowledge of the technology, including myself. I don't think they have a heck of a lot more technology knowledge than I do. But,

> I do think, for the most part, that they think we are too intimidated to have a really good sense of the technology. These teachers act like "hands-off, don't touch me," because they are much more comfortable using technology.

Sophie was dumbfounded by the fact that her colleagues who were "only 3 or 4 years younger" than her considered her to be part of "a different technological generation." Mike feels separated from his peers because they see him "as a veteran teacher" that "can't possibly be a [technology] leader." These findings are also reflected in a study conducted by Pegler, Kollewyn, and Crichton (2010) that looked at how generational attitudes impacted teachers' practice with technology. The authors suggested that it should not be "assumed that teachers from the older generations are incapable or unwilling to infuse or learn technology" (p. 457). Unfortunately, to some degree, this phenomenon was apparent in this study. These perceptions of "incapableness" may be brought to light when veteran teachers express being overwhelmed with what they *don't know* about technology; the teachers are operating outside of their comfort zone. In fact, Pegler et al. (2010) found a "marked difference in comfort levels in use of multimedia with the youngest generation reporting the highest level of use" (p. 452). Sheila shared her sense of *imbalance*:

> In the beginning of this 1:1 initiative, we were all pushed out of our comfort zones. It's been very difficult for those of us who have never used technology to teach. It has been easier for other teachers. For them was like "Eureka!" For me, I was pushing myself constantly.

In describing her experience as an 18 year veteran, Rachael felt that she had "allowed the technology to intimidate" her, because she felt she had to always "do it right in front of others."

Pegler et al. (2010) suggested that schools should "support the establishment of co-mentorship between generations" (p. 457). As 1:1 initiatives expand, the field may be better served to continue to research the added value of organized and informal collaboration with younger peers in transforming veteran teacher practice in 1:1 settings.

Conclusion

Technology integration as a "wicked problem" serves as an appropriate metaphor for the novel and dynamic changes facing all teachers. This study offered greater clarity of secondary veteran teachers' TCK, TPK, and TPACK, while practicing in 1:1 settings. Specifically, it helped make tacit concepts within the TPACK framework more explicit and facilitated a better understanding of what veteran teachers find supportive as well as the struggles they face in their 1:1 schools. Future research involving TPACK theory building and description as outlined above will have major implications for how to best support secondary veteran teachers' successful development of technology-infused lessons that increase their students' learning and achievement.

As the theory, research and practice of TPACK evolves, at least two areas should be taken into consideration. First, veteran teachers will need customized, just-in-time professional development to help them acquire nuanced and critical understandings of how to best use their 1:1 technologies to enhance student content learning. Second, as 1:1 schools develop their professional learning communities, they should be intentional in leveraging veteran and novice teachers' skills and talents in tandem. Veteran teachers tend to have richer content and pedagogical knowledge as the result of years of experience in the classroom; likewise, novice teachers have the advantage of growing up in a digital age and tend to take more risks in applying technologies in their classrooms. Creating space for formal and informal collaborative relationships will help both veteran and novice teachers take advantage of this distributed expertise.

Clearly, veteran teachers want to play an essential role in the intellectual and instructional culture of their 1:1 setting. An essential element in meeting this aim is having veteran teachers leveraging technology innovatively and effectively in their classroom. In order for this to happen, customized professional development should be in place and generational relationships should be nurtured to further develop *all* teachers' TPACK.

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Part IV
TPCK in Subject-Specific Contexts

Theorizing Technological Pedagogical Content Knowledge to Support Networked Inquiry Learning in Science: Looking Back and Moving Forward

Kathrin Otrel-Cass

Introduction

The notion that teachers and students can incorporate digital technology to support science investigations and enhance learning experiences has received considerable interest from researchers, practitioners, and policymakers (Loveless & Ellis, 2001; New Zealand Ministry of Education, 2007; Somekh, 2007). For instance, the World Wide Web offers easy access to multimodal and up-to-date information and opportunities to interact with people and information, compared to facilitating face-to-face meetings or using standard texts (Cowie, Moreland, Jones, & Otrel-Cass, 2008; Slotta & Linn, 2000). Careful orchestration of digital technology in classrooms has the potential to enhance understanding of science ideas, promote learners' independence, motivation and engagement in science, and support visualizing investigations and science learning. However, this requires that teachers and students have *sandpit time*, which means time to practice, and reflect for, the use of digital technology (Otrel-Cass, Cowie, & Khoo, 2011). It has been argued that if teachers want their students to learn about what it means to think and work as a scientist, then they should be involved in activities that are authentic and meaningful. This means that students should get opportunities to apply their growing scientific literacy, practice decision making (Roth, van Eijck, Reis, & Hsu, 2008), and learn about social practices and discourses that contribute to the way scientists generate knowledge (Kovalainen & Kumpulainen, 2009). This demand for authenticity is challenging the traditional school environment, because activities that involve students as self-directed learners, who investigate, interpret, and assess the trustworthiness of information from a variety of sources, for the purpose of answering their own questions,

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are not easily achieved (Duschl, 2008; Otrel-Cass et al., 2011). Although Information and Communication Technology (ICT) has been identified to provide a suite of tools that support such endeavors, digital technology alone will not change teacher practices in science classrooms. If digital technology is to contribute to transforming science learning, those involved with shaping teacher pedagogy, including researchers and teacher educators, need to explore how teachers can use the creative, collaborative, experimental, and evaluative possibilities ICT may have to offer (Somekh, 2007). It is also not enough to assume that twenty-first century students may be digitally literate in using technology for recreational purposes, such as social networking, and to then believe that they can, or want, to automatically transfer those skills into educational settings (Kennedy, Judd, Churchward, Gray, & Krause, 2008). Such oversimplifications of digital technology use and practices in science, or other subjects, may lead to less productive teaching and learning outcomes, and alienate both teachers and students from using digital technology in class.

By now, there are plenty of examples indicating that learning transformations with ICT are possible (GTC, 2006; Hennessy, Deaney, & Ruthven, 2005; Webb & Cox, 2004). However, this requires an understanding of the rationale behind the implementation of digital technology, because the diverse digital technology tools that are available to teachers and students have been developed within particular sociocultural settings and for particular purposes (Sutherland et al., 2004). This means that the use of digital technology in classrooms is shaped by the ways teachers draw on their applied and situated knowledge about technology, together with their content knowledge and their repertoire of pedagogical practices to use technology as an alternative, or supplement, to other tools or artifacts (Somekh, 2007).

Integrating Digital Technologies into Science Inquiry

Inquiry-based science education requires that students investigate their own questions to problems, gather and make sense of data and information, construe explanations, and convey conclusions (Duschl, Schweingruber, & Shouse, 2007; Lee, Linn, Varma, & Liu, 2010). It has been argued that when students undertake their own investigations in science and engage in research, there is a potential that they will take on more ownership over their learning and develop the skills of how to learn, and that this can also change the power relationships between teachers and students (Hipkins, 2006). These outcomes are important, because it is recognized that "schools are not the sole sources of knowledge in society anymore" (Osborne, 2007, p. 110). Inquiry learning in science is also likely to require more and more use of digital technology in the collation, analysis, and representation of data, something that is known to engage students in the learning process (Roth et al., 2008). Subsequently, students are encouraged to network and collaborate, and this may also include web-based communication tools to share information (Feldman, Konold, & Coulter, 2000). Such web-based technologies can support students' gathering, sharing, or disseminating information, locally or remotely, and may include the use of websites, email, as well as audio and video applications (Khoo, 2010). ICT has the potential to support student investigations in science, if they can use the technology to collect, share, and communicate information, and network with each other and communicate beyond the classroom confines. At its core, inquiry learning in science recognizes that learning is a cognitive and social endeavor shaped by the attitudes and ideas that learners bring into the learning environment (Schwartz, 2008). This means that teaching and learning science with technology is a process of negotiation and transaction using tools and artifacts, which bring with them their own social, cultural, and cognitive dimensions. McKinley (2005) suggested that "…all knowledge reflects and has embedded in it the values of the culture from which it is produced" (p. 229) and, as such, knowledge cannot be seen as static, but rather constructed, recycled, and shared. With this in mind, collaboration among learners, where they can network and get access to, and share, information, is at the core of inquiry in science. Conceptualizing networking technologies in support of science inquiry affords theorizing and conceptualizing how interactions among teachers, students, outside people and information can be mediated through technology in new ways. This is so, because collaboration and networking in science inquiry means also to think about new spaces of learning, where multimodality, asynchronous and synchronous communication allow different actors to come together as a learning community.

Not surprisingly, the interest of researchers in teachers' technological pedagogical content knowledge (TPCK) is increased (Mishra & Koehler, 2006). This research is focused on unpacking what it means, when teachers apply their knowledge about technology to integrate it with their pedagogical and content knowledge, which requires a careful orchestration of these three knowledge bases. Notably, when teachers integrate the use of digital technology into their teaching, they draw on their own and their students' histories of prior use of a particular ICT tool, and how they anticipate it might be used in a content-specific context.

The notion of teachers orchestrating their students' collaboration and networking in science affords new ways to conceptualize teacher pedagogy, because networking in the digital environments can also mean that classroom walls are breached to create new hybrid spaces for school science. By this, I refer to digital environments that allow students and their teachers to communicate and exchange information beyond the time spent face to face in the physical classroom. The interactions between the members of such expanded classroom communities mesh old and new ways of talking, thinking, and interacting. I will continue from here on to construct an argument for a reconceptualization of TPCK by looking back and tracing some of the key developments of how research has theorized teaching practices.

Theorizing Teacher Pedagogy: Beginning Ideas

Teaching is a highly complex activity and this is the case for science as for any other subject. The interactions that can be witnessed in classrooms are the cultural products of the knowledge, practices, ideas, and artifacts that teachers and their students

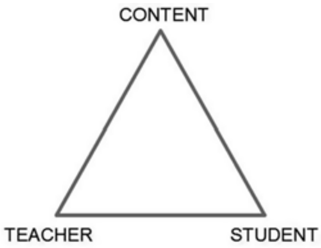


Fig. 1 "*Fach didaktik*" triangle adopted from Künzli (2000)

bring to class. It is the careful orchestration of teachers' pedagogy, their understandings about their specific content and its challenges, and their knowledge about their students that informs whether they select specific artifacts, or technology, to support and amplify opportunities for learning. Traditionally research concerned with teacher pedagogy addressed those with an interest in teacher training and professional development.

In this section, I will describe how subject-specific teacher pedagogy has been discussed and conceptualized differently. I will start with a focus on the German "*Didaktik*" tradition before continuing with the American Curriculum tradition. Only few scholars have examined those different traditions. Van Dijk and Kattmann (2007) have been a notable exception and say that writing about those traditions is not about making comparisons, but to show the different ways that teachers and their role in relation to teaching specific content has been discussed. This is also important when the purpose of the examination is to expand theoretical frameworks, as it is the case in this article.

In Europe, including the Nordic and central European countries, but specifically in the German-speaking countries, teacher education has been theorized and included into teacher education in order to equip future teachers with the competencies to plan, enact, and think about teaching. This resulted in a discourse that was concerned with general and subject-specific pedagogy. More precisely, the German school of teacher education distinguished between "*allgemeiner Didaktik*," which can be translated to general teaching theories that underpin how "to plan, to enact, and to think about teaching" (Van Dijk & Kattmann, 2007, p. 886) and "*Fach didaktik*," the teaching theories that are specific to a subject, such as, science or mathematics.

Theories in "*Fach didaktik*" concentrate on the interrelationship between subject specific content, teacher, and student. This relationship has been also expressed visually in form of the "*Fach didaktik*" triangle (see Fig. 1). The triangle shows the connections between the teacher, student, and content, and identifies them as three discrete but connected entities.

Theorizing teacher pedagogy in this way and making it part of teacher education shaped the way teachers perceived their roles and responsibilities, and contributed to European teachers developing a sense of autonomy in their teaching (Van Dijk & Kattmann, 2007). This is so because it was left to the individual teacher's professional judgment to bridge between prescribed learning goals and specific teaching strategies. "*Fachdidaktik*" was and still is a part of European teacher education with

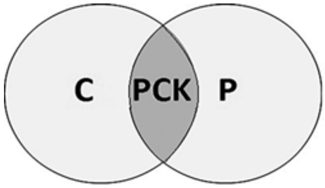


Fig. 2 PCK model adopted from Shulman (1986)

an aim to offer "a thorough analysis of the subject matter" (Van Dijk & Kattmann, 2007, p. 887).

In contrast, early American teacher education presented a more rigid hierarchy, where research of teacher pedagogy was typically reserved to universities (Van Dijk & Kattmann, 2007). The American teacher pedagogy research did not pay much attention to content (Shulman, 1986). This neglect resulted in a separation of several fields of study, including curriculum studies and instruction studies. Curriculum studies were concerned with curriculum implementation and construction, and the research concerned with instruction that measured outcomes and methods (Hopmann & Riquarts, 2000). When Shulman (1986) argued for the need to conceptualize pedagogical content knowledge (PCK), he drew attention to the gap in theorizing content-specific teacher pedagogy and that this would intersect previously separated fields of curriculum and instruction studies (Gess-Newsome, 1999). Shulman's (1986) work was not only significant, because he recognized content knowledge as "the missing paradigm" (p. 6) in research on teaching. Different to the concept of "*Fachdidaktik*," Shulman proposed and described, with his paradigm of pedagogical content knowledge (PCK), the overlap where pedagogy and content come together (see Fig. 2).

He emphasized the integration of content with pedagogy and argued that this would shape teacher-specific expertise. Shulman (1987) realized that: "Pedagogical content knowledge, is that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (p. 8).

One particular focus that emerged among those interested in PCK concerned the application of technology in support of teaching. Teachers' and students' growing access to digital technology drew researchers' attention to think about the properties and opportunities, also described as affordances, that technology has to offer (Norman, 1988; Pea, 1993).

Research concerned with educational technology had been concentrating on practices in case studies and teaching examples. A number of researchers argued however that such approaches looked at technology use only, without a closer inspection of what a teacher needed to know about technology itself to plan for teaching (Angeli & Valanides, 2005; Niess, 2005; Pierson, 2001). Among those scholars were also Mishra and Koehler (2006) who pointed out that research on educational technology at that time lacked theoretical and conceptual underpinnings. Mishra and Koehler's (2006) criticism targeted research focusing primarily on teacher activities and practices, and stressed the importance of reconceptualizing the theoretical framework of PCK. They wrote: "Having a framework goes beyond merely identifying problems with current approaches; it offers new ways of looking at and perceiving phenomena, and offers information on which to base sound, pragmatic decision making" (p. 1019). Selwyn (2011) highlighted three issues for research to consider and stated that all too often the focus is primarily on the materiality of technology. He stated that, while educational technology requires understanding how artifacts and devices work, this needs to be considered before they arrive in the educational setting. Research ought to concentrate on the opportunities technology can offer through activities, interactions, and cultural practices, and what this means in an educational setting. Theorizing technology and education also needs to consider how social arrangements and organizations, the context in which educational technology is set, are shaped (Selwyn, 2011). This suggests that a theoretical framework for teacher pedagogy with technology will need to consider artifacts, practices, and contexts, and how these factors come together.

A Rationale for TPCK

Many researchers have extended on Shulman's (1986) argument for PCK (i.e., Carlsen, 1999; Gess-Newsome, 1999; Magnusson, Krajcik, & Borko, 1999). Continued research contributed to unpacking further why and how aspects of a subject can be best organized, adapted, and represented for teaching–learning purposes. Shulman (1986) drew attention to why pedagogy and content should not be considered as separate entities of teacher pedagogy, but as intertwined types of knowledge. However, the increase of teachers' accessing and using digital technology drew attention to some aspects within Shulman's notion of PCK that did not adequately address "what teachers need to know in order to appropriately incorporate technology in their teaching" (Mishra & Koehler, 2006; p. 1018). Mishra and Koehler (2006) argued that technology in education needs to be viewed not as a separate domain, but one that overlaps, interacts, and interferes with how content and pedagogy are enacted and therefore needed to be conceptualized as "a new triad" (p. 1026). Subsequently, the notion around technological pedagogical content knowledge, or TPCK, revolves around identifying the complex interactions between teachers' knowledge of content, pedagogy, and technology (see Fig. 3). The acronym TPCK was later changed to TPACK (Thompson & Mishra, 2007), but, since scholars use both terms interchangeably, both terms are used in this review.

Mishra and Koehler (2006) wrote that, at the confluence of the three components, TPACK goes beyond what the individual parts encapsulate and that "viewing any of the components in isolation from the others represents a disservice to good teaching" (p. 1030). TPACK, thus, represents the expert knowledge teachers draw on when they use technology to support their teaching.

To strengthen this argument, it helps to explain what is meant by technology. Technology "refers to more than just the material tools and artifacts … used to do something" (Selwyn, 2011, p. XX). It includes practices and processes, but also a consideration of social contexts. Technology transforms activity, not always to the

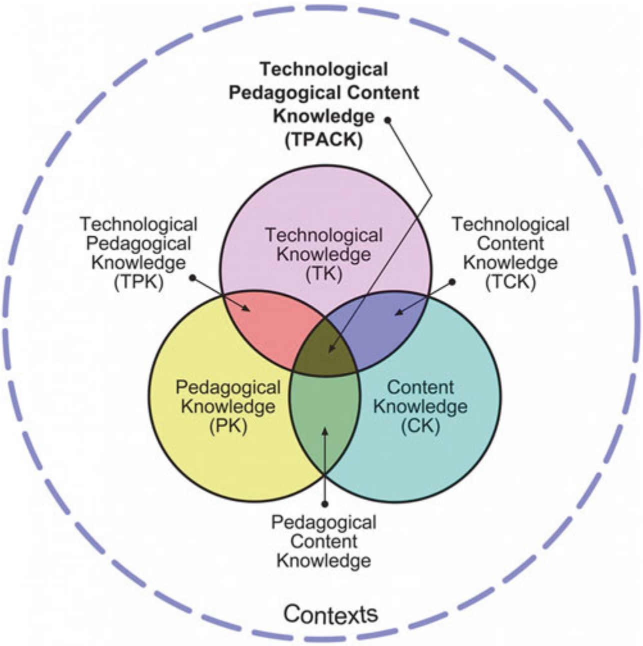


Fig. 3 The TPACK model. (Reprinted from source http://tpack.org/ with permission)

better, but this means that it is consequential in nature. For instance, a microscope affords magnification of small-to-the-naked-eye items. The outcomes from using such technology may be compromised by a person's understanding about the magnification process, and knowledge about how to operate the microscope, the ability to prepare and position an object in the correct way, using the right magnification, and being able to draw sensible conclusions from what can be observed. The microscope mediates the transformation process of the object of interest, but the outcome of this transformation depends on many more factors than a working optical microscope. Textbooks can also be described as technology, because they represent designed artifacts. However, the outcome from using textbooks can range from passive, didactic, and instructional to learner-centered and imaginative (Selwyn, 2011). Schwartz (2008) noted that, unless teachers perceive technology tools as cognitive tools, it will be difficult for them to use them effectively, and he cautions that the inability to select "teaching materials as tools" (p. 392) is the cause for many problems experienced in classrooms.

This is what TPACK tries to address, because it is about the integration of teacher knowledge with what they know about the affordances of technology in support of teaching and learning specific subject matter (Norman, 1988; Pea, 1993; Webb, 2005). Mishra and Koehler's (2006) framework theorizes effective teaching with technology, so that predictions and inferences can be made with the context in mind, where this teaching occurs, to move away from generic pedagogical ideas to the causal relationship of technology integration.

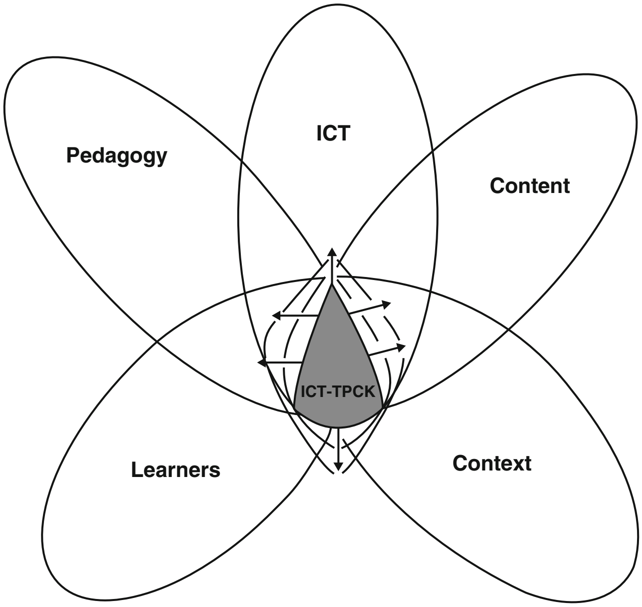


Fig. 4 ICT-TPCK model adopted from Angeli and Valanides (2009) (reprinted with permission)

Angeli and Valanides (2009) refined the notion of TPCK to describe ICT-TPCK as:

…tools and their pedagogical affordances, pedagogy, content, learners, and context are synthesized into an understanding of how particular topics that are difficult to be understood by learners… can be transformed and taught more effectively with ICT, in ways that signify the added value of technology (p. 159).

This idea was also supported by Graham (2011), who noted that Mishra and Koehler (2006) did not distinguish between the types of technology available to teachers. Specifically, when teachers use digital technology, they not only need to know how to use and what to expect from a particular technology, but they also need to know whether their students have the skills and knowledge to identify the affordances of digital technology (Banister & Reinhart, 2011; Webb, 2005). Angeli and Valanides (2009) conceptualized ICT-TPCK as a strand of TPCK, since it specifically addressed the integration of ICT in the teaching and learning environment. The authors also highlighted the necessity to theorize what it means to incorporate a learner's known difficulties with specific content and the knowledge of the context where learning takes place (see Fig. 4).

Angeli and Valanides' model conceptualizes that a teacher's ICT-TPCK is shaped by ICT, as the particular type of technology in combination with the other factors including content, context, as well as learners and pedagogy.

This argument is also interesting, because the authors connect what it means to consider a particular content, with its potential to being supported through ICT, and also that this requires a teacher's awareness of what he knows about his students' ability to use ICT, so it can help to transform and enhance their learning. In the case of inquiry learning in science, this is an important consideration, particularly if students get opportunities to develop their agency and authority over their learning.

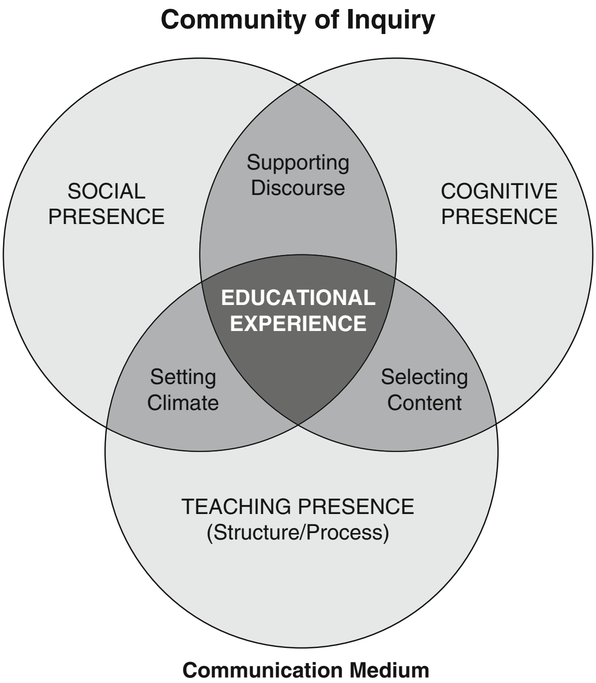
The Community of Inquiry Framework and TPCK

When students investigate their questions as part of their science inquiries they frequently need to communicate with others to seek clarifications, share findings, or access new information. This may involve communication within a classroom community and also with others outside the classroom. It is not uncommon that ICT tools are used to support this form of interaction, utilizing multimodal formats of communication (i.e., text: email or chat rooms; visual: video; audio: Skype). This also allows classroom communities to expand their learning activities beyond what happens in the classroom during normal classroom times, provided of course that there is access to the Internet for all parties involved.

This deliberate inclusion and blending of the face to face with virtual learning interaction has been of particular interest to those involved in higher education research, because universities have taken much interest in offering online courses and programs (Garrison & Vaughan, 2008; Vaughan, 2007). Garrison, Anderson, and Archer (2000) conceptualized what it means to think about teaching online communities and proposed a framework they coined *Community of Inquiry* (CoI) framework. This framework theorizes networking as the communicating, connecting, and coming together of communities using digital means. Importantly, CoI tries to unpack what teachers need to think about, and how to carefully orchestrate and string together different elements when teaching and learning happens in digitally networked environments (see Fig. 5).

The CoI framework describes three elements: social presence, cognitive presence, and teaching presence. With social presence, the authors are pointing out that online environments shape the identity of those who belong to those communities. Learners have a shared purpose and goal for their inquiry, and invest on both a social and emotional level into this type of activity (Garrison & Arbaugh, 2007). Cognitive presence describes the intellectual engagement and becomes more so apparent when online relationships are established and academic goals are being pursued. Cognitive presence is also signified by the refinement process of ideas among members of online networks and indicates the need for reciprocity among community members. This process also involves that ideas move forward to a point where learners are in a position to integrate and apply them. Finally, teaching presence builds on teachers' knowledge and awareness of both social and cognitive affordances to then carefully develop the pedagogical strategies needed to support learning aims and goals. Significantly, Akyol, Garrison, and Ozden (2009) talk about the shared roles and responsibilities that teachers and students are taking, and that the teacher, in this situation, should be conceptualized as a facilitator and guide who moves discourse and learning along. In today's schools it is not uncommon that teachers and their students use communication platforms, such as Moodle or create blogs or perhaps use videos to share ideas with each other and sometimes outsiders.

Fig. 5 Community of inquiry model adopted from Garrison and Arbaugh (2007) (reprinted with permission)



Learning activities that focus on multimodal discourse imply that reading, listening, responding to others, and seeking clarifications on ideas in the online environment can allow for additional meaningful learning experiences in science (McCrory, Putnam, & Jansen, 2008).

However, the online learning context carries with it new layers of complexity. Angeli and Valanides (2005) emphasized that socially situated knowledge is highly contextual and that context has to be considered in the same way as pedagogy, ICT, and learners. They stated that the understanding teachers have about what works and what does not, with *their* students in *their* school, greatly impacts on the selection and execution of teaching and learning tasks. When learning activities include that, students communicate with each other and sometimes outsiders, and when such interaction happens not only during but also outside the normal class time, new contextual rules apply. For example, working in class on a computer during class time means that a student has to accomplish certain tasks within a given time frame, while being at home, or outside the classroom, a student can take time to read, think about, and respond. When teachers plan to include teaching with ICT that goes beyond defined classroom times, it requires the careful orchestration of a very particular ICT pedagogy.

New Hybrid Spaces for Science Learning

When learning in online environments allows that different groups, or cultures, engage with each other and students mix new and old engagement practices, hybrid or third spaces are created (Gutiérrez, Baquedano-López, Alvarez, & Chiu, 1999).

For example, a hybrid space may develop when students communicate outside their normal class time visually (through video) or in writing (using email, podcasting, etc.) with each other, or outside people, and digital resources. For asynchronous learning activities, this may mean that students, who are less dominant in a face-to-face classroom, get more time to think about, voice their ideas, and make contribution to the joint meaning-making process. In such a case a teacher needs to conceptualize carefully what this means for the teaching. Not only will a teacher need to think about ICT in relation to pedagogy, learners, and content, but the specific considerations concerning the context need to include whether and how rules and practices change when students are working from home, away from the classroom. Such different joint activities need to be carefully coordinated to be part of the planning of the bigger learning context in order to become “a resource for learning in moment-to-moment interaction among students” (Gutiérrez et al., 1999, p. 87). A conceptualization of what it means to think about a teacher’s ICT-TPCK that includes the blending of in class and outside class learning environments may require further explorations.

Expanding the Notion of ICT-TPCK Further for Future Discussions

Graham (2011) argued that solid theoretical frameworks are essential to build, strengthen, and extend fields of study, in particular in the rapidly rising field of educational technology. He argued that it is particularly important to unpack and understand the components of frameworks, so that research can apply appropriate instruments to interrogate, measure, and describe when and how teaching and learning with technology occurs. Graham (2011) is critical and challenges researchers that too little emphasis has been placed on a good understanding of the theoretical frameworks, but rather that too often they are being used unchallenged without careful examination of their hidden complexity.

Reviewing the five theoretical frameworks that were discussed in this chapter allows identifying how the frameworks have conceptualized teacher pedagogy. This does not necessarily imply that those frameworks have built their ideas in a linear and gradual fashion on top of each other, but rather that looking across those frameworks allows for an examination how they have conceptualized teacher pedagogy and what can be learned from it.

Table 1 provides a simplified overview over the frameworks presented in this article.

Fachdidakik conceptualizes teacher pedagogy, but does not identify it as a unique area of teacher knowledge. PCK achieved this by identifying the confluence of pedagogy and content knowledge as a distinct field, but did not conceptualize the complexity of technology. TPCK or TPACK emphasized the need to address the practices and processes specific to technology. While ICT-TPCK defined this concept even further by conceptualizing the specificity of ICT and what this means for teacher pedagogy with a particular focus on the importance of the context. The COI

Table 1 Five frameworks concerned with teacher pedagogy

	Fach-didaktik	PCK	TPCK/ TPACK	ICT-TPCK	COI
Key components	Teacher, content, student.	Pedagogy, content, and intersection where the two meet	Technology, pedagogy, content, and intersection where the three meet	ICT (specific technology), pedagogy, content, learners, context, and intersection where the five meet	Social presence (online context, shaped by emotional investment of learners), cognitive presence (content and task dependent), teaching presence (defined by content and context)

framework problematized teacher pedagogy in the online learning environment as a space that is distinctly different to the face-to-face environment to outline the social, emotional, and cognitive dimensions of learning, and what this means for teaching.

A teacher pedagogy framework that includes the blending of formal classroom contexts with hybrid online contexts, as it can be the case in inquiry learning situations in science, may justify an expansion of Angeli and Valanides (2005) ICT-TPCK model to conceptualize what it means when different learning contexts are part of the learning experience with ICT technology. A possible model is suggested in Fig. 6. In this model, Pk stands for pedagogical knowledge, ICTk for knowledge about ICT as a technology, Ck stands for content knowledge, Lk is the knowledge a teacher has about his learners, Cxk1 and Cxk2 should identify different contexts or learning spaces, resulting in their confluence in a specific type of ICT-TPCK that identifies blended learning environments.

This adaptation of ICT-TPCK is not a new model per se, but rather an expansion of Angeli and Valanides' model under consideration of what has been put forward in the CoI framework. This ICT-TPCK model that considers blended learning environments is meant to prompt future research to consider, test and query whether such an expansion is useful, warranted, or even needed. Future research may need to continue by critically reviewing conceptualizations of teacher pedagogy, particularly with the rapidly changing teaching and learning environments and approaches involving ICT. Careful reexaminations of ideas may need to foreground aspects and help to express what it means when teachers use ICT during classroom time and beyond. In order to do so, future research should consider the history of the process of theorizing teacher pedagogy in order to respond to the growing awareness of teaching and learning complexities. Such approaches will help to unpack ideas and inform researchers, teacher educators, and teachers when they apply, think about, or plan with their TPCK in a combination of face-to-face and online learning environments, targeting to expand their students' opportunities to learn science and enhance the possibilities students have to express, discuss, and develop their ideas.

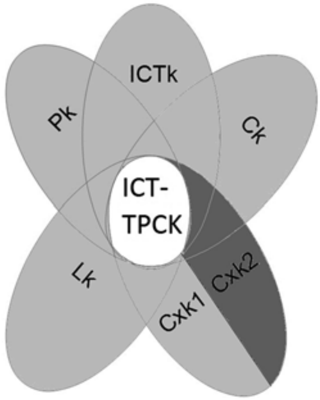


Fig. 6 ICT-TPCK model that considers blended learning environments

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Design and Implementation of Educational Scenarios with the Integration of TDCK: A Case Study at a Department of Early Childhood Education

Aggeliki Tzavara and Vassilis Komis

Introduction

The increasing current demands for technological literacy, in combination with the limited efficiency of the educational programs concerning the training of educators in the effective integration of Information and Communication Technologies (ICT) in Education, have emphasized the demand for the definition of a theoretical model for the implementation of ICT in the educational process (Duran, 2000; Koehler, Mishra, & Yahya, 2007; Moursund & Bielefeldt, 1999).

Such a model, based on valid theoretical foundations and defining novel, constructive and robust strategies of teaching and learning through ICT, will provide more possibilities to the educators and enable them to further implement innovative processes in their classrooms (Angeli & Valanides, 2005, 2009; Koehler & Mishra, 2008; Niess, 2005; Valanides & Angeli, 2002). In view of this issue, researchers seem to intensify their efforts to construct a new theoretical foundation which will extend the concept of Pedagogical Content Knowledge (PCK). PCK was introduced by Shulman (1986) in an attempt to describe the link between Content and Pedagogical Knowledge.

Following the aforementioned reasoning, this study aims at proposing a further analysis, enrichment, and specialization of Technological Pedagogical Content Knowledge (TPCK): the Technological Didactical Content Knowledge (TDCK). The TDCK emerged from the need to contextualize and provide with a theoretical framework the design of pedagogical activities with the use of ICT in a university department of Early Childhood Education. Specifically, we propose replacing the Pedagogical Knowledge (PK) with Didactical Knowledge (DK) to take into account modern approaches stemming from teaching each subject area. Therefore, this

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model emphasizes the individual characteristics of each subject area (Didactics) and not only the general pedagogical approaches (Pedagogy). We also elaborate on the implementation of the proposed theoretical framework on the development of educational scenarios with the use of ICT by student teachers. More specifically, TDCK is based, applied, and validated in the education of future preschool teachers in the context of two undergraduate courses in the Department of Early Childhood Education of the University of Patras.

From the Pedagogical Content Knowledge to the Technological Pedagogical Content Knowledge

Shulman (1986), considering that research in teaching and teacher preparation did not adequately address the importance of the content of the subjects to be taught, introduced the term PCK. PCK is therefore defined as the intersection between the Pedagogical Knowledge and the Content (Fig. 1). It also constitutes the framework according to which each teaching module should be restructured, so that the learning process can be facilitated, based on the characteristics, the interests, and the potential of the students (Bullough, 2001; Gess-Newsome, 1999; Mishra & Koehler, 2006; Shulman, 1987; Suharwoto & Lee, 2005; Van Driel, Veal, & Janssen, 2001).

Shulman (1986) considered PCK as the foundation of the teaching process. He described the following elements of PCK: (1) Content knowledge: the knowledge of the content of each module; (2) General pedagogical knowledge: the principles and strategies, which should govern teaching and learning; (3) Curriculum knowledge: knowledge of the current curriculum; (4) Knowledge of the learners and their characteristics; (5) Knowledge of the educational context: knowledge of the educational environment; and (6) Knowledge of the educational objectives, purposes, and values. Further research built upon these units and introduced additional elements and features for better delineating the concept of PCK (Cochran, Derutier, & King, 1993; Geddis, Onslow, Beynon, & Oesch, 1993; Grossman, 1990; Lederman, Gess-Newsome, & Latz, 1994). Nevertheless, even though researchers agree in specific common principles, there seems to be no globally accepted definition of PCK (Angeli & Valanides, 2009).

The rapid developments in the field of education, combined with the developments in technology, further stress the importance of a seamless and constructive integration of ICT in the teaching and learning processes. This integration seems to be the goal of current research in the area. In the framework of their investigation for the most appropriate approach for the examination of the integration of ICT in education, the addition of the term "Technology" in Shulman's (1986) initial conception of PCK has been proposed by a number of researchers. A new term was therefore introduced: the term "Technological Pedagogical Content Knowledge" (TPCK). Margerum-Leys and Marx (2003) have initially referred to the "PCK of Educational Technology." They distinguish between three types of educational technology, namely, (a) Content Knowledge: the knowledge and the method through

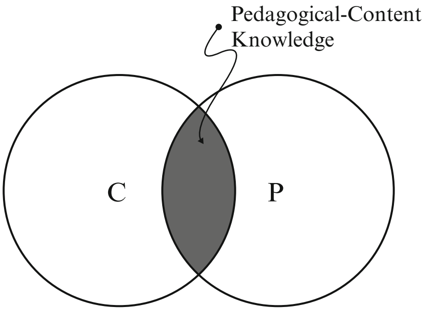


Fig. 1 Pedagogical Content Knowledge (Shulman, 1986)

which the potential of technology is implemented in the teaching and learning processes, (b) Pedagogical knowledge: knowledge and employment of the appropriate pedagogy through the use of technology, and (c) PCK of educational technology: "…it is knowledge, which arises from experience with using technology for teaching and learning, and which, in turn, applies to the use of technology for teaching and learning" (Margerum-Lays & Marx, 2003, p. 6).

Furthermore, Pierson (2001) argued—through her investigation of the relation between the use of ICT and the different teaching approaches, with the aim to clarify the term "integration of technology"—that a "good teacher" may have acquired expertise in the Content Knowledge and the Pedagogical Knowledge, but Technological Knowledge is also essential for an effective integration of technology in teaching any content knowledge.

Niess (2005) defined TPCK as the unification of a continuous process of development of two main components: (a) the knowledge of subject area with the development of technology and (b) knowledge of teaching and learning. She referred to a constant process, as an aspect which has to be considered by the educators, so that their teaching approaches become flexible and adjustable to the requirements of each subject area and also to the use of ICT.

Guerrero (2005) introduced the term "Technological Pedagogical Knowledge," as a new framework of knowledge relevant to teaching and also to issues regarding the management of the classroom, the interaction between Content and Technology, and the pedagogically appropriate perceptions for the use of the Technology in the classroom. In his analysis, the theoretical model of the Technological Pedagogical Knowledge was presented as a system of individual constructs, which emerge from the field of cognitive psychology, and are based on specific distinctions among and within the theoretical constructs of knowledge and perceptions.

Arguing that the term TPCK requires further clarification, Angeli and Valanides (2005, 2009) proposed the ICT-TPCK. They elaborated that:

> We define ICT knowledge as knowing how to operate a computer, knowing how to use a multitude of tools/software, and knowing about the affordances of tools. ICT-related PCK can be described as the ways knowledge about tools and their affordances, pedagogy, content, learners and context are synthesized into an understanding of how particular topics can be taught with ICT (pp. 3031).

ICT-TPCK includes, beyond the three main categories of knowledge (Content, Pedagogy, Technology) two additional elements: knowledge of the characteristics

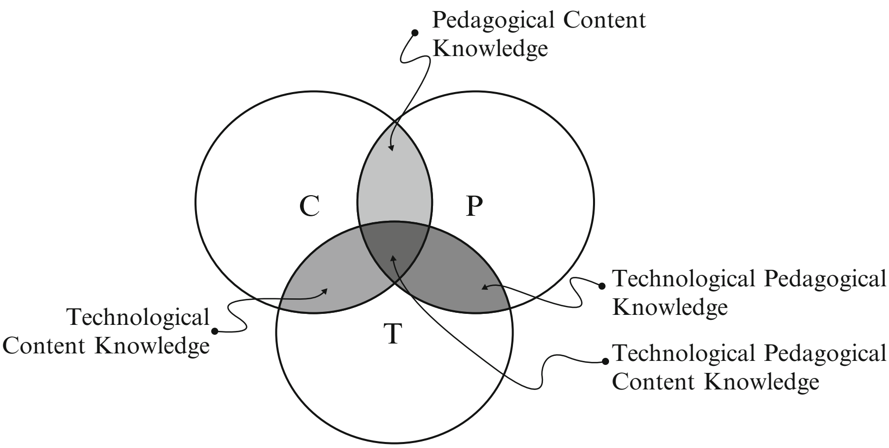


Fig. 2 Technological Pedagogical Content Knowledge (Mishra & Koehler, 2006)

of the students and knowledge of the environment within which the educational process takes place.

> ICT–TPCK is a body of knowledge that grows continuously with systematic engagement in rich teaching experiences. This means that any program, or instructional design model, that aims at the development of ICT–TPCK must consider teachers' knowledge and classroom experiences, and use them as the starting point for initiating efforts aiming at the development and/or growth of ICT–TPCK. (Angeli & Valanides, 2009, p. 159).

Mishra and Koehler (2006) also investigated the term TPCK over a long period of time. They concluded their work with the proposal of the term TPACK (Koehler & Mishra, 2008; Mishra & Koehler, 2006). This new term accurately represents the two main arguments of the researchers: (a) the acronym emphasizes the three distinct fields of knowledge included in the concept of TPACK (Technology, Pedagogy, and Content); and (b) the fact that these three elements have to be studied as a single system (Total PACKage). TPACK (Fig. 2) is, therefore, a concept consisting of three distinct fields of knowledge (Content, Pedagogy, Technology) and is also supplemented by the interactions among these fields, as presented in Fig. 2.

Technological Didactical Content Knowledge

International research in the field indicated that further clarification of the theoretical model of TPCK is required. This requirement led to the introduction of new, enhanced, or modified models (Angeli & Valanides, 2005, 2009; Hammond & Manfra, 2009; Jang & Chen, 2010; Jimoyiannis, 2010; Lee & Tsai, 2010; Mishra & Koehler, 2007; So & Kim, 2009). In their majority, these models constitute recommendations relevant to the design and implementation of educational programs, mainly in the field of Science and Mathematics. Their objective was an increasingly more meaningful integration of ICT in the teaching and learning processes. These studies highlighted the particularities of each subject area for the construction of

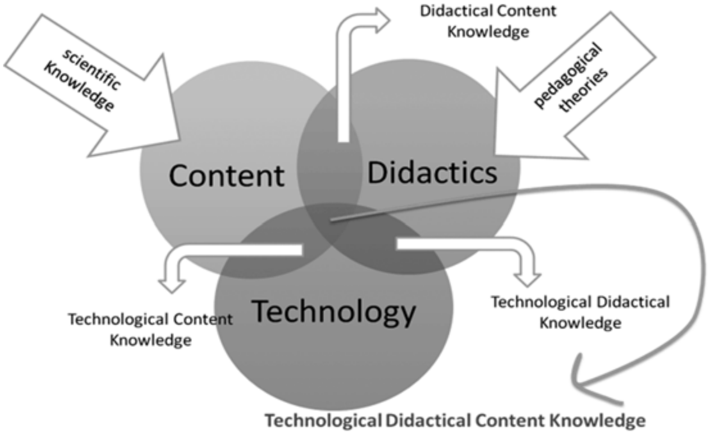


Fig. 3 Technological Didactical Content Knowledge

TPCK, by focusing on the individual fields. These particularities were not so much relevant with the principles of general pedagogy, but rather with the specific didactic principles, closely relevant to each individual subject field.

In this paper, the model of the "Technological Didactical Content Knowledge" (TDCK) is proposed. TDCK is proposed with the aim to address the aforementioned requirements for the construction of a new, enriched theoretical model for the implementation of ICT in education. The constructs of TDCK will be further presented in this section (Fig. 3). TDCK is based on the three main knowledge areas (Content, Didactics, Technology) and is related to their three separate combinations. The intersection of these constructs constitutes the conceptual definition of TDCK. This chapter concludes with the application of the proposed model on student teachers of early childhood education.

Content Knowledge

One of the three main constructs of TDCK is Content Knowledge (CK). In the proposed model, CK refers to the educational content which includes knowledge of the curriculum, knowledge of each subject area in early childhood education, and the relevant teaching objectives. Based on the current curriculum of Greek early childhood education, content consisted of five subject areas: Mathematics, Greek Language, Study of the Environment, Creation and Expression, and Information Technology. It has to be highlighted that this knowledge of the five subject areas, particularly in early childhood education, does not refer directly to the scientific knowledge (or scholar knowledge), as it is defined in the respective scientific fields but it rather refers to knowledge to be taught (a didactically reconstructed knowledge); knowledge which has emerged from appropriate processes of didactic transposition, as proposed by Chevallard (1991). Student teachers of early childhood education will not become experts in the different subject areas (mathematics, sciences, language, etc.). They acquire the scholar knowledge in these subjects through introductory classes to mathematics, science, biology, language, informatics, etc., but under no circumstances this knowledge is at the same level as the respective knowledge acquired, for example, by a future mathematician or physicist throughout their studies.

Didactical Knowledge

The second main construct of the TDCK model is the Didactical Knowledge (DK). The term DK refers to the understanding of the concepts and methods in the field of the Didactics of Sciences. The Didactics of Sciences constitutes a separate scientific field within the framework of the Sciences of Education, with distinct concepts, specific methods and techniques, and a clear conceptual framework. The Didactics of Sciences currently extend to all the subject areas and aim at the extensive study and the definition of the methods through which the students learn specific subjects (e.g., mathematics, history).

Therefore, at this point, we do not refer to general pedagogical principles and concepts, as it is usually proposed in different models of TPCK, but to specialized concepts of the Didactics of Sciences, further specializing in accordance to the subject area (e.g., sciences, language). Most of these concepts derive from the field of educational and cognitive psychology and are appropriately adapted to the framework of the Didactics. Such concepts are, for example, the ideas and the representations of the students, the cognitive conflict, and the conceptual change. Other concepts have been developed in the framework of the Didactics of Sciences, such as, the didactical transposition, the didactical contract, and the didactical situation. In this context, it is essential that student teachers have adequately mastered these concepts, by appropriately adapting them to each teaching objective.

Technological Knowledge

Technological Knowledge (TK) is the third main area of knowledge of TDCK (use of computers, peripherals, software, etc.). TK refers to the technological competence of the student teachers, and their degree of familiarization with the use of computer environments for the design of educational activities. TK is certainly linked to current advances in digital technology. Although it has to be highlighted that in the area of early childhood education, there are specific particularities and constraints. The student teachers have to also understand the limitations of technology for young children, as well as the appropriate specialized computer environments that can be used. They also have to be familiar with existing technologies and their applications in early childhood education (appropriate interfaces, technical features of the software and applications for children, etc.), as well as with the general limitations of the technology at the particular level of education.

Technological Content Knowledge

The Technological Content Knowledge (TCK) constitutes one of the intersections between Technological Knowledge and Content Knowledge. It is relevant to the possible added value of ICT employment for the design of educational activities in each module of the early childhood education curriculum. At this point, the particularities of preschool and early school age in relation to the existing digital environments have to be again highlighted. Each digital environment has its own affordances, and every future teacher has to be familiar with these affordances. Most of the existing computer environments, excluding the environments that have specifically been designed for early childhood education, cannot be directly employed in the particular education level, unless a number of adjustments are made. A conventional text editor, for example, can only be used for the development of language skills in early childhood, if the appropriate adaptations are made. TCK refers to the knowledge of all the relevant computer environments and tools that can be implemented, with the appropriate didactic approach to each subject area of early childhood education, as well as knowledge of the relevant specific adjustments required for this purpose.

Technological Didactical Knowledge

The Technological Didactical Knowledge (TDK) constitutes the intersection of Didactics and Technology. It refers to the knowledge of selecting the most appropriate method for the implementation of the available technological tools and also the knowledge of being able to choose the best possible use of ICT in order to have the best possible outcomes. In this context, the student teachers have to be able to select the appropriate affordances of the digital environments, so that they can implement the most effective teaching approach.

Didactical Content Knowledge

From the intersection of DK and CK, the Didactical Content Knowledge (DCK) emerges. It refers to the approaches through which the Didactics of Science is implemented in the teaching of each subject area. More specifically, DCK can be identified in the way the student teachers design, prepare, manage, and complete their activities, while employing the appropriate didactical principles, based on the didactics of each field (e.g., didactics of mathematics, didactics of physics).

Technological Didactical Content Knowledge

The concept of the TDCK emerges in the intersection of the TK, the DK, and the CK constructs. According to our proposed model, the Didactical Knowledge, the Content Knowledge, and the Technological Knowledge constitute one system, and each conceptual construct functions in close relation with the other construct. TDCK delineates the essential knowledge required by student teachers, so that ICT can be best implemented in the everyday practice.

TDCK in the Training of Early Childhood Education Students

In this section, we examine the application of TDCK in the design of educational activities and educational scenarios by student teachers of early childhood. Students of two undergraduate courses in the Department of Early Childhood Education of the University of Patras were required to design scenarios including educational activities based on the current curriculum, aiming at preschool and early school education children, and involving the use of ICT (Tzavara, Komis, Georgoutsou, & Siampou, 2012).

More specifically, the first course ("Pedagogical activities with (and for) computers in preschool and early school age") is offered during the third year of studies and aims at raising the awareness of the student teachers regarding the interdisciplinary field of ICT, through the design and the assessment of educational scenarios, which integrate ICT in the classroom. The second course ("Teaching of Informatics and ICT") is also offered during the third year, and aims at the description and analysis of the main concepts of the Didactics of Informatics and of ICT, and also of the particularities of Informatics, as a subject area in early childhood and early school education Georgoutsou et al. (2012).

Each course is structured in two parts: the theory part (3 h per week for 12 weeks) and the workshop part (2 h per week for 9 weeks) in groups of 20 students each. For the workshop part, the students are working together in teams, and they design technology-enhanced teaching scenarios. The courses also involve access of the students to online material, through an e-learning platform (Moodle). In this platform, the theory part, as well as links to the software that the students will have to become familiar with and employ in their scenarios, and additional support material are also posted. Furthermore, in the framework of the course, Web 2.0 tools, such as, blogs, wikis, and forums, are also used, for facilitating the cooperation of student teachers in the design of their activities, and for the final assessment of their scenarios.

The final assignment the students have to submit upon completion of their course involves the development of educational scenarios. These scenarios have to, certainly, be both relevant to the requirements of the early childhood curriculum and early school education, and to aim at the instruction and learning of different subject fields by employing the appropriate computer environments.

TDCK and the Design of Educational Scenarios

In this section, the concept of the educational scenario from the perspective of the TDCK will be presented. An educational scenario which includes ICT, describes the activities and the tools employed (abstract tools, such as schemata, software, or physical tools, such as special artifacts), which constitute both the starting point and also the framework within which the teaching and learning activities take place (Komis, Tzavara, Karsenti, Collin, & Simard, 2013). It involves the use of the appropriate didactic strategies and aims at the attainment of a teaching objective through the use of the appropriate computer environment (educational software or other material). In most of the cases, the scenario targets at the teaching and learning of one or more main concepts of the subject area of the curriculum (Misirli & Komis, 2015). The scenario may also approach concepts of different subject areas interdisciplinary, or it may target the learning of concepts beyond the curriculum.

For the design of a scenario, specific design and development stages have to be followed (Fig. 4). TDCK applies to all these steps of the design. More specifically, the design of the scenario consisted of seven stages (Komis, 2011):

A. The identification of the *teaching subject* of the scenario (title, class, e.g., pre-school, early school, or primary, subject areas involved, prerequisite cognitive skills, etc.). The teaching subject is based on the curriculum of early childhood

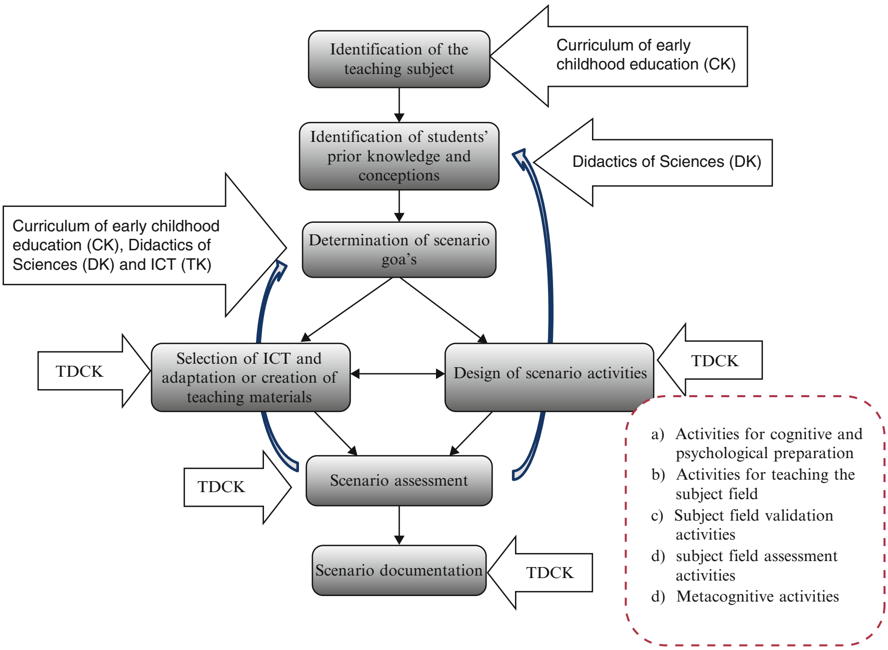


Fig. 4 Design stages of the educational scenario

education and may cover more than one subject fields or areas. Consequently, for this stage, content knowledge as described in the TDCK is essential.

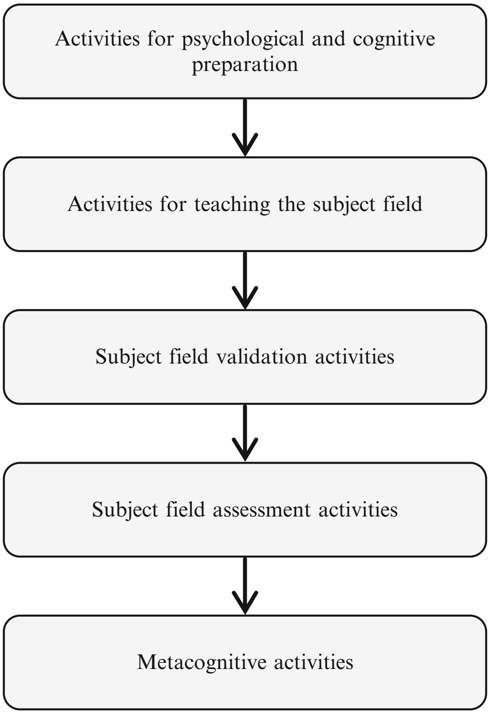
B. The identification of *students' prior knowledge and conceptions*: at this stage, ideas, perceptions, representations, possible errors, and potential difficulties of the children regarding the teaching subject are identified and discussed. For addressing these issues, knowledge of the content and general didactic knowledge do not suffice. Knowledge of the *didactics of the subject* as defined in the TDCK is also essential.
C. Determination of the *goals*: at this stage, the teaching objectives of the scenario are defined. The objectives are grounded on (a) the knowledge of the content and particularly the aims of the curriculum (they, therefore, are linked to the subject area); (b) the learning process as described by the didactics of the particular subject (they are objectives relevant to the exchange of specific ideas, overcoming cognitive obstacles, etc.); and (c) the employment of ICT (they are, therefore, objectives relevant to the knowledge of technology, so that the aim of the scenario can be attained). Consequently, at this stage, the CK, the DCK, and the TK are applied (objectives relevant to the required ICT knowledge of the student so that the scenario can be applied).
D. The *teaching material* of the scenarios and the required infrastructure. At this stage, the teaching material for the scenario and the necessary infrastructure are described. The student teachers, therefore, have to efficiently manage their CK, DK, TK, as aspects of the TDCK.
E. The management of the teaching process considering the *appropriate activities for the implementation* of the scenario in the classroom (teaching approaches and strategies, exploitation of the added value of ICT in the learning process, worksheets, etc.). This stage seems to be the most crucial one and is further examined later in this section.
F. *Assessment* (of student and scenario) and possible implications of the scenario. The assessment stage requires skills relevant to the CK, and particularly the curriculum, the DK, and the methods ICT can be employed, as effective assessment tools.
G. *Scenario documentation*. At this stage, the main stages of the scenario are summarized, while additional supporting guidelines can also be included (comments, teachers' instructions, suggestions for potential extensions of the scenario, references, etc.). This stage is relevant to a summary of TDCK, as this is adjusted for the particular educational scenario. It involves a succinct description of how the scenario implements specific computer environments for attaining the objectives of the curriculum, as these objectives are specified by the didactics of the particular subject field.

In Table 1, the above stages and their descriptions are summarized. On the left column, the different stages for the development of the educational scenario with ICT are presented, while in the remaining columns the relevant TDCK constructs, as described in this section, are indicated.

Table 1 Design stages for the educational scenario and relevant TDCK aspects

Educational scenario						
	TDCK conceptual constructs					
Design stages	Content Knowledge	Didactical Knowledge	Technological Knowledge	Didactical Content Knowledge	Technological Didactical Knowledge	Technological Content Knowledge
A. Teaching subject	X					
B. Students' prior knowledge and conceptions		X				
C. Teaching objectives	X	X	X			
D. Teaching materials	X	X	X	X	X	X
E. Activities	X	X	X	X	X	X
F. Assessment	X	X	X	X	X	X
G. Scenario documentation	X	X	X	X	X	X

Fig. 5 Activity categories



In stage E of the scenario development, in which the activities for the attainment of the learning objective are designed and developed, a number of different categories of activities emerge (Komis, 2011). These categories follow a specific sequence and are inextricably linked with each other. At this stage, TDCK is fully applied. For the management of the following activity categories (Fig. 5) the educator has to have acquired CK, DK, and TK, as well as their different combinations.

The activity categories are presented sequentially and are described further on Fig. 5. They are all organized at the basis of TDCK. Good knowledge of TDCK is required since the DCK, the TCK, the TDK, and their combinations (TDCK) are all essential for the design of the appropriate activities, effectively integrating ICT.

Activities for Psychological and Cognitive Preparation

The initial activities of the educational scenario refer to the psychological and cognitive preparation and are relevant to the establishment of an appropriate emotional climate in the classroom, the motivation of the children, the acknowledgement of the aim and the objectives of the lesson, and also the assessment of existing knowledge of the children, detection of any cognitive difficulties, and of the representations of the children.

Activities for Teaching the Subject Area

This stage usually constitutes the main and largest part of the scenarios, since at this point the target knowledge is introduced and most of the activities for the acquisition and construction of knowledge and skills are described.

Subject Area Validation Activities

The validation activities (activities for the comprehension and the integration of new knowledge) usually involve strategies similar to the strategies for the implementation of the teaching activities. They usually include questions and answers, practical problem solving, and transfer of the knowledge acquired in specific situations.

Subject Area Assessment Activities

Even though these activities constitute an integral part for the application of the educational scenario, they are examined in detail in stage F, which refers to the general assessment of knowledge acquired.

Metacognitive Activities

The metacognitive activities constitute an integral part of the scenario and are taking place both inside and outside the classroom. They usually involve a cross-examination and comparison of the initial knowledge and perceptions of the children, before the implementation of the scenario, with the knowledge acquired after the completion of the scenario. Homework may also be assigned, in accordance to the curriculum.

Discussion: Conclusions

The TPCK constitutes today one of the major conceptual models describing the integration of ICT in the educational process by student teachers and it is also used as a tool to study their daily educational practices when using ICT. As a conceptual model as well as an analysis tool, it is found in most literature concerning the educational uses of ICT. This model, because of its macroscopic characteristics, allows us to define and describe the basic knowledge needed to integrate ICT in an appropriate manner in the educational process and as an analytical tool allows us to observe and study many educational situations. However, given its generality, it does not often allow us to study in depth more concrete educational situations and functions. For this reason, there are often attempts of its enrichment so that it can be applied to the specific characteristics of individual subject areas or levels of education. In particular, the designing of daily educational practice, and in particular, the design and implementation of specific teaching and learning activities with ICT should (a) follow the general conceptual constructs deriving from TPCK and (b) take into account the specific characteristics that each educational situation presents. In other words, it must include specific stages of planning and implementation which should reflect the characteristics of TPCK. However these features, due to the nature of this model, are often very general, further analysis or enrichment is needed. This paper aims at contributing to this aspect.

More specifically, this chapter presents a new, enriched theoretical framework, TDCK, which was developed on the basis of TPCK by Mishra and Koehler (2006) and involves teaching particularities of each subject area. Therefore the TDCK model proposes the replacing of Pedagogical Knowledge with Didactical Knowledge and concerns the incorporation and utilization of its characteristics. We also present its integration by student teachers in designing educational scenarios with ICT. This model is based, applied, and validated in the education and training of future preschool teachers. The implementation and validation of the model are linked, by the student teachers, to the design and implementation of the educational scenarios. In particular, at the second part of the chapter, we present the stages of an educational scenario that is a set of educational activities and their content, developed and build upon the basis of the knowledge areas and their interrelation of the proposed model.

Student teachers are, therefore, trained not only on the theoretical framework of this model (TDCK), but are also required to implement it explicitly through the detailed design of an educational scenario. We, therefore, elaborate on the adaptation of the general model TPACK to the specific needs of teaching different subject areas and we further associate this adjustment with the design and implementation of educational scenarios with ICT.

Finally, we further describe the connection of the two proposed constructs (TDCK and educational scenarios with ICT) to point out their close relation. In this perspective, student teachers are required to have knowledge of both aforementioned frames, which seems to be in complete interdependence, for effective introduction and use of ICT in the educational process. In other words, the student teachers have to become familiar with TDCK, as a model for developing activities integrating ICT and also with the design process of the activities. This process, as previously described, is based on the structure of an educational scenario and the relevant stages corresponding to different TDCK concepts.

Concerning further perspectives, the proposed model should be applied on a larger scale (range and variety of courses) and validated with specific field studies under real conditions of student teacher's education. The analysis of both the designing and implementation of educational activities and the comparison between them using TDCK as an analytical tool seems also to be of particular interest.

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Technological Pedagogical Content Knowledge as a Framework for Integrating Educational Technology in the Teaching of Computer Science

Ioannis Ioannou and Charoula Angeli

Introduction

According to the Association for Computing Machinery (ACM) and the Computer Science Teachers Association, computer science is the study of computers and algorithmic processes, including their principles, their hardware and software designs, their applications, and their impact on society (ACM K-12 Task Force Curriculum Committee, 2003). At the same time, computer science is considered to be a young field in relation to others, and little is known, thus far, about the teaching of computer science topics and students' difficulties in understanding computer science concepts. Current related research efforts aim toward approaching the teaching of computer science in learner-centered ways taking into consideration learners' alternative conceptions or teachers' difficulties in teaching the content adequately, while at the same time the integration of educational technologies in the teaching of computer science is also a priority (Ioannou & Angeli, 2013; Kadijevich, Angeli, & Schulte, 2013).

In accordance with this line of research, the authors herein describe their efforts toward designing technology-enhanced instruction for the teaching of computer science concepts, taking into consideration learners' content-related difficulties and teachers' difficulties in effectively teaching the content. The framework of Technological Pedagogical Content Knowledge (TPCK), as proposed by Angeli and Valanides (2005, 2009), was adopted to guide the design of three computer science lessons, namely, (a) a lesson that targeted the teaching of three basic

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computer science concepts, namely, data, processing, and information, (b) a second lesson about the representation of data in computer language, and (c) a third lesson about the concepts of main memory (RAM) and secondary memory. The purpose of the chapter is to provide examples of learning activities with the use of educational technologies, and in particular spreadsheets, that were designed based on the principles of the TPCK framework.

Technological Pedagogical Content Knowledge

TPCK was introduced to the educational research community as a domain-general theoretical framework of what teachers need to know to teach with technology (Angeli & Valanides, 2005; Koehler & Mishra, 2005; Niess, 2005; Pierson, 2001). The research community has embraced with enthusiasm the framework and a substantial body of research has been published thus far (Voogt, Fisser, Pareja Roblin, Tondeur, & van Braak, 2013). The authors herein adopt TPCK as the framework for guiding the design of computer science lessons and conclude with their insights regarding the usefulness of TPCK in the domain of computer science.

While the authors acknowledge the fact that there are different theoretical conceptualizations about the construct of TPCK in the literature, in this study they adopted the transformative conceptualization of TPCK (Angeli & Valanides, 2005, 2009). The transformative view of TPCK conceptualizes TPCK as a unique body of knowledge. From this perspective, Angeli and Valanides (2009) proposed a model (shown in Fig. 1), where content, pedagogy, learners, technology, and context are regarded as significant contributors to the development of TPCK. TPCK is regarded as an extension of Shulman's (1986, 1987) Pedagogical Content Knowledge (PCK), which identifies the distinctive bodies of knowledge for teaching and highlights a special amalgam of content, pedagogy, learners, and context (Shulman, 1986).

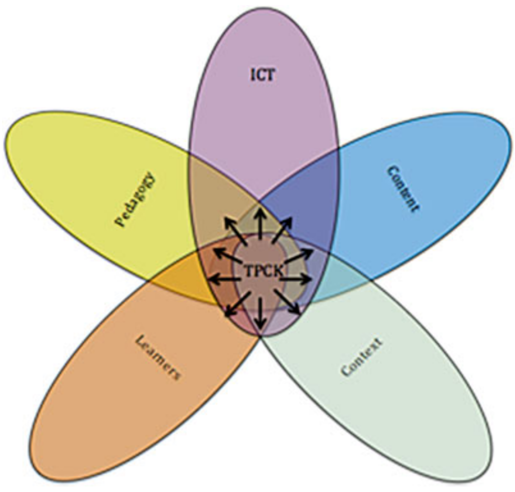

Fig. 1 Technological Pedagogical Content Knowledge (adopted from Angeli & Valanides, 2009)

Shulman's (1987) conceptualization of PCK goes beyond teachers' knowledge of subject matter and pedagogy per se and encompasses the dimension of how to teach and transform content into forms or representations comprehensible to learners, taking always into consideration learners' content-related difficulties.

Consequently, TPCK as a transformative body of knowledge is defined as knowledge about how to transform content and pedagogy with ICT for specific learners in specific contexts and in ways that signify the added value of ICT (Angeli & Valanides, 2009). As illustrated in Fig. 1, there are a number of individual knowledge bases that contribute to the development of TPCK; however, as it was found in a series of empirical studies (Angeli, 2005; Angeli & Valanides, 2005; Valanides & Angeli, 2006, 2008a, 2008b), growth in the individual contributing knowledge bases alone, without specific instruction targeting exclusively the development of TPCK, does not result in TPCK growth. Angeli and Valanides (2009) also proposed that TPCK, as a unique body of knowledge, is better understood in terms of competencies that teachers need to develop in order to be able to effectively teach with technology. A conceptualization of TPCK in terms of competencies has led to more robust and reliable ways of assessing learners' TPCK, bypassing measurement difficulties of the nature that researchers, who adopted other frameworks, reported in their studies (Archambault & Barnett, 2010; Cox & Graham, 2009; Graham, 2011; Niess, 2011). These competencies are related to knowing how to:

1. Identify topics to be taught with ICT in ways that signify the added value of ICT tools, such as, topics that students cannot easily comprehend, or that teachers face difficulties teaching or presenting effectively in class. These topics may include abstract concepts (i.e., cells, molecules) that need to be visualized, phenomena from the physical and social sciences that need to be animated (i.e., water cycle, the law of supply and demand), complex systems (i.e., ecosystems, organizations) in which certain factors function systemically and need to be simulated or modeled, and topics that require multimodal transformations (i.e., textual, iconic, and auditory), such as, phonics and language learning.
2. Identify appropriate representations for transforming the content to be taught into forms that are pedagogically powerful and difficult to support by traditional means. These include interactive representations, dynamic transformation of data, dynamic processing of data, multiple simultaneous representations of data, and multimodal representations of data.
3. Identify teaching tactics, which are difficult or impossible to be implemented by other means, such as, the application of ideas in contexts that are not experienced in real life. For example, exploration and discovery in virtual worlds, virtual visits (i.e., virtual museums), testing of hypotheses, simulations, complex decision-making, modeling, long distance communication and collaboration with experts, long distance communication and collaboration with peers, personalized learning, adaptive learning, and context-sensitive feedback.
4. Select tools with appropriate affordances to support 2 and 3 above.
5. Infuse computer activities with appropriate learner-centered strategies in the classroom. This includes any strategy that puts the learner at the center of the learning process to express a point of view, observe, explore, inquire, think, reflect, discover, problem solve, etc.

Technology Mapping: An approach for Developing TPCK

Technology Mapping (TM), as it is shown in Fig. 2, was introduced as an approach for developing teachers' TPCK (Angeli & Valanides, 2009). TM was proposed as an approach for mapping tool affordances onto content and pedagogy in powerful and transformative ways, enabling teachers to develop complex and interrelated ideas between the affordances of technology and their PCK. Angeli and Valanides (2009) argued that TM can engage learners in a process of developing technological solutions to pedagogical problems, by aligning teachers' PCK with knowledge about the affordances and constraints of various computer-based technologies. Mapping refers to the process of establishing connections or linkages among the affordances of tools, content, and pedagogy in relation to learners' content-related difficulties.

As shown in Fig. 2, context is an overarching factor in the process of designing learning with technology. The process of designing technology-enhanced learning

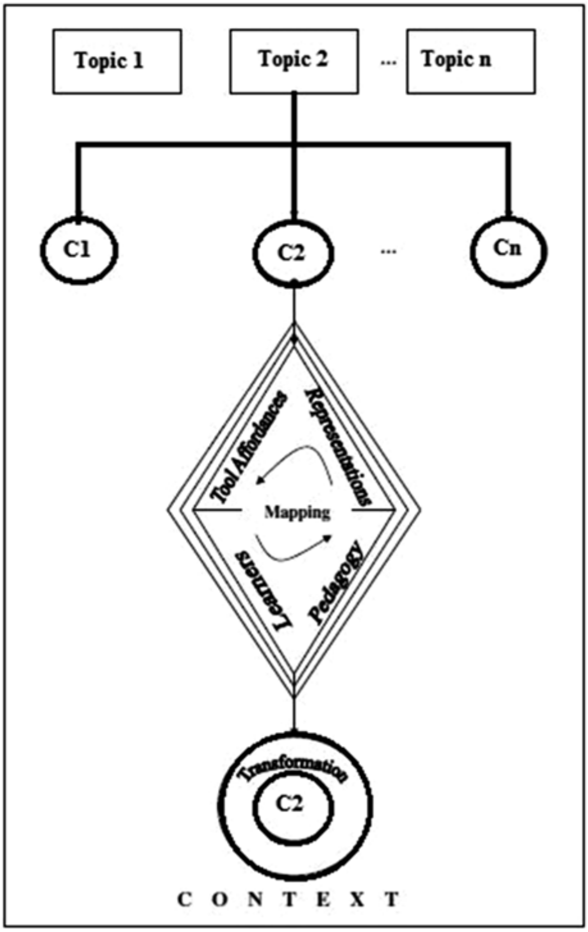

Fig. 2 Technology mapping (adopted from Angeli & Valanides, 2009)

is influenced by certain context-related factors, such as, teachers' beliefs about how students learn, teachers' practical experiences about what can and what cannot work in a real classroom, teachers' views about the role of technology in teaching and learning, teachers' adopted instructional practices, school's vision and educational goals. These context-related factors influence teachers' thinking about how technology is integrated in the classroom (Abbit, 2011; Niess, 2005; Ottenbreit-Leftwich, Glazewski, Newby, & Ertmer, 2010).

Furthermore, according to the model depicted in Fig. 2, teachers choose a specific content domain, which they find difficult to teach or students find difficult to understand. For the specific content domain, they identify topics, and based on their experiences, they indicate difficulties they face in making the most challenging aspects of the topics teachable to students, in connection with students' content-related difficulties. Subsequently, for each topic, teachers associate relevant content (represented as circles in Fig. 2) and tentative objectives based on learners' related alternative conceptions that need to be addressed. Then, teachers are engaged in iterative decision making in order to think how to go about transforming the content with technology into representations that are more understandable to learners. In doing so, teachers need to first decide how tools can be used to transform the content into powerful representations (upper part of the diamond) taking into consideration the specific needs of their students, and how to use technology in innovative ways to transform existing pedagogical practices in their respective classrooms (lower part of the diamond).

Designing Computer Science Instruction with Spreadsheets

The authors followed the TM approach to identify topics to be taught with educational technologies, and in particular, they used MS Excel to transform computer science content using computer-based representations for the purpose of making it more understandable to learners. Instruction was designed for three lessons that are usually taught in seventh or eighth grade: (a) Data, Processing, and Information, (b) Representation of data in computer language, and (c) Main memory (RAM) and secondary memory. MS Excel was used for teaching all three lessons, because it has powerful educational affordances, as shown in Table 1, while, at the same time, is also user-friendly. As shown in Table 1, four educational affordances of MS Excel were used in this study: (a) MS Excel as a tool for organizing data, (b) MS Excel as a tool for providing immediate and context-sensitive feedback, (c) MS Excel as a tool for performing calculations, and (d) MS Excel as a modeling tool. The second column in Table 1 shows Excel's technical functions in support of each educational affordance found in the first column, while the third column is simply an elaboration of the first one regarding the educational uses of each affordance.

Table 1 Educational affordances of MS Excel, technical functions, and educational uses for each affordance

Educational affordances (from simple to complex)	MS Excel technical functions	Pedagogical uses
1. MS Excel as a tool for organizing data	File—New/Open/Close/Save/Save as/Page setup/Print area/Print preview/Print/Send to	1. Organization of data
	Edit—Cut/Copy/Paste/Fill/Clear/Delete/Delete sheet/Move or copy sheet/Find/Replace	2. Use of multiple presentations, i.e., text, numbers, images
	Insert—Cells/Rows/Columns/Worksheet/Chart Pictures	
	Format—Cells/Row/Column/Sheet/Style	
	Review—Spelling and Grammar/Protect Sheet	
	Data—Sort/Text to columns/Group and outline	
	Tools—Macros	
2. MS Excel as a tool for providing immediate and context-sensitive feedback	Insert—Function/SUM/IF/AVERAGE/COUNT/MAX	1. Use of functions
	Data—Data Tools/Data Validation/Setting …/Drop down list	2. Provide feedback in different modalities taking into consideration learners' current level of literacy skills
		3. Dynamic processing of data
3. MS Excel as a tool for performing calculations	View—Formula bar	1. Utilization of Functions such as SUM (), IF (), AVERAGE () etc.
	Insert—Function/SUM/IF/AVERAGE/COUNT/MAX	2. Utilization of Formulae
		3. Dynamic processing of data
4. MS Excel as a modeling tool	All of the above, as needed	Decision-making
		Testing hypotheses
		Dynamic processing of data

Lesson 1: Data, Processing, and Information

The lesson regarding the concepts "Data," "Processing," and "Information" is part of computer science foundations, and thus, it is imperative that all students develop sufficient understanding about the three concepts. A recent research study (Ioannou & Angeli, 2013) revealed that students have misconceptions about these concepts, as they mistakenly regard the terms data and information as synonyms. Therefore, it is important for teachers to pay close attention to students' misconceptions and find effective ways for destabilizing them, because if they [misconceptions] persist, then students will not be able to develop correct conceptions about other topics, such as, for example, Algorithms, Databases, and Programming, for which knowledge about data and information is considered to be prerequisite knowledge (Ioannou & Angeli, 2013).

In order to illustrate that information is processed data, the authors used MS Excel to develop three learning activities, as shown in Fig. 3a, b, c. The activity shown in Fig. 3a asks students to enter integer numbers in designated cells. An arithmetic operation is performed on these numbers, and subsequently after processing, the result is stored and displayed in a different cell (labeled as INFORMATION in Fig. 3a).

In order to further understand how data are processed and transformed into useful information, a second activity with MS Excel was developed, as shown in Fig. 3b. In Fig. 3b, students are invited to write their name (first name and surname) in the column labeled as DATA, then based on the action of a processing operator, as explicitly stated in the column labeled as PROCESS, students observe the result of the processing operation in the column labeled as INFORMATION.

Lastly, one final activity was prepared with MS Excel, as shown in Fig. 3c.

In this activity, students are given a problem from daily life. In particular, students are asked to answer whether Maria, who has 5€ and wants to buy a cheese pie, a bottle of water, and a chocolate, has enough money to buy everything she wants. The cost of each item is given, and students have to type in the data, the processing operation, and finally the information (the numerical result).

Data Representation in Computer Language

A second set of activities, for the topic of data representation in binary form, was also developed with MS Excel. The main goal of this set of activities is for students to understand that all types of information (i.e., text, image, sound, etc.) that are received as inputs from the computer are read and converted into electronic signals. The language of the computer consists of two symbols, namely, the binary digits 0 and 1. This topic is difficult to be taught, because teachers face difficulties in explaining the relationship between electronic signals and the binary system, which constitutes the language of the computer. Therefore, the main learning objectives of this unit are to (a) represent data in binary form, (b) convert binary numbers to integer numbers, and (c) use the ASCII table to learn how text and symbols received as inputs from the keyboard relate to binary numbers. Accordingly, the activities shown in Fig. 4a, b were developed using MS Excel for meeting these objectives.

In Fig. 4a, students are asked to insert a number from 0 to 255 in order to be converted into its binary equivalent. Then, the software shows in a series of steps how this number is converted into a binary number. Essentially, the number 100, as

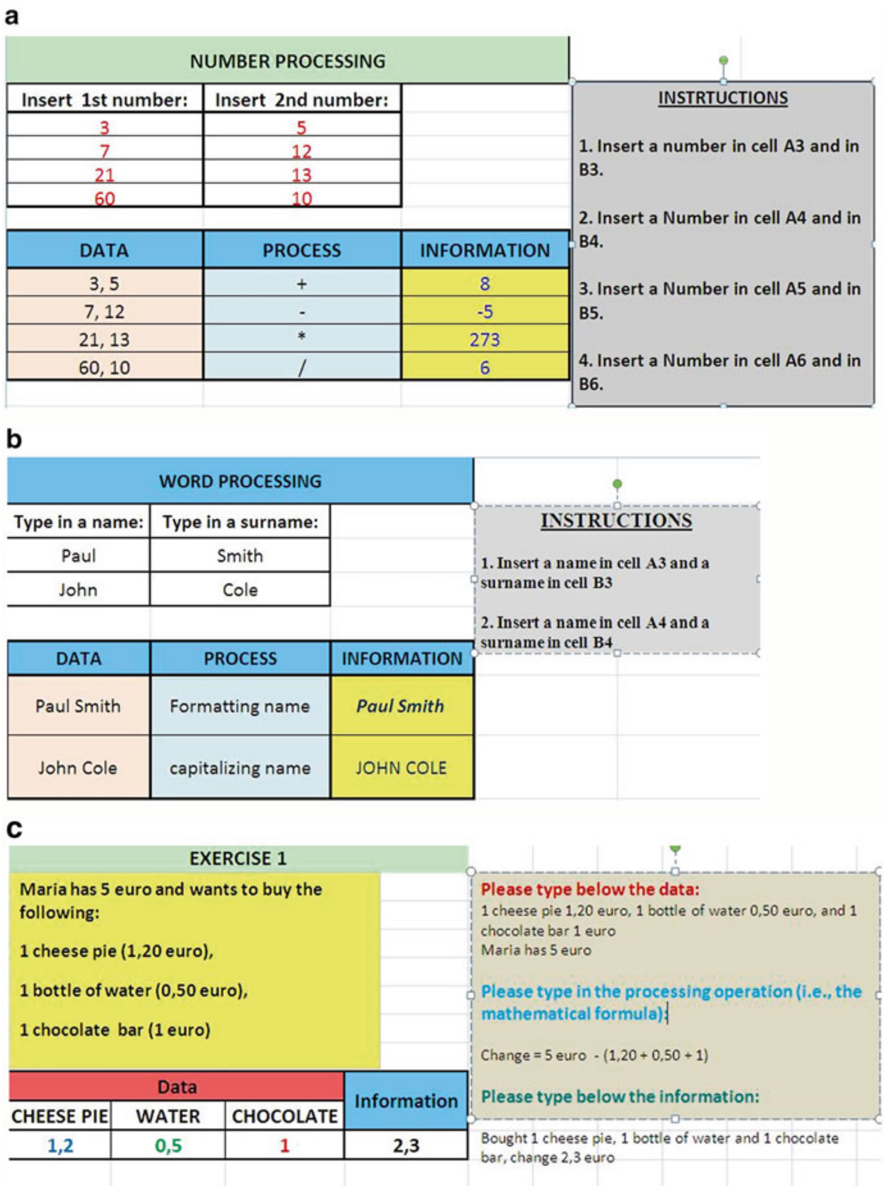

Fig. 3 (**a**) Numerical processing with MS Excel. (**b**) Text formatting with MS Excel. (**c**) Problem solving with MS Excel

shown in Fig. 4a, is divided by two, which gives the result of 50 and a residual of zero. Then, the number 50 is divided by two again, which gives the result of 25 and a residual of zero. This process continues for a number of repetitions until the result of the last division is zero. All residuals from all divisions carried out are written in a sequence from right (the residual from the first division) to left (the residuals from

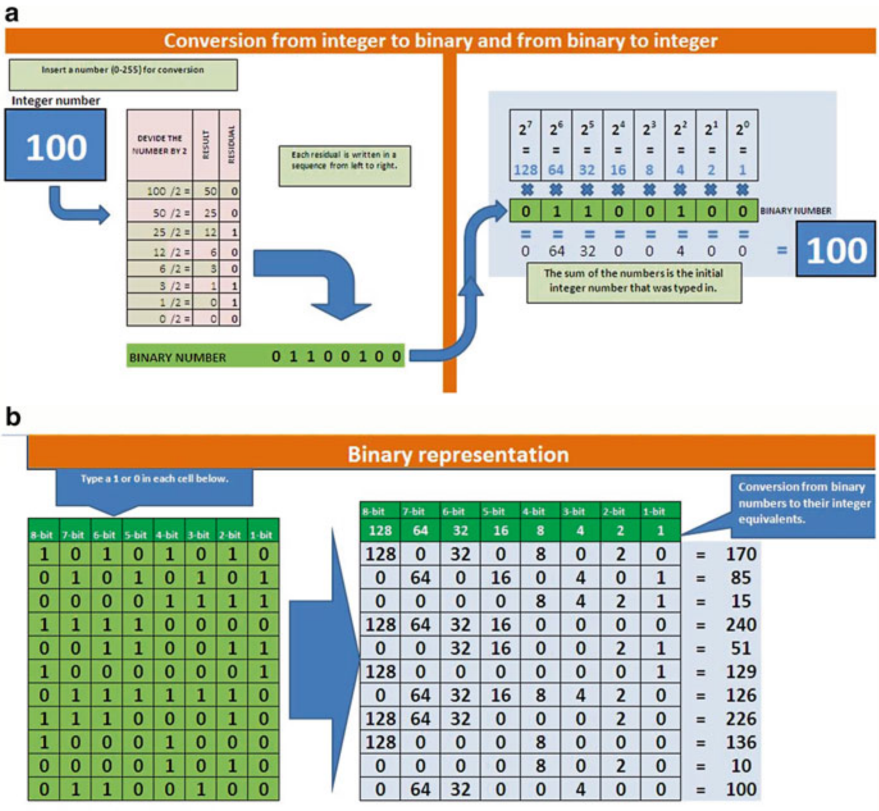

Fig. 4 (**a**) Data representation in binary and integer form. (**b**) Data conversion from binary to integer

all subsequent divisions) and constitute the binary number. Then, on the right side of the screen (see Fig. 4a), it is illustrated how the binary number can be converted back to its integer equivalent.

In Fig. 4b, students are given a table with eight columns labeled as eighth bit, seventh bit, sixth bit, fifth bit, fourth bit, third bit, second bit, and first bit, from left to right, respectively. Students are asked to enter a zero or one in each column to indicate absence or presence of each bit. Then, in another table the equivalent integer number for each of the eight bits is shown, so that learners can immediately do the conversion from binary to integer.

Main Memory and Secondary Memory

A third topic that computer science teachers find difficult to teach is that of computer memory, and in particular, the differences between main and secondary memory. In a recent research study (Ioannou & Angeli, 2013), it was found that most students think that there are no differences between the two types of computer memory. Three activities, as shown in Fig. 5a, b, c, were developed with MS Excel about computer memory. In essence, through these simulated activities, students are engaged in investigating the basic characteristics of RAM (main memory of the computer), and exploring secondary memory devices. In the activity shown in Fig. 5a, students are asked to insert, in designated cells, input data, such as, for example two integers followed by a mathematical expression. On the right side, learners observe how the input data get converted into their binary equivalent forms, and MS Excel visualizes in a simulated way how these data get stored in the computer's RAM. It is illustrated that RAM also contains other items, such as, for example, computer programs (i.e., MS Word, Paint, and MS Excel). Students are instructed to click on the icon of each program and observe that when a computer program gets launched, it is stored temporarily in the computer's RAM.

In the activity shown in Fig. 5b, students discover what happens to the contents of RAM during restarting or shutting down a computer. First, students insert two numbers and a mathematical expression. They observe the processing of data into information, the conversion of data and information to their binary equivalent forms, and how they are all saved in RAM. Then, students are asked to click either on the Restart or Shutdown Button and notice that the contents of RAM get erased during a computer restart or shutdown.

The purpose of the activity, shown in Fig. 5c, is to understand that data, information, and computer programs are stored permanently in secondary memory and are always available for retrieval. Students are first instructed to input two integer numbers along with an arithmetic operation. They observe the processing of the input data to information, and the conversion to binary form. Then, they are asked to click on the left icon, which shows a diskette (for saving). Upon clicking on the diskette icon, the icons representing various secondary memory devices (i.e., hard disk, CD, DVD, USB memory) simulate the functions of secondary memory.

Final Remarks

In this chapter, the authors presented eight computer activities that were developed using MS Excel. The activities were designed based on the framework of TPCK and the explicit guidelines of TM and aimed at transforming abstract computer science concepts into concrete forms in order to make the content more understandable. The guidelines of TM are particularly useful in thinking about computer science topics that are difficult to teach or understand, and how the affordances of spreadsheets can be used to make the content more teachable, through a variety of powerful visual and dynamic representations. The authors of this chapter, based on their extensive use of the framework and the guidelines of TM, conclude that the framework of TPCK and the TM guidelines are adequate to be used for the domain of computer science. It is necessary to mention that the experiences of the authors herein focused primarily on the cognitive domain of learning. It is, however, recognized that

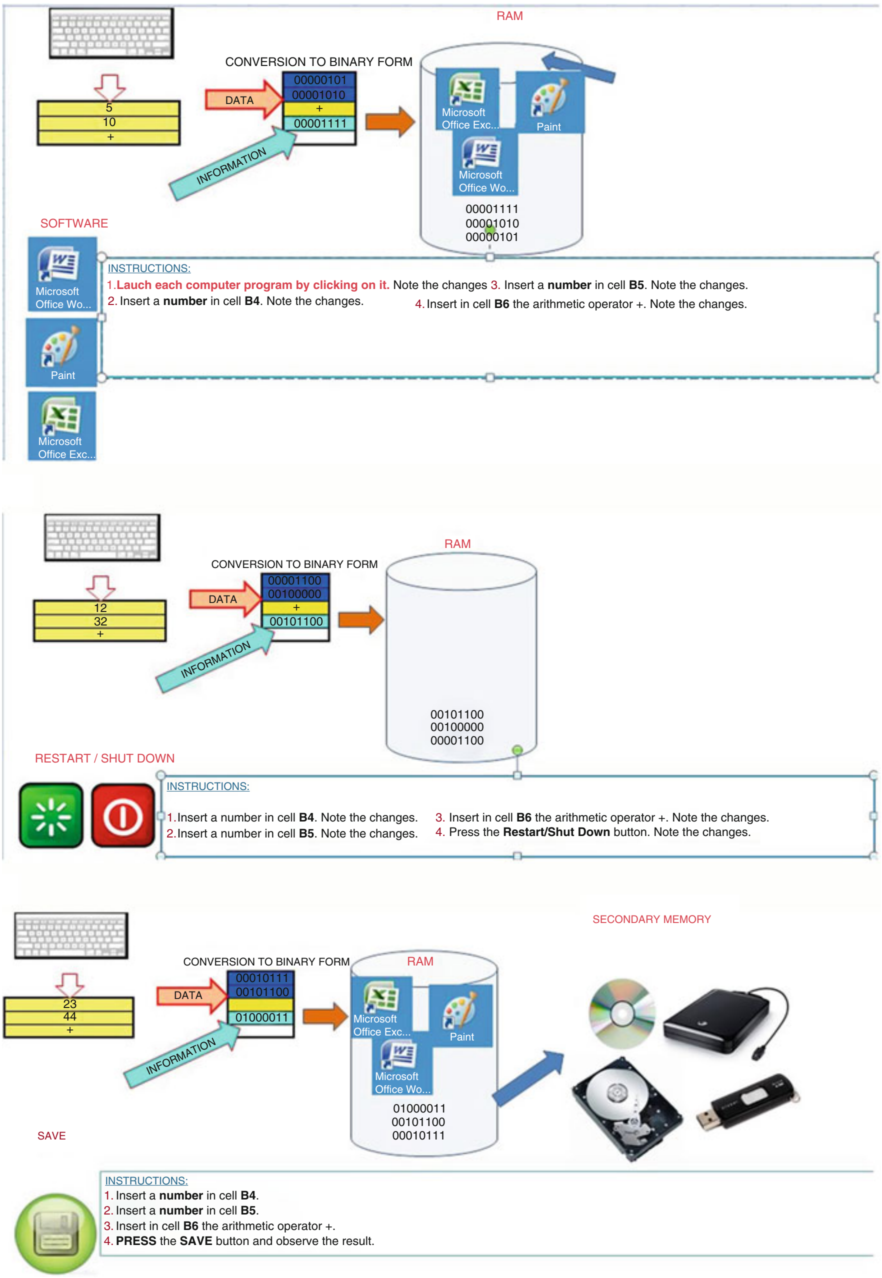

Fig. 5 (**a**) Contents of RAM. (**b**) The contents of RAM during a computer shutdown or restart. (**c**) Contents are stored permanently in secondary memory

learners' difficulties in understanding content might not always be cognitive in nature. For example, in music, students need to use both their cognitive and affective skills in order to perform or create music. Therefore, it is the authors' conviction that it would be valuable and promising to invest research time, effort, and resources for the purpose of examining TPCK and TM in conjunction with various facets of both the cognitive and the affective domains of learning, as these are exemplified by different content domains.

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Pre-service Teachers' Developing Technological Pedagogical Content Knowledge (TPACK) and Beliefs on the Use of Technology in the K-12 Mathematics Classroom: A Review of the Literature

Helen Crompton

Introduction

In today's rapidly changing society, many educators and governments have advocated for educational reforms with a focus on utilizing technologies in classroom instruction (Bereiter & Scardamlia, 2006; Common Core State Standards Initiative, 2010; Greenhow & Robelia, 2009; Jonassen, Howland, Marra, & Crismond, 2008). A clear migration is apparent, with K-12 disciplines taking advantage of the many affordances offered through the plethora of hardware and software tools. In mathematics, technologies can have many useful qualities. For example, technology offers the opportunity for students to actively participate and reorganize the way they see mathematical concepts (Stohl-Lee, Hollenbrands, & Holt-Wilson, 2010), and the various mathematical representations can reveal alternative methods, with the potential to positively affect students' thinking and learning processes (Heid, 2005).

Recent studies provide evidence that teachers are not effectively incorporating technology into curriculum-based teaching and learning. Technology is applied in a way that demonstrates a lack of breadth and depth (Groff & Mouza, 2008; Levin & Wadmany, 2008; Russell, O'Dwyer, Bebell, & Tao, 2007). In a retrospective 20-year study, Culp, Honey, and Mandinach (2003) found a significant disparity between how educational leaders see technology integration in schools and how it is actually utilized. Research findings indicate that most mathematics teachers do not know how to integrate technology effectively (Ferrini-Mundy & Breaux, 2008; Kastberg & Leatham, 2005). Research findings also indicate that negative teacher beliefs about technology inhibit its use (Walen, Williams, & Garner, 2003; Yoder, 2000).

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Pre-service teacher (PST) education programs are entrusted with the role of preparing future teachers and can substantially influence the way they will teach once they leave the program (Gao, Choy, Wong, & Wu, 2009; Hammond et al., 2009; Lim, Chai, & Churchill, 2010). To encourage effective technology use, it is essential that PST education addresses both the lack of knowledge and the antagonistic beliefs concerning its pedagogical value. Training should ensure that PSTs have an opportunity to develop knowledge and skills on how to effectively integrate technology into mathematics. The programs must also foster positive attitudes towards the integration of technology to ensure it is appropriately utilized.

Integration of Technologies and PST Beliefs

The National Council of Teachers of Mathematics (NCTM, 2000) highlighted the many ways technology can be used to facilitate mathematical problem solving, reasoning, proof, and communication. The NCTM (2000) stated that the integration of technology into mathematics is essential, as it positively influences and enhances students' mathematical awareness. With the call for technology integration into the curricula, the members of the International Society for Technology in Education (ISTE, 2008a, 2008b) recognized the need to develop teacher skills in the rapidly changing digital society, and they designed a set of National Educational Technology Standards for Teachers (NETS-T). The standards identify key skills teachers need to apply to effectively integrate technology into the curriculum and to encourage others to do so:

1. Facilitate and inspire learning and creativity
2. Design and develop digital age learning experiences and assessments
3. Model digital age work and learning
4. Promote and model digital citizenship and responsibility
5. Engage in professional growth and leadership

The NETS-T provide further detail with sub-categories delineating teacher actions to accomplish these goals. However, for this chapter, Koehler and Mishra's (2008) definition of effective technology integration is adopted and used for the teaching of mathematical concepts with the appropriate selection of technologies and pedagogical practice, while considering the interactions among the three components; mathematical content, pedagogies, and technologies.

Although effective technology integration can enhance and extend student learning in mathematics, it may not be taught, modeled, or encouraged in PST training. Niess (2005), and Syh-Jong and Kuan-Chung (2010) lamented that, while PST training programs offer technology classes, teachers often learn about technology without connecting it to subject matter. Furthermore, although technology skills, such as word processing, are important, they are taught independently from the pedagogical context (Selinger, 2001). With the dynamic nature of technology in the twenty-first century, PST programs must re-evaluate and constantly redesign their training in order to prepare future teachers to effectively incorporate technology (Goktas, Yildirim, & Yildirim, 2009). This will not be an easy task—not only must teachers gain knowledge and skills regarding the use of technology, but they also need particular beliefs to ensure that technology will be used.

As PSTs complete their programs and begin teaching, technology use may be also hindered by certain beliefs. Those beliefs can often be developed through feelings towards the use of technology. For example, PSTs, with little experience using technologies, may feel apprehensive, which, in turn, may cause a negative feeling towards the use of technology (Gros, 2003; Rosas, 2003). PSTs may fear that this lack of knowledge could undermine their competence with the students in the class. On the other hand, PSTs may be fully competent in the effective incorporation of technology, yet they may not choose to use it (Amado, 2008; Amado & Carreira, 2006). This decision can be due to negative beliefs towards the use of technology in the mathematics classroom. For example, teaching mathematics with technology may not fit with the way the PSTs themselves experienced mathematics in school.

Lortie (1975) described the phenomenon of "*apprenticeship of observation,*" as the preconceptions that PSTs hold about teaching, due to the thousands of hours they have spent observing and evaluating teachers. This is often the case for mathematics PSTs, who "*have developed ideas about the teacher's role, formed beliefs about what works in teaching math, and acquired a repertoire of strategies and scripts for teaching specific conten*t" (Loewenberg-Ball, 1988, p. 40). These preconceived ideas about the teaching and learning of mathematics can be found in current research. Since educational technologies are becoming more commonplace in schools, this issue is becoming more pronounced. Although there are no guarantees that these negative ideas and beliefs can be entirely eradicated, a strong technology framework during PST training could lead to the PST developing a better understanding of the affordances of technology for mathematics.

To summarize, the beliefs that can hinder PSTs' use of technology include:

- Negative feelings towards the use of technology caused by the PSTs' lack of confidence in their abilities to use technologies.
- Belief that the teachers' competence can be undermined, as students may have more knowledge about certain technologies than teachers do.
- Using technology to teach mathematics does not match with the way in which they were taught at school.

PST training is a crucial period that can influence the effective incorporation of technology in future K-12 mathematics classrooms. In this chapter, the author carefully examines the literature closely to determine whether and/or how PSTs develop knowledge and alternative beliefs during their period of training and identifies a gap in academic knowledge relating to PSTs' developing TPACK and the beliefs connected to the teaching of mathematics with technology. To remedy for this gap in academic knowledge, Mishra and Koehler's (2006) TPACK model is used as a framework to evaluate the PSTs' knowledge, and as a lens to discuss the PSTs' beliefs in regard to the incorporation of technology into mathematics.

Therefore, the purpose of this chapter is to draw together empirical and theoretical evidence to fill this gap in the research. As the connection between TPACK and mathematics is relatively new, there is a paucity of studies in this area. Studies described in this chapter were obtained from a search in EBSCO and ERIC for "*TPACK*" and "*mathematics,*" and worldwide studies involving PSTs developing knowledge and beliefs were selected. When appropriate, other generalized TPACK PST studies were included to confirm findings in studies focused on mathematics.

TPACK Framework

Incorporating technology effectively into the curriculum is not an easy task. Koehler and Mishra (2008) described how teaching and learning with such technologies presents a "*wicked problem,*" as it involves a number of variables, independent of each other and contextually bound, that need to be brought together in order to be effective. TPACK is used as one such framework to address the many contextual variables. Derived from Shulman's (1986) model, which incorporated the dynamic connection between pedagogy and content, Mishra and Koehler (2006) developed the TPACK framework. Since the initial publication of TPACK in 2006, it is becoming a popular analytic lens for studying teacher knowledge about educational technologies and has been used in a number of published research articles (e.g., Hofer & Swan, 2008; Koehler, Mishra, & Yahya, 2007; Ozgun-Koca, Meagher, & Edwards, 2010; Syh-Jong & Kuan-Chung, 2010). Figure 1 provides a visual representation of Mishra and Koehler's (2006) TPACK framework.

The framework identifies three areas of knowledge: pedagogical, technological, and content knowledge. Mishra and Koehler (2006) defined content knowledge as the subject matter that is to be learned or taught; for this chapter, this component will describe the mathematical content knowledge. Technology knowledge includes the understanding of digital and non-digital standard technologies, and pedagogy knowledge is the process, practice, or methods used in teaching and learning. As shown in Fig. 1, Mishra and Koehler's (2006) conceptualization of TPACK moves beyond seeing technology, pedagogy, and content knowledge working independently. The framework also points out the intersections connecting different knowledge areas, with the significant convergence of all three knowledge areas defined as TPACK, referring to Technological, Pedagogical, and Content Knowledge as a cohesive whole, working and interacting effectively together.

Altogether the framework identifies seven different components. With the large number of components and the relative newness of the framework, investigations are still underway for an effective methodology. Koehler et al. (2007) used discourse analysis to track the development of TPACK, although this is a time-consuming process that is also methodologically specific to the particular context under investigation. Angeli and Valanides (2009) used research-based performance assessments, including self-assessment, peer assessment, and expert assessment, to determine TPACK competency. Again, this approach was both time-consuming and

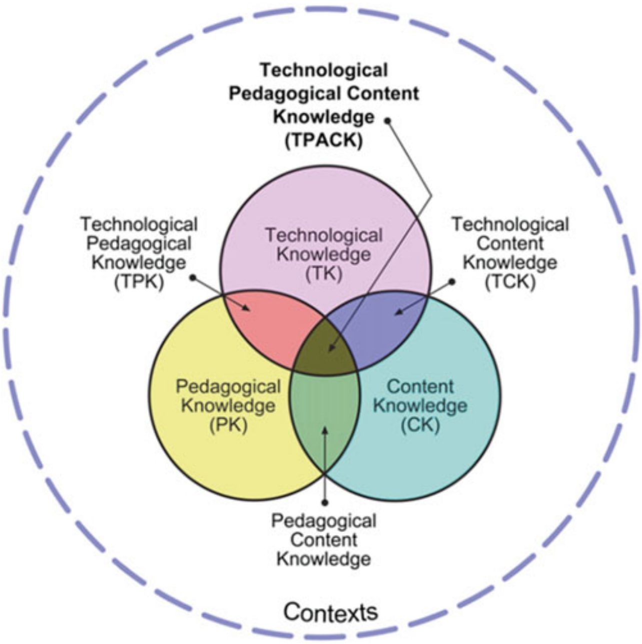

Fig. 1 Mishra and Koehler's (2006) TPACK framework

context-specific. A number of surveys have been examined for internal reliability (e.g., Lee & Tsai, 2010; Schmidt, Baran, Thompson, Koehler et al., 2009), but construct validation of a number of surveys are still ongoing (e.g., Archambault & Crippen, 2009; Schmidt, Baran, Thompson, Mishra et al., 2009).

Research on the Developing Knowledge of PST's TPACK and Beliefs

Although this chapter seems to be focusing on two distinct areas—knowledge and beliefs—a dichotomy cannot be made between the two. In other words, TPACK cannot be considered as a body of knowledge that exists independently of teachers' beliefs. The connection between beliefs and TPACK knowledge was apparent in the research reviewed for this chapter, with a large number of papers addressing both issues concurrently. From the search of the literature, articles connected with technology, mathematics, TPACK and PSTs have been chosen. This section of the chapter describes some of those studies and their findings. Hardy (2010) undertook a study that connected PSTs' developing TPACK with a version of Maslow's needs hierachy (1943). The research developed from the X-Tech project, which was developed to enhance PSTs' perceptions of their preparedness to teach mathematics with technology. The study involved 12 pre-service secondary teachers enrolled in a methods course that taught strategies for teaching mathematics both with and without the use of technology. Mathematics topics, such as, probability, patters, sequences, linear regression, data representation, distance-rate-time problems and limits, were included in the study and technologies included videos to motivate or enhance instruction. PowerPoint for lectures, the use of Geometer's Sketchpad, spreadsheets and graphing calculators to solve problems, teach new concepts, and link to real-world contexts were also used.

Various data sources were collected, including pre- and post-surveys focused on participants' self-reports in regard to perceptions of their knowledge of technology integration, how prepared they were to teach with technology, and their perceived efficacy of the methods class in fostering technological abilities. These data showed that the instruction during the methods course had a positive effect on participants' perceptions of their knowledge and resources for teaching, as well as their preparedness to teach with technology. A number of student comments were reported to substantiate this claim, such as:

> I was exposed to a lot of technology, such as, spreadsheets activities, calculator activities, PowerPoints, that I did not know how to implement in a math classroom before. By showing the different features of Geometer's Sketchpad, I feel very motivated and well prepared to use these technologies in my classroom (pp. 80–81).

Other PSTs also used the word *comfortable* to describe their perceived technology ability, following the course. The participants directly connected their increase in knowledge (TPACK) from the instruction in the course with confidence to effectively teach with technology and to choose technologies in their teaching practice in the future.

Hardy's (2010) findings are of interest to PST educators, but the small number of participants means that the results cannot be generalized. Other studies (e.g., Chai, Koh, & Tsai, 2010; Pierson, 2001) reported similar findings in regard to PSTs' perceived comfort levels and their perceived TPACK abilities with larger participant groups. Chai et al. (2010) examined the perceived development of 456 PSTs in terms of their TPACK. Similar to Hardy's (2010) study, Chai et al. (2010) designed a training program to enhance teachers' TPACK. The program targeted pedagogical knowledge, in which the PSTs studied theory, explicating various pedagogical practices, and were engaged in experiential learning of a number of student-centered pedagogical approaches; technological knowledge, in which the PSTs studied both the affordances and limitations of a number of technologies available; and technological, pedagogical, and content knowledge (TPACK), in which the students consolidated their knowledge into a final project.

To determine student perceptions in regard to how the program was supporting their development of TPACK, Chai et al. (2010) administered pre- and post-surveys. Stepwise regression models indicated significant differences between PSTs' perceptions towards the use of technology before and after the TPACK program. These results concurred with Hardy's (2010) study on the positive effect of TPACK training programs on PSTs' perceived technical abilities. The data from Chai et al.'s (2010) study included some additional findings of interest. The pre- and post-survey results found pedagogical knowledge to have the largest impact on PSTs' TPACK, which is similar to the findings of a study conducted by Niess, Suharwoto, Lee, and Sadri (2006), who found that mathematics teachers weak in pedagogical knowledge were not able to make the link between pedagogy and technology, even if they were rated high in technological knowledge.

The PST's content knowledge in the pre- and post-surveys was stable and Chai et al. (2010) equated this to content knowledge not specifically being covered in the course. It would have been interesting if the PST TPACK perceptions could have been compared with the PST actual TPACK, as the content knowledge might have been increased as the PST made alternative connections to content knowledge through the TPACK collective process. This increase in content knowledge may not have been obvious to the PST, but could have been identified with assessed TPACK capabilities. The research conducted by Chai et al. (2010), Hardy (2010), and others (e.g., Brown & Warschauer, 2006; Lee, Chai, Teo, & Chen, 2008) made claims that courses specifically addressing technology can positively enhance PST/teacher perceptions of their competencies and bolster their willingness to use technology in future teaching.

Harrington (2008) conducted a qualitative study of five PSTs enrolled in a mathematics licensure program for grades 3–12. The program was designed to encourage the development of TPACK through field placement, TPACK-centered assignments, and discussion board reflections. Classes were videotaped, and assignments and discussion board posts were collected as data. Using a qualitative methodology, Harrington (2008) was able to identify a number of specific moments of change in the PSTs' belief systems, highlighting disequilibrium between preconceived ideas of educational technologies and TPACK. Throughout the coding of the data, Harrington (2008) identified two emergent themes in which TPACK beliefs were altered: *Doing the technology* to *Using the technology* and *Technology as a simplifier/extension* to *Technology as an enhancer/differentiator*. Through the experiences gained from participation in the program, Harrington (2008) described a shift in the conceptions of the PSTs to *Using the technology* and *Technology as an enhancer/differentiator* through TPACK.

Similar findings were observed in a study conducted by Mudzimiri (2010), who studied high school mathematics PSTs. The PSTs were all enrolled in two classes: mathematics methods and technology-intensive mathematical modeling. PSTs were asked to complete a pre- and a post-survey used to investigate three areas: to assess beliefs and understanding about the use of technology in mathematics, to investigate the students' technology experiences, and to measure any changes in understandings (TPACK) and beliefs. PSTs also designed three lesson plans and were required to develop in-class learning activities for students in various grades. It was clear that the PSTs' TPACK developed throughout the program, and it was interesting to identify specific evidence of how beliefs towards the technologies changed. Similar to Harrington's (2008) study, a number of PSTs' quotes provide interesting insights into the changing beliefs, for example: Student (pre-test): "*I think calculator use should be limited, because students can become dependent and forget how to do math*." Student (post-test): "*I think technology should play a significant role. Before calculators were widely available, it was important to be able to do math by hand.*

But with so much technology available today, it makes sense to teach students how to use it effectively" and "*I've learned in modeling class and methods that I can expand mathematics to higher order concepts. Also, I feel it's the teacher's responsibility to teach appropriate use of technology*." A clear progression in beliefs towards the use of technology is apparent as the PSTs move from thinking of technology as a tool to gain answers to a tool that can be used to develop higher order thinking. Although the students gained a better understanding of TPACK and their beliefs have been developed, programs and learning opportunities need to continue for further developing positive beliefs.

In one case study, Ozgun-Koca, Meagher, and Edwards (2011) used journal writing, observations, document analysis, and interviews to study teaching practice with a focus on TPACK development. The investigation highlighted a significant obstacle, as the traditional role of teaching mathematics clashed with the use of technologies. One participant, Jane, made numerous comments advocating for the use of paper and pencil approaches: "*I believe doing calculations by hand gives them [students] a better understanding of where the numbers are coming from and makes it easier for them to do more complex mathematics later on*" (p. 213). To answer a question, "*they will be just like copying this graph off of their calculator or I don't really feel like they are getting the idea that the graph has a meaning behind it, unless they have that by hand kind of experience*" (p. 214).

Following the implementation of the TPACK model to train Jane to use a particular graphing calculator, a significant difference was reported, as she could see the affordances of the technology:

> The students were able to see how the graphs, equations and tables are related together, all on the same screen… I think it was also very good for them to see how the values in the table change, as we manipulated the line by moving it up and down or by rotating it about its y-intercept (p. 219).

However, during this learning process, Jane had to overcome feelings of anxiety, as she believed the students were more capable of using the technology than she was. In addition, she described how she had to become familiar with the device before feeling comfortable working with the students.

As stated at the beginning of this section, knowledge and beliefs are highly intertwined. This connectivity was highlighted earlier through the discussion of PSTs' beliefs and the choices they make in regard to technology use. During this discussion, researchers revealed how PSTs may develop a high level of TPACK competancy, yet they did not initially choose to use technology, as it did not fit with their epistemic beliefs.

Conclusion/Future Implications

New technologies are advancing into many aspects of our lives, and this progression is evident in the development of technologies to support the teaching and learning of mathematics. The ability to teach mathematics with technology means more than just mastery of skills; it also requires an understanding of the dynamic interaction between the technology tools, content, and teaching practice (Koehler & Mishra, 2005). The TPACK framework provides a model that can assist in the development of teacher education programs to ensure that mathematical content knowledge, pedagogical knowledge, and technological knowledge are effectively integrated. From the review of the literature, it appears that there is an increase in PSTs' TPACK, as they progress within the teacher education programs. Nonetheless, these are programs that have in some way considered the TPACK framework in the design of tasks and activities. For example, the PST programs that taught technology skills interconnected with mathematical content and pedagogy reported a significant increase in the PSTs' TPACK abilities and their capacity to effectively incorporate technology into the curricula.

One interesting finding was that pedagogical knowledge was critical; a PST could have a high level of content and technological knowledge, but without the pedagogical knowledge to link the two together, his or her lessons may not be effective. This is particularly relevant to those universities that teach technology as a stand-alone subject. In the reported studies, as the PSTs' TPACK has developed, beliefs have been also positively changed. From the studies, it appears that the PSTs' beliefs changed, as they develop a better understanding of the affordances that technology brings to the teaching and learning of mathematics.

Mathematics teachers may have to overcome a number of negative beliefs in regard to the integration of technology in mathematics. For example, in Mudzimiri's (2010) study, one of the participants believed that calculators provided the students with answers leading to the students to forget how to "*do math*." With an increased TPACK understanding, the same participant described how technology should be significantly used in the mathematics classroom, and that calculators could enable students to move onto learning higher order concepts.

Although the research identified in this paper showed a trend towards the development of PSTs' TPACK and beliefs, further research is needed to gain a better understanding of how the two are connected. The literature search only provided a limited amount of studies, which included technology, mathematics, TPACK, and PSTs. At this time, further evidence is needed to see exactly which approaches foster TPACK development in teacher education programs and how this development affects PST's beliefs towards technology integration in mathematics. Longitudinal data could also provide evidence to determine whether TPACK continues to develop as the PSTs move into a full teaching position.

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Part V
The Assessment of TPCK

Exploring TPACK Model Practices: Designing, Facilitating, and Evaluating Effectiveness of Technology Experiences Among Pre-service Teachers

Shannon Haley-Mize and John Bishop

Introduction

In the midst of ubiquitous technology use to support communicative and professional pursuits, there is evidence that the potential for digital tools to facilitate teaching and learning in K-16 classrooms has not been widely realized (Bauer & Kenton, 2005; Project Tomorrow, 2009). There is a growing number of scholars calling not only for technology use in classrooms, but for pointed capitalization of available digital tools to help transform classrooms toward spaces more pedagogically and epistemologically dynamic, collaborative, and student-centered (Belland, 2009; Ertmer & Ottenbreit-Leftwich, 2010; Leander, 2007). Pre-service teacher education has a role to play in shifting the paradigm and addressing deficits in classroom technology integration. This role is best assumed through facilitation of knowledge construction in pre-service educators at the intersections of technology, pedagogy, and content (Mishra & Koehler, 2006).

This study examined the potential for increasing Technology, Pedagogy, and Content Knowledge (TPACK) development among pre-service teachers within one teacher education program. More specifically, this work first examined pre-service teacher perceptions, beliefs, and attitudes about technology, then evaluated the effectiveness of researcher-crafted course experiences designed to foster specific technological skill sets that intersected with pedagogical practices framed by student-centered and collaborative knowledge construction.

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In addition, a qualitative case approach was used to supplement existing quantitative data through interviews and classroom observation of three former students, who exhibited well-developed and sophisticated TPACK practices, honing in on one practicing teacher in her elementary classroom setting. Through this examination, the work contributes to the growing collective voice calling for a transformation of education, one that uses the affordances of digital technologies, in addition to the myriad of other tools, to recreate learning spaces that empower students to be *participatory citizens* prepared for twenty-first century landscapes (Jenkins, Purushotma, Weigel, Clinton, & Robison, 2009). Specifically, we used Web 2.0 tools (i.e., blogs and microblogs, wikis, photo and video publishing sites, social networking sites, and information RSS aggregators) to encourage students to assume roles of active creators of content, critical consumers of information, and creative and collaborative problem-solvers.

Theoretical Framework

This work emerged from multiple theoretical crossroads. First, the design built heavily on our understanding of New Literacy Studies (Coiro, Knobel, Lankshear, & Leu, 2008; Lankshear & Knobel, 2003; Pahl & Rowsell, 2005), namely, as it applies to classroom pedagogy by broadening the scope of "*literacy*" and "*text*" to include the ever-increasing digital milieu of twenty-first century communication. These broadenings within New Literacy Studies (NLS) overlap with a theoretical focus on multimodality (Hull & Nelson, 2005; Jewitt & Kress, 2003; Kress & van Leeuwen, 2001; Pahl & Rowsell, 2005), one that highlights different ways that various modes (written alphabetic text, audio, still and moving imagery, and the combinations of each) function in our understandings and practices of literacy in the present digital age. With these underpinnings informing our work, along with the overarching theoretical frame that knowledge is socially constructed (Vygotsky, 1978), we ultimately found complimentarity with educational technology researchers working through various methodologies to highlight the value of inquiry aimed at the intersections of technology, pedagogy, and content knowledge (Chai, Koh, & Tsai, 2010; Koehler & Mishra, 2005; Koh & Divaharan, 2011; Mishra, Koehler, & Henriksen, 2011). However, we understand that our leanings toward social constructivism do not equate to "good" TPACK development; rather, it reflects our philosophical and pedagogical framework within this study.

Finally, this work is built both on qualitative and quantitative methodological studies that also employed Mishra and Koehler's (2006) TPACK framework, allowing us to better theorize a mixed methodology that "*invites us to participate in dialogue about multiple ways of seeing and hearing, multiple ways of making sense of the social world, and multiple standpoints on what is important and has to be valued*" (Greene in Creswell & Clark, 2011, p. 4). In turn, we include data oriented toward an *instrumental case approach* (Creswell, 2007; Stake, 2005), one that allows us to pursue a critical reflection of our own teaching practices and course designs, and how that process of reflexivity might inform the design of future course facilitation. The use of the term *design* is of no small consequence for us, just as our brief note about incorporating case methodology is no small theoretical component within our work, and we owe, at least in part, the promising conceptualization of *design-thinking* (Brown, 2009) for education, particularly as we believe the term "*design*" carries much weight in models of TPACK.

Paramount to our project is a direct intent for us to practice, play, and reflect on our own teaching, while designing, facilitating, and evaluating course experiences intended to foster Technological Pedagogical Content Knowledge (TPACK) in pre-service teacher education candidates. This process of iteration is for us a necessity for innovative and creative pedagogy, one that informs a more comprehensive approach to evaluating TPACK development among undergraduates.

TPACK: Synthesizing Technology, Pedagogy, and Content Knowledge

TPACK is a cornerstone of current research examining technology integration at post-secondary levels, providing pre-service teachers with opportunities to capitalize on affordances through multiple technologies for teaching and learning. Mishra and Koehler (2006) urged scholars and practitioners to expand the ways teacher technology knowledge is viewed, maintaining that standalone educational technology courses are not sufficient to parlay into meaningful technological innovation in the K-12 classroom. Rather, Mishra and Koehler (2006) posited that seamless integration will not occur, unless teachers develop a complex and situated knowledge that brings together three different types of knowledge—content, pedagogical, and technological knowledge.

It is only through the development of these three overlapping areas of expertise that educators will effectively utilize technology for teaching and learning in a manner that transcends "*low level*" practices with technology that are too commonly typified by teacher-directed presentations of information, or utilization of computer software, simply for administrative, or non-pedagogical, communicative purposes. Mishra and Koehler (2006) conceptualize necessary teacher knowledge as a combination of these three areas of understanding, refuting the notion that technology skills should be considered separate from pedagogy and content knowledge. They thus extended the previous work of Shulman (1986), who highlighted the overlap between pedagogical knowledge and content area knowledge as pedagogical content knowledge (PCK). The three types of knowledge culminate through "*complex interplay*" (Mishra & Koehler, 2006, p. 1025) into TPACK, often through intuitive and nuanced understandings of ways content expertise, pedagogical practices, and technology integration intersect. This theoretical framework, depicted in Fig. 1, is the conceptual lens through which we designed, facilitated, and evaluated pre-service course technology experiences, aimed at fostering teaching practices in line with effective K-12 technology integration.

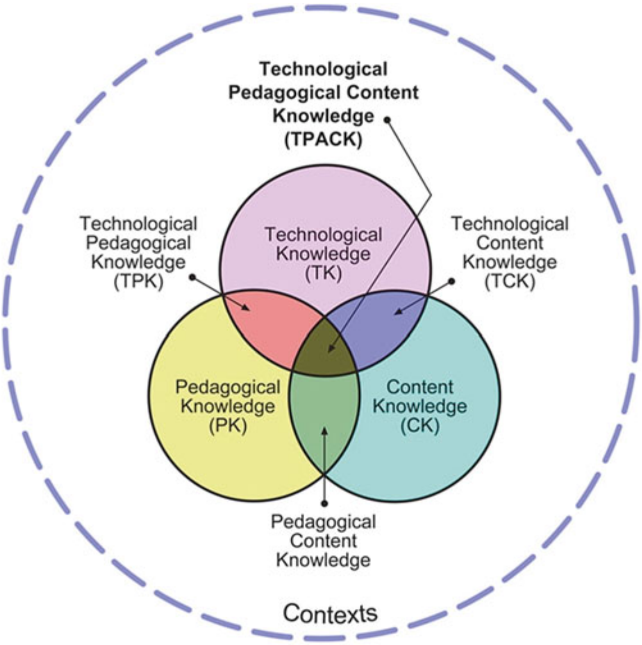

Fig. 1 TPACK framework (Adapted from www.tpack.org)

From Mishra and Koehler's (2006) work, emerging research has examined various course experiences aimed specifically at increasing pre-service teachers' TPACK development. For example, research has demonstrated significant gains in TPACK, when course experiences included *design* activities, or when Instructional Technology courses were facilitated to teach future teachers both about technology tools *and* about how to teach effectively with those tools (Chai et al., 2010). Likewise, Shin et al. (2009) utilized a pre/post-test design to examine the effectiveness of an instructional technology course sequence, designed to "*expose teachers to ideas and skills from educational technology in the context of theories of learning and development*" (p. 4152), arguing about how specific course experiences worked directly to help increase participants' level of TPACK overall.

Coupled with these examples is the argument that teacher candidates are consistently lacking exposure to learning experiences in their pre-service programs that support development of skills necessary to integrate technology for teaching and learning in meaningful ways (Ertmer, 2005; Kay, 2006). Not only do pre-service teachers lack modeled use of technology-enhanced instructional activities, but candidates also have inadequate opportunities to design collaborative learning activities, combining the affordances of various technology tools with specific learning objectives (Gotkas, Yildirim, & Yildirim, 2009). Addressing this increasingly documented gap in teacher education programs, we found helpful as a starting point

Kay's (2006) literature review identifying effective strategies for integration of technology into teacher education programs (i.e., providing mini-workshops, infusing technology into all courses, use of multimedia, facilitating collaborative design opportunities, and providing hands-on practice in field settings). The programs that proved most successful in affecting change in attitude, ability, and use were those that engaged in four or more identified strategies. Kay (2006) challenged researchers to delve more comprehensively into multiple forces at play, when considering effective technology integration together with pedagogy and content.

Research Questions

This study was guided by the following research questions:

1. How do pre-service teacher candidates view the role of technology across multiple contexts (K-12 classrooms, university courses, personal spaces)?
2. In what ways along a spectrum of readiness are pre-service teacher candidates prepared to integrate technology into K-12 classrooms, namely, in ways that foster student-centered and collaborative learning?
3. What insight might be gained about technology integration from case-oriented interviews and classroom observations of practicing teachers, specifically those who completed teacher preparatory courses designed with TELs?
4. How might we evaluate the effectiveness of our technology-enhanced course designs [i.e., the facilitation of "Technology Enhanced Lessons" (TELs)] to increase the depth of pre-service candidate understanding of TPACK?

Methodology

Our work is best described in three phases—each informing and in some cases redefining subsequent research questions. Phase one, for example, consisted of qualitative data via survey questions aimed at pre-service teacher candidates' perceptions of technology; at the ways digital tools function in their experiences in K-12 settings, in their university courses, and in their personal lives; and at their self-efficacy and self-reported comfort levels with technology. Our second phase of research included follow-up observations and interviews with candidates, who participated in the initial data gathering, yet presented strikingly mature anomalies within their narrative discourse, namely when asked to articulate notions and uses of technology in K-12 spaces. The third and final phases were informed by issues raised through our qualitative analysis and quantified pre/post-test measurements, aimed at evaluating statistically the impact of specific instructional practices on participants' depth of understanding regarding TPACK.

Phase I: Exploring Technology and Literacy Practices in Multiple Learning Spaces

During the course of two semesters, we surveyed approximately 40 undergraduate seniors in an elementary education program regarding their perceptions and attitudes about using "*technology*" for their future teaching and in their personal lives. Using Lankshear and Knobel's (2007) paradigm of "*new literacies*," we analyzed data for words and descriptions that are indicative of the values and priorities of new literacies, shaped by two major components—new digital technologies and a focus on *new ethos stuff*, evidenced primarily through terms and phrases suggesting collaboration, distributed authority, collective knowledge production, innovation and creative problem-solving. Initially, we sought evidence linked to what Lankshear and Knobel (2007) term a "*cyberspatial-postindustrial*" mindset, exemplified most readily by the participatory content production, created with Web 2.0 tools and social networking websites.

Our initial analysis work, however, provided little to substantiate the supposition that pre-service teacher candidates viewed technology as transformative pedagogical tools capable of fostering collaborative knowledge construction in classroom settings. Rather, the tools were situated within their narrative responses predominantly as a means to foster student interest and increase motivation. Perhaps the most predominant theme throughout our data during phase one involved the notion that technology, in and of itself, is an inherently good thing for teaching and learning. It "*makes learning more engaging;*" it is "*vital for our times;*" it "*makes learning fun*." These comments speak to a powerful grand narrative that positions technology as something more conceptually singular than the myriad of tools and practices that might occur in various educational contexts. What became disconcerting for us appeared to be a disconnect between positive statements about technology use in learning environments and an ability to articulate specific examples of how technology had in fact functioned during their own preparatory learning for future teaching. The role of pre-service teacher candidates, along with beliefs about pedagogy and technology integration in K-12 classrooms, seemed to be defined through participant narratives about learners as recipients of knowledge rather than collaborators and active participants in knowledge co-construction.

However, as we delved deeper through questions about the use of technology, we discovered the term *technology* to be both multifarious and loaded, depending on its context. For example, in both survey and interview data, undergraduates defined the use of technology in the elementary education program and in public school classroom practicum experiences through specific tools, namely, interactive whiteboards and software, such as, Microsoft Word and PowerPoint. What resonated consistently involved the distinction pre-service students made between tools for pedagogical purposes in their university courses and elementary classroom experiences (i.e., PowerPoint and interactive whiteboards) and the use of "*daily life*" tools (i.e., text messaging via cell phones and social networking through sites, such as FaceBook). Interestingly, the "*daily life*" tools often functioned to help navigate successfully their academic responsibilities by organizing and communicating with one another:

> Last semester, we set up a FaceBook page, so if there's an assignment, then someone will post something. That way we are all on the same page. It's been helpful for me. Each of us can modify and there are about 20 of us. It has been a really good tool, so you can address the entire class. A lot of times, we also send mass text to everyone. Everyone has everyone else's number.

This distinction seemed to occur when thinking about technology tools as (1) those that are incorporated into classroom learning by university faculty or by public school mentor teachers and (2) those that are incorporated into learning practices specifically by students.

Ultimately, three learning spaces—personal lives, university academic settings, and public school classrooms—emerged as predominant, regarding the use of technology tools as a means for teaching, learning and, more generally, for socializing. Overlaps concerning similar literacy practices associated with various technology tools occurred among the three spaces and, likewise, noticeable gaps stood out in the data when comparing each of the three learning spaces. Through these overlaps and gaps, we gained insight about ways we might integrate technology across these spaces to further weave personal knowledge concerning literacy and technology practices into creative and effective pedagogical practices.

Teaching with Technology and/or Teaching About Teaching with Technology

When prompted, it became evident that many of our undergraduates agreed that various tools provided specific affordances for teaching and learning. For example, when asking students about engaging young learners through interactive whiteboards and Internet resources, we found a high frequency of comments noting the ability to "*break free from textbooks and experience things more realistically*." Likewise, a consistency within responses highlighted beliefs that educators can use technology to "*differentiate*" for "*visual learners*" by interspersing content with images, phrases harkening back to a still prevalent discourse surrounding Gardner's (1983) theory of multiple intelligences. This continues to raise questions about what and how to teach, particularly in light of multimodal theories applied to education (Hull & Nelson, 2005; Jewitt & Kress, 2003; Kress & van Leeuwen, 2001) and the diverse offerings of new digital technologies. For example, reading alphabetic text is in and of itself a practice of "*visual learning*," yet one that is modally different from the visual process involved while viewing still images, which presents all information simultaneously rather than in alphabetic and therefore sequential order (Kress & van Leeuwen, 2006). This has implications for twenty-first century educators who seek to challenge learners to grow as active, critical consumers of an increasingly visual milieu of digital information. Likewise, add speakers and the affordance of auditory representation is gained; moving images (movies) offer an even more sophisticated combination of skills across the various epistemological modes of constructing knowledge.

The concept of differentiating using tools, such as LCD projectors and interactive whiteboards, to facilitate learning with the use of images is indeed a pedagogical affordance associated with these tools. Likewise, comments about using interactive whiteboards and websites, such as http://www.brainpop.com, to "*make it more fun, because kids could get up and touch it and play with it*" speak indirectly to multimodal affordances. Our inquiry soon focused on whether our pre-service undergraduates were simply learning *about* certain technology tools (and if so, which ones and why), or whether they were also explicitly learning *how to choose and teach purposefully* from among a variety of technology tools, particularly ones capable of fostering opportunities for collaborative and participatory knowledge construction. In one sense, we shared excitement about the enthusiasm for using technology from participants in phase one of our qualitative work. On the other hand, we questioned the pedagogical beliefs coinciding with technology integration—pedagogical beliefs being arguably most central to facilitating "*high-level*" classroom technology uses in line with constructivist beliefs (Ertmer & Ottenbreit-Leftwich, 2010; Judson, 2006).

Phase II—Incorporating Instrumental Case Study Methodology

Of the approximately 40 pre-service teachers we surveyed in phase one, we chose three participants to interview, selected specifically for their written responses, which served as striking anomalies to survey questions, when compared to descriptions by their peers, indicating beliefs more in line with transformative uses of technology to facilitate collaborative and student-centered pedagogical practices. In a follow-up interview, one of the three participants spoke about experiences teaching in a setting that valued types of computer use with students, counter to teacher-led PowerPoints, or instructor-driven whiteboard flipchart lessons:

> We use their [students] laptops for research. I will give them a topic or a question and have them research. I've had a lot of conversations with my kids about credible sources and what to steer away from online. We talk about how to tell if a website is a valuable place to look for information. And then, I leave it up to them to use their laptops to conduct their research. The times with their computer are probably more student-led than other times of the day.

Building, therefore, on research that brings into question data solely self-reported about relationships between teacher technology integration practices and pedagogical beliefs (Bai & Ertmer, 2008; Judson, 2006) and the call for researchers to further address an absence in the literature of direct classroom observations (Polly, Mims, Shepherd, & Inan, 2010), we followed one student after graduation into her first teaching assignment to observe classroom practice, and to continue collecting formal and informal interview data. Though localized, highly contextual data, it proved insightful when considering pre-service transitions into classroom teaching and, following Ertmer and Ottenbreit-Leftwich's (2010) work, how school culture functions in fostering technology integration and how self-efficacy among new teachers emerges surrounding technology use. These focal points coincided with our phase three data, which speak to the effectiveness of "*Technology Enhanced Lessons*" (TELs) to increase TPACK development among our undergraduates.

In observations and conversations with our case participant Margaret (pseudonym) in her first year of teaching, we observed an innovative and effective use of technology integration. Specifically, though Margaret stated that she found the learning curve for capitalizing on the potential of her classroom interactive whiteboard technology rather steep, she exemplified a student-centered pedagogical approach by facilitating other technologies, in one instance student blogs, in which she taught her students explicitly the affordances of the technology—the capacity to share writing in progress, to choose and publish "*best*" pieces, and to receive peer feedback online—while also focusing on specific learning objectives (to practice and improve writing processes and grammar skills). Margaret followed her students' blog enthusiasm with a culminating event, a mock coffee house sharing in which Margaret and a fellow teacher dressed the role of coffee house baristas, bringing lamps to emulate real coffee house mood lighting, requiring students to choose favorite pieces to share, opening the classroom doors during a school day morning for parents to visit, and ultimately, reflecting on the experiences together.

About teaching the use of blogs in school and the potential barriers teachers face when using this type of Web 2.0 tool, Margaret stated, "*We have it to where only the kids in the school can become a follower and view the blogs—well, outside people can come to view them, but they cannot edit or comment.*" The purposeful (and careful) use of blogs, the sharing of classroom learning and artifacts, and the opening up of her classroom to "*outsiders*" is no coincidence; rather, the cultural atmosphere of learning within the school, a "*vision shared*" among faculty and administrators, encouraged this type of pedagogical iteration, a modeling of risk-taking and subsequent reflection that highlighted parallels between decisions during the craft of teaching and student choices during learning processes. Though notably an isolated event to celebrate as teacher educators, these observations inspired our own creative spirits for technology integration in our elementary education program. As researchers, it raises a complex question, not unlike inquiries regarding "*school readiness*" and other indicators of academic success—What forces are at play, when considering the wide spectrum of TPACK efficacy among new teachers?

Phase III—Evaluating TPACK Through "Technology-Enhanced Learning" Experiences

Our phase three quantitative design drew from existing work, namely, Chai et al.'s (2010) use of "*technology enhanced lessons* (TELs)" (p. 66) in which pre-service teachers learn about affordances and limitations of technology tools and pedagogical applications, and Schmidt et al.'s (2009) development and validation of an assessment instrument regarding TPACK development among pre-service teachers. Our research included course experiences for pre-service teachers that model and provide exposure to various uses of technology for content learning and offer opportunities to practice and design lessons with digital tools. Specifically, these course experiences incorporated digital tools and included the following:

1. Developing an overarching social networking website (http://www.ning.com), allowing participants to create and share individual webpages, music, photos, and blog post reflections on course topics.
2. Blogging to articulate written critical reflections, receive peer feedback, and foster classroom dialogue on specific course content topics.
3. Choosing from a variety of digital tools (i.e., online video streaming resources, mobile devices, such as cell phones, coupled with software or websites for informal assessment and real time polling (http://www.pollanywhere.com), and multimedia production of texts via CAST's UDL (Universal Design for Learning) or Book Builder website (http://bookbuilder.cast.org), to model epistemologically diverse uses of technology during student lesson planning.
4. Utilizing online interactive resources through the IRIS Center (http://iris.peabody.vanderbilt.edu) and Vanderbilt's comprehensive website for education of students with disabilities.
5. Collaborating on the input of wiki content, specifically regarding instruction for diverse learners (i.e., collectively creating an educator UDL checklist).

The threads that connected the narratives of our pre-service candidates were promising—students expressed excitement about the affordances of various technology tools and shared nimble use regarding their own personal and academic pursuits. However, we found less evidence of direct intersections between technological, pedagogical, and content knowledge (TPACK). The majority of the candidates did not describe technology as tools capable of shifting classroom dynamics from teacher as expert and purveyor of information to teacher as collaborator and facilitator of knowledge construction.

This emerging theme guided the redesign of an existing course in the education program, the components of which were designed intentionally to reinforce course learning objectives and to encourage discovery of preexisting, albeit latent potential apparent in the candidates' use of technology for personal and academic pursuits. By design, the course instructor, a member of the research team, modeled a variety of digital tools to teach the content of the course, challenging participants to wrestle with and reflect upon the potential for those tools in K-12 spaces.

In order to measure the effectiveness of these course experiences on participants' level of TPACK, we measured pre- and post-test administrations of the Survey of Pre-service Teachers' Knowledge of Teaching and Technology (Schmidt et al., 2009). Students accessed this 147-item self-report survey the first week of the course, then again after 8 weeks of the course TEL experiences. The instrument, appealing for its previously determined internal consistency reliability (Schmidt et al., 2009), assessed student knowledge through the division of seven TPACK subscales: Technology Knowledge (TK), Content Knowledge (CK), Pedagogical Knowledge (PK), along with the more refined combinations of PCK, TCK, TPK, and ultimately, TPACK.

Technology-Enhanced Lessons (TELs)

From our beliefs embracing New Literacy Studies (Lankshear & Knobel, 2007), our conceptualization of TPACK as a nuanced and complex model of intersecting knowledges, and Chai et al.'s (2010) TEL approach for increasing TPACK development among pre-service teachers, a productive model emerged for us from which to design course experiences. In line with new ethos thinking, TELs used digital tools that allowed students to participate in collaborative knowledge construction. The intent behind the design was threefold: (a) *to expose* students to a variety of tools that can be integrated into K-12 classrooms with diverse learning needs; (b) *to model* integration of tools in order to explicitly teach course content (in this case special education methods), and (c) to provide opportunities *to design* activities using digital tools, fostering opportunities to experience and reflect on student-centered learning practices.

Findings

Valuable Technological Knowledge in Contexts Beyond School Rarely Translated into TPACK

Open-ended survey responses and one-to-one interviews yielded a nuanced picture of the plethora of ways that pre-service teachers in one education program experienced and perceived technology across multiple spaces. Pre-service teachers discussed a myriad of uses of tools interwoven in their personal lives—FaceBook groups to collectively organize, inform, and adhere to deadlines regarding school coursework (a strikingly powerful community building practice among cohorts); the ability to connect and share with family and friends beyond school settings through various social networking sites; and the capacity for information gathering through tools, including online search engines, GPS and mapping sites accessed via computer or mobile device; and the ability to receive status updates about friends and family, or news and entertainment. Despite these descriptions of agile uses in personal and academic spaces, and the perception that technology could engage and motivate students, there were few responses that alluded to a deeper understanding of the potential role of technology in fostering collaboration and student-centered learning. Few of the terms associated with "*new literacies*" were reflected in discussions, and little evidence existed to substantiate the supposition that technology can be a transformative pedagogical tool capable of empowering students to dialogue, produce content, and co-construct knowledge. Rather the tools were situated solely as a means to foster student interest and maintain motivation.

Stand-Alone Technology Courses Functioned Little to Impact TPACK Development

Comments gathered and analyzed during phase one highlighted a discrepancy between student experiences in terms of the value they attributed to a single required technology course for our education majors. For some, the material was "*very easy*," "*more of a review of the technology I already used*." Others "*learned a great deal*," or perhaps more poignantly stated, "*felt like everyone in the class was on different levels of understanding*." What seemed to define the worth of the course, when analyzing participant responses, hinged on how much of the information presented was novel and how much coincided with participants' prior technological knowledge. Not surprisingly, students self-reporting a preexisting degree of adeptness with the tools incorporated in the course curriculum (blogs, for example) represented the course expectations as review.

The collective narrative that emerged regarding learning experiences in one stand-alone technology course speaks loudly of the lack of TPACK development as a "*trans-disciplinary*" responsibility (Mishra et al., 2011) throughout the program holistically, a responsibility that requires content and methods instructors to "*repurpose*" digital technologies for complex and contextual interplays between content, technology, and pedagogy. We found the lack of evidence supporting connections between the tools taught in a stand-alone course, and how they could be used pedagogically for teaching and learning in the K-12 classroom, a call to further examine, as researchers and pre-service education faculty, our own classroom practices and the potential for TPACK development to increase.

Technology-Enhanced Lesson (TEL) Participants Showed an Increased Level of TPACK

Our conversations with pre-service candidates consistently paralleled other researcher critiques lamenting the overall ineffectiveness of standalone instructional technology courses (Groth, Dunlap, & Kidd, 2007; Mishra et al., 2011). It was apparent that although candidates assigned different values to the technology course, whatever gains in technological knowledge occurred was translated little toward the development of a more complex understanding of how TK interplays with content and pedagogical knowledge. More promising methods of teaching candidates about and with technology include course designs that *model* student-centered technology practices, while teaching content, and that integrate opportunities for candidates to practice designing with digital tools. In order to evaluate the effectiveness for increasing TPACK development among pre-service teachers, a MANOVA compared the mean for each TPACK subscale on pre- and post-test results, regarding specifically student experiences with course TELs. The results indicated a significant difference between scores on the pre- and post-test

Table 1 Pre- and post-test means and standard deviations for subscales

Subscale	Time	Mean	Standard deviation	*N*
TK	1	3.59	0.81	66
	2	3.68	0.59	68
CK	1	3.68	0.49	68
	2	3.85	0.49	68
PK	1	3.74	0.59	68
	2	4.01	0.41	68
PCK	1	3.39	0.65	66
	2	3.80	0.51	68
TCK	1	3.31	0.77	66
	2	3.89	0.76	68
TPK	1	3.86	0.76	66
	2	4.22	0.47	68
TPACK	1	3.65	0.63	66
	2	3.97	0.48	68

scores on the pedagogical knowledge subscale, $F(1, 132) = 10.04$, $p = 0.002$, $\eta^2 = 0.071$; the PCK subscale, $F(1, 132) = 16.76$, $p < 0.001$, $\eta^2 = 0.113$; the technological content subscale, $F(1, 132) = 23.51$, $p < 0.001$, $\eta^2 = 0.151$; the technological pedagogical knowledge scale, $F(1, 132) = 11.03$, $p = 0.001$, $\eta^2 = 0.078$; and the technological pedagogical content subscale, $F(1, 132) = 10.90$, $p = 0.001$, $\eta^2 = 0.076$. The means and standard deviations for each subscale are presented in Table 1.

TEL participants did not demonstrate a significant growth in technology knowledge (TK), as a result of participation in the course, but this did not prevent the skills measured by the other subscales from showing significant increase. We find validity in the possibility that these participants were in fact already "*literate*" with multiple technologies, and subsequently, repurposed this knowledge in academic contexts, resulting in the insignificant TK scores. In addition, the lack of TK increase could be attributable to the course design, one focusing on special education rather than on educational technology. Similarly, there was not a significant increase in content knowledge (CK), an anticipated result, considering that the content of the course did not deal with specific content-area information or instruction germane to a single content subject area. More credence surrounded the practice of instructor modeling tools for teaching special education content, opposed to course time spent learning the tools for specific content-area purposes.

Discussion

Our findings reiterate existing work that reports ineffectiveness of standalone technology courses, as sole means for adequately preparing pre-service teachers (Choy, Wong, & Gao, 2009). Modeling effective technology use for pedagogically sound instruction (Bai & Ertmer, 2008) and integrating technology in content area courses

(Judge & O'Bannon, 2008) are promising approaches for preparing pre-service teachers. Our research furthers notions that TPACK development *throughout* pre-service education programs is achievable. Within our data sets, the significance of change between pre- and post-test scores on six of the eight subscales demonstrated that concerted efforts through TELs for collaborative and participatory learning likely contribute to increased TPACK scores for pre-service teachers. TELs, as we conceptualize them, can be integrated into any course throughout education preparatory sequences. We are further encouraged that within 8 weeks, with the exception of scores on the technology and content knowledge subscales, our data show significant increase in TPACK skills, as measured by the survey for participants in the course. The non-significant subscale findings are noteworthy, however, reminding us that the TPACK framework "*offers no specific directives about what content to teach … which pedagogical approaches are useful…and what kinds of technologies to use*" (Mishra et al., 2011, p. 24). Therefore, our TELs represent a contextual approach, notably one that relies on a constructivist theoretical framework, to apply understandings of TPACK development through specific course designs; it is ultimately valuable for programs to evaluate and tailor TPACK developmental needs in content area courses to best fit the efficacy of those pre-service teachers.

This and other work examining the impact of course experiences on TPACK indicate a growing body of literature that speaks directly to teacher education program design and practice.

Further work is needed to examine and discern instructional practices that are effective in pre-service education programs in transforming course experiences to better address TPACK development. The disconnect between what teachers believe about teaching and how they actually teach is a thread in the multifaceted public discourse about how to best reform education. Futrell (2010) perhaps questioned best, "*Do we want to reform or transform our system of education*?" (p. 432), transformation defined as change that enables the system to accomplish new things, whereas reform tweaks an existing system to improve performance of existing operations. We are encouraged by our data—we view the affordances of various digital tools and opportunities for more participatory course experiences as a means to increase pre-service teacher TPACK, a development we deem necessary to *transform* twenty-first century K-16 education. The integration of carefully designed course experiences contributes to the momentum of examining purposeful practices at all levels of the K-16 educational system, a worthy endeavor in light of much noted adherence to traditional modes of instruction and "*low level*" technology use.

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Making Tacit Knowledge and Practices More Explicit for the Development of TPACK

Meng Yew Tee and Shuh Shing Lee

Introduction

A teacher draws on a considerable amount of knowledge about the teaching and learning of a subject matter (Shulman, 1986), and how technology can play a role in the educational process (Angeli & Valanides, 2009a; Mishra & Koehler, 2006). Educational technology scholars have come to define this knowledge base as technological, pedagogical, and content knowledge (TPACK). When a teacher draws from this knowledge base, he or she may have understandings about teaching and learning that are not easily visible, as it is embedded in many layers of life experiences. These understandings may lay tacit until a particular situation requires its use. Some of these understandings can be positive, but others can be negative (Torff, 1999). For example, a teacher may have grown up on a staple of "*chalk and talk*" method of teaching, and over time, experienced reasonable success with such a method. As technology becomes more available, the teacher may intuitively transition into a "*PowerPoint and talk*" method of teaching. However, the teacher may not be fully aware that existing technology can be used to improve learning in ways that were not quite possible before. Even worse, the teacher may only be using technologies, because they have been forced onto him, or because they were made available and relevant training was also provided. Eventually, the teacher becomes a mere consumer of knowledge about technological tools, rather than one who is capable of using technology in ways that can improve learning (Koehler & Mishra, 2005).

Teachers, like the above example portrays, need opportunities to change their mental models. More specifically, according to Bransford, Brown, Cocking, and National Research Council (2000), teachers need opportunities to explore their

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prior conceptions that drive their practices and try things out in the classrooms and then receive feedback. In addition, they also need opportunities to develop the capacity to judge successful transfer of a given technique to the classroom and its effects on student learning.

In other words, there is a need to create ways and conditions for teachers to encourage their tacit knowledge and practice to bubble up to the top, subject these to evaluation and feedback, and make necessary amendments for another trial run. We argue for a course design based on this idea, and a research that is guided by the following questions: Will such a design help teachers develop TPACK? If it does, how did this design help develop teachers' TPACK? How did the activities make teachers' misunderstandings (and understandings) more visible, paving the way for the development of TPACK? The conceptual foundation and how it can be operationalized are discussed in the following sections.

Conceptual Foundation of a Course Design

To cultivate a more robust TPACK base, the basic idea is to design a course for teachers, where they can make their conceptions toward teaching and learning practices visible to a community, and who can then have feedback for continuous improvement. One of the key challenges relates to how to facilitate the emergence of tacit pre-understandings, so that it can be evaluated by a community, and then adjusted and applied by the teacher for the purposes of developing more robust tacit post-understandings. It is this tacit understanding trajectory that differentiates this study from other studies on the development of TPACK (Angeli & Valanides, 2009b; Hammond & Manfra, 2009; Niess, 2011; Pierson, 2008).

To address this challenge, a number of assumptions must be explicated. Technological pedagogical and content knowledge (TPACK)—much like the knowledge involved in managing an organization (Tee & Karney, 2010) or teaching a room full of 7-year olds (Torff, 1999)—can include a significant tacit dimension. Much of TPACK can remain tacit for three primary reasons: (1) The knowledge base is too vast—the complexity of understanding human learning is a good example of the vastness and subjectivity of this knowledge base; (2) The context in which the knowledge base is utilized is extremely diverse—too diverse to be completely specified in advance; and (3) the constant fluctuation of the interaction between the context and the knowledge base that is being applied— "*every student-teacher interaction can change the teacher's goals and choice of operators*" (Bruer, 1993, p. 32) and the dynamics of the entire learning context.

Based on the above assumptions, it is argued that the pedagogical design must contain two key ingredients. First, it must put knowledge as well as practice in the forefront of the learning experience, so that tacit understandings can come to light in discussion and in practice. Experience alone is not enough and it must be combined with reflections, both of individual and collaborative nature (Dewey, 1933; Posner, 2005; Vygotsky, 1978). Second, it must create conditions and stimulate cycles of learning that account for the vastness of the knowledge base, the diversity of contexts, and the fluctuating interaction between knowledge and context.

Problem-based learning (PBL) was chosen to meet the requirements of the first ingredient. PBL was chosen, because it is a learning approach that requires intense discussions, reflection, and application. It is triggered by real-world complex problems and can be solved through a combination of collaborative, iterative, and self-directed activities (Hmelo-Silver, 2004). In the context of this study, Bransford and Stein (2002) IDEAL model was used to guide the classroom planning and management process. The IDEAL problem-solving process consists of five primary components: identify problems and opportunities; define goals; explore possible strategies; anticipate outcomes and act; followed by, look back and learn.

The details to meet the requirements of the second ingredient were found in Nonaka's work. Some scholars have argued that tacit knowledge cannot be captured in order to be transferred to somebody else, so that it can be converted to explicit knowledge for future consumption (Buckingham Shum, 1998; Polanyi, 1967). Tsoukas (2003) argued that tacit knowledge cannot be "*captured*" or "*converted*," but asserted that it can be displayed or manifested in what we do. Nonaka and his colleagues (Nonaka & Nishiguchi, 2001; Nonaka & Takeuchi, 1995; Takeuchi & Nonaka, 2004) took a differing perspective, arguing that knowledge can be converted or captured in several ways: from tacit knowledge to tacit knowledge (through socialization); from tacit knowledge to explicit knowledge (through externalization); from explicit knowledge to explicit knowledge (through combination); and from explicit knowledge to tacit knowledge (through internalization). According to Nonaka and Konno (1998), these knowledge conversions must take place in a *ba*, a Japanese character that basically means an overall shared condition. This *ba* is designed to energize the knowledge sharing and cultivating activities, by providing enabling conditions of autonomy, fluctuation and creative chaos, redundancy, requisite variety, and trust and commitment.

In relation to the design of the course, the *ba* can be operationalized in a number of ways. Students are given the freedom to act with relative autonomy, so that they can motivate themselves to experiment and discover new knowledge. Significant fluctuation and creative chaos are expected to grow from the deconstruction and reconstruction of rich and ill-structured real-world complex problems, largely to allow for the breakdown of old, encrusted mental models and routine behaviors and to make way for new ones. Numerous information sources can be made available to the students that go beyond of what they are accustomed to in classroom settings. This kind of information redundancy is expected to force students to learn how to discriminate the most critical information from the less important information. This is further accentuated by the principle of requisite variety, which calls for internal diversity to match the variety and complexity of its external environment. In this regard, the rich and ill-structured real-world complex problem investigated by teachers becomes a critical part of the design milieu. After all, effectively integrating technologies in the classroom is in itself "*a complex and ill-structured problem involving the convoluted interaction of multiple factors, with few hard and fast rules that apply across contexts and cases*" (Koehler & Mishra, 2008, p. 10). And finally, a culture of trust and commitment—such as, honest, but respectful communications and constructive feedback—was emphasized and practiced whenever possible.

In this regard, creating a *ba* is essentially about creating a condition, where there is an unifying form and ethos to share, stimulate, create and utilize knowledge, punctuated by the necessary energy, quality, and medium to perform the individual knowledge conversions in ongoing and interacting spirals of socialization, externalization, combination, and internalization (Nonaka, Toyama, & Byosiere, 2001; Tee & Karney, 2010). The place of creating a *ba* can be physical, virtual, or mental, or a combination of these forms, involving a network of people with common goals and aspirations. This concept is related to the work of Lave and Wenger (1991), who argued that knowledge, particularly practical knowledge, is situated. Knowledge exists in a social as well as a physical environment and is difficult, if not impossible, to be separated from its context (Bereiter, 2002). In this regard, the situativity as well as the individual and group processes of knowledge cultivation must be allowed to emerge, so that it can be subject to feedback, improvement, and change. In other words, more robust forms of TPACK can be cultivated through a series of PBL, social interaction, personal reflection and insight, and through different forms of experiential learning, where one's actions, or communications, are recursively emphasized, as new layers of knowledge are conceived (Tee & Karney, 2010).

In the following sections, we will describe an example of a course that was designed and implemented based on the set of principles and ideas discussed earlier.

Operationalizing and Researching the Course Design

Course Background

The students were enrolled in a 14-week course as a core subject in a master's program in Instructional Technology, or as an elective, for several other graduate programs in the School of Education. The students in the course comprised of 24 in-service teachers, with their ages ranging from mid-20s to early 40s. They taught at elementary, secondary, and tertiary levels, in varying subjects, including language arts (English language, Malay language and Chinese language), social sciences (history and business), and mathematics. Twenty-two of the 24 participants were women. All of them have been teachers for at least 1 year, with an average of 8 years of experience. This chapter reports the broad-based statistical data for the entire class, and specific quantitative and qualitative data for one of the groups that had adequate empirical data in relation to the research objectives.

Operationalizing the Course Design

As mentioned earlier, a PBL approach together with the Nonaka's SECI framework was used. Learning activities were based on the five PBL phases (I, D, E, A, L) complemented by *ba*-like conditions that were created to stimulate socialization, externalization, combination, and internalization.

Since socialization has to do with open as well as relatively unstructured dialogue and sharing, the instructor facilitated open-ended in-class discussions in every session and encouraged self-directed asynchronous online discussions. For example, students were asked to share stories from their everyday classroom experiences. The overall ethos tended to be less formal and low-stake in order to create conditions for facilitating the sharing of feelings, emotions, experiences, and mental models.

Externalization has to do with sharing to meet specific requirements, such as, negotiation and articulation of agreement of common terms, concepts, meanings, and ways of doing things. The sharing can be in the form of dialogue, writings, actions, or prototypes. The overall ethos is more formal than socialization (but not to the level of combination), with the stakes increasing (i.e., more concerned with do-ability). In the context of this course, activities to stimulate externalization included individual-written reflections and focused group discussions, as the participants prepared to propose a solution or implement their plan.

Combination has to do with synthesizing emerging knowledge bases to meet a specific need, in a way that is easily shareable with different audiences. In this regard, the students were asked to design and act on the best solution possible, tell their story in a way that was suitable for public consumption (i.e., group-based writing of a chapter for a wiki-based book), as well as to carry out their oral presentations in the presence of guests (e.g., teachers from other institutions).

Internalization has to do with engaging in action and reflection. As such, students in this course were asked to not only propose the best solution possible, but also to carry out what was proposed. They were also asked to reflect before, during, and after these activities, either orally or in writing.

The design of the course was operationalized roughly into four chronological segments. The first 4-week segment intended to give students time to provide context and meaning to the problems they were facing in their real-life teaching practice, with the initial discussions taking place in a Moodle-based discussion board, and later transitioning to a face-to-face setting. The problems had to be directly related to teaching and learning (as opposed to policy, management issues, or technical problems). The problems had to be complex, as opposed to being too simplistic (for example, the LCD projector in my classroom is unreliable). The problem preferably had to be common, or similar, to what two other people were also facing. The students worked in teams based on the specific problems they chose to own and work on.

The second 4-week segment was for the teams to consider different solutions, propose, and select a solution. The third 4-week segment was for each group to implement the selected solution in a pilot or full-blown situation, and subject it to further evaluation. The fourth and final 2-week segment was for students to present and discuss the process and outcome of the entire learning cycle.

Throughout the semester, approximately two of the 3-hour class sessions were used to share findings and suggest and justify ways forward. The remaining time was mostly devoted for collaborative meetings. The latter proved important as students found it difficult to find common times to meet outside the scheduled class time, due to professional and personal obligations. Each group was required to write a chapter in an electronic book (e-book) project, using Wikispaces to document their on-going experience during the course. The wikis were accessible to all members of the class, but edits could only be made by respective members of each group. In addition, they were also requested to write, every 4 weeks, a two- to three-page reflection paper about what they have learnt during the process.

Five articles—including two articles on TPACK (Koehler & Mishra, 2005; Mishra & Koehler, 2006)—and two videos (including the “Did you know?” video made by Fisch & McLeod, 2009) were selected for focused discussions. Mini lectures and reflections by the instructor were given on an as-needed basis (Hmelo-Silver, Duncan, & Chinn, 2007), and the longest one—which occurred only once during mid-semester—went for approximately 45 min, while the shorter ones—which occurred throughout the semester—had a duration of about 3 or 4 minutes. Mini lectures were triggered by common and critical questions asked by different individuals or groups in the class. The instructor responded directly to the questions, or facilitated a discussion, that eventually led to a conclusion.

Researching the Course Design and Implementation

This study was carried out using an action research design (McNiff & Whitehead, 2002). This method is ideal to research how a course design can address a real life problem, in this case the development of TPACK.

The first author of this chapter was a participant observer, functioning as the course designer, the instructor, as well as the researcher. As with a typical action research process, four steps were taken: plan, act, observe, and reflect. The planning step was discussed earlier. In the subsequent steps, the design was carried out, while observations and reflections were done during and after the implementation. Five types of data were collected, namely: self-progress survey; learning reflections from the participants; progressing draft and final version of the writings and discussions in the wiki-based e-book; documents, records, and artifacts that reflect the overall design of the course; and the instructor’s reflections. The self-progress survey initially developed by Schmidt et al. (2009) was utilized to gain an indicator of the participants’ own beliefs about their abilities to teach with technology, as a result of the experience of going through the course. The results from the survey, administered at the beginning of the course, were compared with the results at the end of the course.

The remaining sources of qualitative data were coded and analyzed. Salient incidences were first identified. These incidences primarily had the following characteristics: description, discussion, and evaluation of past, present, and future practices of teaching and learning. Then, further analysis of all the data sources was done to identify the activities and conditions that led to the salient incidences, iteratively comparing with the conceptual framework discussed earlier, as well as to identify gaps, or details, not represented by the framework. Isolated incidences without triangulated descriptions of triggering activities and conditions were put aside in order to focus on "*complete*" incidences that allowed for fuller narrative to emerge. In this study, credibility was addressed with four techniques: triangulation, prolonged engagement, persistent observation, and referential adequacy. The use of triangulation was particularly important to detect tacit aspects of TPACK. In terms of referential adequacy, all analyzed data were captured and documented in its original form. In addition, the data were coded by two coders (both authors). Problematic cases were handled carefully until consensus was reached.

Results and Discussion

This segment begins with reporting the results of students' evaluation of their own progress, based on a paper-and-pencil survey they filled out at the end of the course. An analysis and discussion of the qualitative results is presented thereafter. In this regard, the discussion revolves around one of the more successful groups that presented more salient data in relation to the research questions. The group is called Beemer and consists of five members (with pseudonyms of B1, B2, B3, B4, and B5). Their age ranged from 25 to 34, with an average teaching experience of almost 5 years. B1, B2, and B3 were language teachers, while B4 and B5 were in mathematics and instructional technology, respectively. The problem they identified revolved around B1's Year 9 students, who were struggling with learning Bahasa Malaysia, or BM (Malay Language). This happened to be the national language, but many of B1's students did not seem very interested in learning it.

Overall and Group Self-Progress Survey

The overall indicators—based on repeated measures *t*-tests—for the whole class showed that the teachers believed that their TPACK had improved, with a statistically significant mean difference of 1.09 ($p < 0.003$, $N = 24$) and a large effect size of 1.75 (as reported in Tee & Lee, 2011). The other sub-components that were measured also improved significantly (numbers in parenthesis indicate mean difference): TK (0.27), PK (0.62), CK (0.31), TCK (1.00), TPK (1.39), and PCK (0.63). The results for the Beemer group—as presented in Table 1—showed similar trends.

Similar to the measures for the whole class, Group Beemer's mean difference for technological knowledge (TK, group = 0.33 and class = 0.27) score was also the lowest compared to the other dimensions. Based on the qualitative data, there may be two possible explanations. First, the explicit awareness about their indirect learning of technology in itself may have been low. Second, the course was designed to emphasize how technology can be used more effectively in relation to the intended learning outcomes (content knowledge), pedagogical practices of the teacher (pedagogical knowledge), and how students were responding to the culmination of these

Table 1 Summary statistics of teachers' beliefs in using technology for teaching: Group Beemer versus whole class comparisons

	Group Beemer's mean at the START of semester	Group Beemer's mean at the END of semester	Group Beemer's mean difference	Whole class mean difference
TK	3.25	3.58	0.33	0.27[a]
PK	3.22	3.81	0.59	0.62[a]
CK	2.58	3.00	0.42	0.31[a]
TCK	2.50	3.25	0.75	1.00[a]
TPK	3.15	4.10	0.95	1.39[a]
PCK	2.50	3.00	0.50	0.63[a]
TPCK	2.58	3.75	1.17	1.09[a]

[a]Statistical significant difference, $p<0.003$, $N=24$

components in the classroom. As a result, some teachers learned to repurpose technologies that they already knew how to use. For example, B3 said that she was a regular technology user and had taken more than five technology courses, and thus was already quite comfortable with technology, but have yet to learn how to use technology effectively in the classroom.

Students' understanding of the relationships between technology and content (TCK), the relationship between technology and pedagogy (TPK), and the relationship between technology, pedagogy, and content (TPACK) improved over time. Most notably, Group Beemer's mean difference of 1.17 was higher than the mean difference of the whole class, which was found to be 1.09, providing a strong indication that the teachers in Group Beemer believed that their TPACK improved. The questions that remain are: how did the design of the course help develop teachers' TPACK? How did the activities make teachers' misunderstandings (and understandings) more visible, paving the way for the development of TPACK?

Socialization Leading to Re-evaluation of One's Teaching

Active socialization exchanges allow for relatively open sharing of feelings, emotions, experiences, and mental models, creating opportunities for the development of trust and rapport (Nonaka et al., 2001; Tee & Karney, 2010). Some very clear indicators of these kinds of exchanges were apparent in Group Beemer early in the semester.

In the first 4 weeks of the course—as the teachers talked about the problems they were facing in their classrooms—B1 expressed her heart-felt frustration in teaching her students. She said that she felt like giving up and was on the verge of tears, when she explained the different teaching approaches that she had attempted with little success ("*Actually, I almost gave up on teaching the class… The students are very weak in BM*," [translated] B1 said in exasperation). Her students were not engaged, showing little or no interest in learning the language. The moment was so intensely disheartening that weeks later, one of the group members—B2—wrote about B1:

> I still remember the face of B1 when she started talking about her case, she looked so hopeless that I felt we had to think hard and give her good and refreshing ideas.

Here, we also realized how sharing of feelings can begin to energize the socialization and externalization process. Somewhat out of desperation, B1 went back to the drawing boards. She began to re-evaluate her own teaching and the way she related with her students. She wrote about this in her reflections:

> When the group studied my case, I found many weaknesses in my teaching and learning approach. It also affected my students' interest in learning. From the discussions, I realized that I was far behind with no improvement, and always holding on to the "chalk and talk" method.... While discussing my problem, I also realized that I needed to take my students' background into consideration. (Translated)

Here, a number of pre-understandings were beginning to bubble up to the top, allowing them to be subjected to evaluation and feedback. For B1, at this point, there was a realization that didactic methods might not always work, and a recognition that perhaps her choice of pedagogy was dependent on how the students responded. The other members of the group also began re-evaluating the role of the teacher. B3, for example, reflected about ceasing the tendency to blame the students and instead to consider different ways to help improve students' understanding. B2 reflected about being challenged by the authentic situation they were facing as a group, and the need to figure out a way to make meaningful learning for the students:

> What to do then? It seems we always have to go back and recheck and ask ourselves: is this going to help my students? Is this (the) right approach to take? How will this work with my students? At the end, it is about making learning meaningful for them.

By the fifth week, after a series of investigations chronicled through videos and descriptions in the eBook, B1 reflected about her inability to reach out and motivate her students to fully engage in the learning process, but was thankful for a supportive group ethos. Still, the problem continued to pose a significant challenge. As B3 wrote, here we see again tacit pre-understandings emerging in the forefront allowing for remediation:

> Finding the root problems of B1's case was not easy, because there were several factors to be considered, but, at the end, we realized that the most significant factors for our root cause were: how lack of… (basic proficiency and) vocabulary prevented the students from learning, and how their attitudes toward (the subject) was careless, since (it was) not meaningful to them.

The two researchers reflected that these candid evaluations were quite unique to this group, especially at the early stages of the semester. By contrast, the other groups in the class were mired for a longer period of time in a "*blame the students*" mental model—or what Biggs (1999) referred to as *Level 1 approach of teaching*. At this level, according to Biggs (1999), the teacher still has strong feelings that this is just the way the students are—they either could learn, or could not learn. Group Beemer's mental model, however, moved quickly to Level 2, where the focus was on "*what the teacher does*" (Biggs, 1999). Two key factors probably contributed to this—B1 was desperate for change, and her group members responded in a candid but supportive way. In this climate consistent with the intended design of the course, they were galvanized to make their tacit pre-understandings visible, and thus, open up opportunities for remediation, and, in the process, deconstruct and reconstruct the problem as well as their existing mental models, while they deliberated on the predicament they were facing. In this regard, the socialization *ba* also seemed to be taking shape quite well, as this was evident from their willingness to share their experiences and feelings even from potentially vulnerable situations.

Externalization of Goals and Synthesis of Emerging Ideas

Externalization has to do with articulation, negotiation, and development of common terms, concepts, ways of doing things, and meanings (Nonaka et al., 2001; Tee & Karney, 2010). The members of the group were motivated to solve the problem they were facing, but now they had to figure out a way they were going to approach the nitty-gritty task of problem solving. They used the TPACK framework from their readings, and with the urging of the instructor, to make sense of the source of the problem. For instance, this is what B1 wrote in her reflection paper:

> I found out that TPACK is very important in each case. This framework helps each group to investigate their case according to the content—are the learning objectives being met and is it suitable for the students? Were the pedagogies used appropriate for the students? How deep is the teacher's knowledge for that particular subject and what about students' prior knowledge? And, ultimately can we identify suitable technologies to teach the subject (translated)?

As their exploration for possible solution progressed, a more nuanced understanding began to emerge, as they began to recognize the importance of deconstructing their pedagogical practice and options (PK), followed by how technology can support the learning needs, as can be seen in B4's reflections:

> Actually, in our case we are trying to use the TPACK framework with more emphasis on PK. For instance, we use different strategies for teaching… (different from) those strategies that were used by the teacher previously. We tried to use technology to change the students' attitude (towards acquiring a second language)…

As they visited B1's class to observe and collect data, the group began to recognize that B1's students were mostly uninterested in learning the subject matter. The group's priority began to focus on increasing motivation and relevance. First, the group recommended a change from a chalk-and-talk approach to a more active and practical language laboratory setting. Secondly, B2 and B4 went into B1's class as guest speakers to talk and share thoughts about the benefits of bilingualism. The group also tried other means to motivate the students:

> We utilized a ticket and rewards system for the students. Changing the learning environment by taking the student to the language laboratory, where all the chairs and tables are arranged according to different groups… The outcome was very good.—B1

B1 students' positive response to the different approaches reinforced the need for change. It sent a clear message that the right kinds of change can lead to more positive consequences. It was at this point when the group seemed to be more hopeful in their outlook.

Soon, four more lesson plans were developed to help students achieve the intended learning outcomes. It was this phase where the process of combination or synthesis was the most active as the group began attempting to systematically organize and prepare to apply their solutions that were derived from diverse knowledge bases. The following is an account from the group's e-Book entry of what began to transpire with one of the lesson plans:

> B3 told us about comics as a possible solution… (citing a paper by Ujiie & Krashen). According to the authors, comic book reading is associated with reading for pleasure for the children. Knowing that students don't feel so inspired to learn BM … It will be a good idea to use comics to engage them in reading and writing. Using http://www.makebeliefscomix.com/Comix/, or a similar website, students will be able to create their own comics using BM.... After they finish their comic, they can either print or email to others their comic (strip).

This signalled a more purposeful use of technology. They drew from Krashen's work to use comics to re-engage their students. Instead of giving comic strips to their students, they asked them to create strips in the Malay Language, meant to be shared with their classmates. The researchers noted that this shift to focus on learning outcomes is consistent with what Biggs (1999) refers to as "*what the student does*" approach of teaching, or *Level 3*, where the focus is on using teaching-learning activities to help students attain desired depth of understanding. In other words, the focus is on what students learn. This is a significant mental model change, and also signalling again an emerging knowledge base that is consistent with TPACK.

Internalization in Action and Reflection

Internalization occurs through a series of action and reflection, with the support of the other key processes—socialization, externalization, and combination—and vice versa, usually involving an ongoing culmination and refinement of one's knowledge (Tee & Karney, 2010). In other words, none of these processes is sufficient alone and all must be present to feed off each other (Nonaka et al., 2001). The members of Group Beemer engaged in these processes, as they dealt with a common problem, analyzed the problem situation, discussed possible solutions and eventually acted on an agreed upon decision, and prepared themselves to respond to what transpired.

In the early weeks of the course, the overall ethos was quite bleak. B2, for example, wrote: "*None of us in the team were excited nor hopeful for B1's students, when we first started…*" But a sense of hope grew from the collaborative work. As B1 wrote that when she shared new teaching problems with her group members, it gave her a "*new energy to improve her teaching*." This "*new energy*" clearly reflects the importance of a galvanizing *ba* that occurs in effective socialization and externalization. Later, in her final reflection, B1 wrote:

> At first starting this e-book project (on wiki), I wasn't sure it would change my students' attitude towards BM, however, there have clearly been changes after we used ICT in the teaching and learning process. They are more active in class and they are more earnest in doing the task given to them (translated).

In the following closing narrative, take particular note of the series of social interaction, personal reflections and insights, and through different forms of experiential learning, where a variety of tacit pre-understandings emerged in actions and communication, thus allowing for remediation activities and creating new layers of more robust knowledge. B1, for example, began to be inspired in terms of attitude and the development of new ideas. B2's observations captured these changes in B1:

> I noticed that by sharing her case with the class and with our team, B1 didn't feel so hopeless as before, and I started noticing she was gaining a sense of hope again. The following week, I kept observing B1's attitude towards her case and how she was gaining her lost confidence, and getting full of new ideas and energy to implement them.

B1, who had rarely used technology for her teaching in the past, began implementing new ideas that emerged from her group discussions as well as from class discussions:

> From dealing with each of our case problems, I think it helped create greater awareness of one's own teaching and learning weaknesses and ways to overcome them. For example, the use of online games in Mathematics used by Iza (from another group in the class), indirectly attracted the interests of students who were weak in the subject.

B1 also wrote that she would share the various new ideas with her colleagues at work. Clearly, the learning was not limited to B1. For example, B3 expressed a more robust TPACK in her reflections:

> Sometimes, we will get excited about a new tool that we have seen and our first reaction is… that is the solution to our problems, and then when we think more critically, we realize that may be it is not.

B2, in her final reflection, wrote this:

> At the beginning, we were not very clear about the use of technology, basically because we were thinking that technology by itself was an excellent tool to use in teaching, but, as the class progressed, we realized that we had to focus first on the analysis of our situation and choose the right technology only after doing the whole analysis of the teaching and learning scenario.

A more nuanced TPACK also emerged in B2's reflections:

> By learning from the other groups as well, we realized that may be some technological tools that worked well with a group of students may not work the same way with others, and that is why it is important to work using the framework to not get lost in the process, by the sense of novelty of new and attractive technologies.

Learning Through PBL and SECI

The SECI-based PBL process has created ways and conditions for the teachers' tacit knowledge and practice to bubble up to the top, and thus allowing for evaluation and feedback, followed by improvements for another trial run. It opened up opportunities for the in-service teachers to re-evaluate their teaching practices, to rethink the nature of the subject that they were teaching, and how technology might play a role to support the learning of the subject matter. For example, the teachers began to realize that technology in itself is not likely to improve ineffective teaching practices.

Much of the class was designed with the intention to create a helpful environment for the purpose of stimulating SECI. Socialization and externalization were largely manifested in the form of class discussions, occasional online discussions, and out-of-class group discussions. Both externalization and combination can be seen in the wiki-based e-book project and higher-stake presentations at the end of the course. Internalization was stimulated in the implementation and reflections in class, and in the reflections they were writing for the course. About two thirds of the scheduled class time was used to encourage students to present where they were at, and more importantly, justify their diagnosis of the situation, as well as justify their way forward. The overall milieu—as the accounts presented above suggest—enabled conditions of autonomy, fluctuation and creative chaos, redundancy, requisite variety, and trust and commitment.

This study provides some important guidance on designing a course for the development of TPACK. However, to be able to further extrapolate, similar studies need to be done in different types of classes involving different demographics. In addition, more explicit data are needed to track the importance of the *ba* qualities to the knowledge cultivation process. Pedagogically, in a broader class context, one of the more serious issues was that at least five of the 24 individuals took on minimalistic or passive roles during collaborative work. Further iterations of these kinds of studies are required to better understand why this occurred, and how it can be remedied.

Conclusion

This chapter argues that the PBL approach guided by the SECI model (Nonaka et al., 2001; Tee & Karney, 2010) can help in-service teachers cultivate technological pedagogical content knowledge. Within this design, the teachers were given opportunities to make explicit their prior conceptions that drive their practices, re-evaluate them within a supportive community, and to try new things out in the classroom and then receive feedback again for continuous improvements. In all, various different technologies were learned throughout the course, including wikis, blogs, videos, and picture editing tools, as well as online games. Several tools, such as

PowerPoint (as students' storytelling tool) and camera video phones (to record students' creative works to post online for their friends and parents to view), were repurposed to stimulate learning.

Most importantly, the in-service teachers demonstrated a more nuanced and tacit understanding of the complex interplay between the three basic components of knowledge—content, pedagogy, and technology. They demonstrated in their implementation of solutions that they understood the need to use a combination of pedagogical methods and technologies that give the students the best opportunities to achieve the intended learning outcomes.

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Part VI
Future Directions

Intersection and Impact of Universal Design for Learning (UDL) and Technological, Pedagogical, and Content Knowledge (TPACK) on Twenty-First Century Teacher Preparation: UDL-Infused TPACK Practitioner's Model

Beatrice Hope Benton-Borghi

Introduction

Innovative technologies provide infinite opportunities for teachers to support and enhance the creative, communicative, collaborative, and critical thinking of *all* learners. Information and communication around the world are more accessible, instantaneous, vibrant, and rich with visual and audio elements. The electronic modality of the digital age empowers teachers and students to learn in innovative ways and in dynamic, accessible, and global environments, increasing the opportunities for inclusivity and equity (Benton-Borghi, 2012, 2013) in increasingly diverse classrooms (Aud et al., 2012). The World Wide Web has grown exponentially since the 1990s and is becoming ubiquitous in higher education (Burgstahler, 2008) and in P-12 schools along with increased availability of technology (Wells & Lewis, 2006). In the United States, the national technology plan (U.S. Department of Education, 2006, 2010, U.S. Department of Education, Office of Educational Technology, 2004) provides guidance and mandates the role of technology in teaching and learning. The National Council for Accreditation of Teacher Education (NCATE) adopted technology standards in the professional teaching standards (2008) aligned with the International Society for Technology in Education (ISTE) technology standards (2002). The American Association of Colleges of Teacher Education (AACTE) awarded the 2013 Best Practice Award for innovation in teacher preparation to integrate technology in teaching and learning to Michigan State University (MSU) for the Technological, pedagogical, and content knowledge (TPACK) model. State Departments of Education and specialized professional organizations (e.g., National Science Teachers Association, Coalition for

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Exceptional Children) expanded the role of technology in teaching twenty-first century skills (Partnership for 21st Century Skills, 2012). Forty-five states and three territories in the United States have adopted the Common Core State Standards and universal design for learning (UDL) principles is interwoven throughout these new robust standards with explicit reference to students with disabilities (Common Core State Standards, 2010). Legislation and judicial decisions in the United States (Higher Education Opportunity Act, 2008; Individuals with Disabilities Education Act, 2004; No Child Left Behind, 2002) have mandated the use of technology, application of UDL principles, and access to the general education curriculum. Even with United States legislation, new policies, national standards, and availability of innovative technology, research indicates that confident and technology-literate teachers have not transferred these skills (Russell, O'Dwyer, Bebell, & Tao, 2007) or embraced the digital world in teaching and learning (Russell, Bebell, & O'Dwyer, 2003).

Even though information and communication technology (ICT) in the digital world have grown exponentially, teacher educators and teachers continue to be more reflective, introspective, and slower in transitioning to the electronic modality. Teachers continue to resist new technologies to improve student performance (Angeli & Valanides, 2005; Russell et al., 2007) despite years of attention given to promote the integration of teaching in teacher preparation programs (Polly, Mims, Sheperd, & Fethi, 2010). Given the historically unhurried evolution from the print modality of the twentieth century with the medical model of disability (Hahn, 1985, 2002) to the electronic modality of the twenty-first century with the social constructivist model of disability (Davis, 2002), the gap found in teacher efficacy to integrate technology and to teach students with disabilities (Benton-Borghi, 2006) was not unexpected. This efficacy divide to integrate technology and to teach exceptional and diverse student populations continues among in-service and pre-service general and special education teachers, even with decades of concentrated focus on diversity and disability in courses and field experiences in teacher preparation programs (Benton-Borghi & Chang, 2012). Marino, Sameshima, and Beecher (2009) reported teacher educators are unprepared to teach in-service and pre-service teachers to use technology. Zhao and Frank (2003) found that they require a coherent rationale that will support their thinking and dispositions.

It will take time and effort to change the attitudes and dispositions of teachers [and teacher educators] from the medical model with the emphasis on diagnosis and treatment to the social constructionist model of disability with the emphasis on social justice. The availability of user-friendly and accessible technology has moved us along that path at a faster pace, because technology provides much needed scaffolds and support for those who require the electronic modality to learn. Researchers determined that, despite evidence of the positive impact of technology on student learning during the past decades (Edyburn, 2005, 2010; Englert, Manalo, & Zhao, 2004; Hartshorne, Ferdig, & Dawson, 2006; Lee & Vail, 2005), teachers do not integrate technology in teaching even though they use it in their personal lives (Kumar & Vigil, 2011; Kvavik, 2005), and new teachers [and teacher educators] continue to teach using the same methodologies they were taught (Russell, Bebell, O'Dwyer, & O'Connor, 2003). Technology remains of minor importance for most teachers in practice (Lemke, Coughlin, & Reifsneider, 2009), because they must believe that it improves student learning (Abbitt, 2011; Ertmer, 2005; Ertmer & Ottenbreit-Leftwich, 2010; Guskey, 2001, 2002; Miranda & Russell, 2011) and have a strong teacher's sense of efficacy to use technology (Bandura, 2002; Benton-Borghi, 2006; Benton-Borghi & Chang, 2012).

The transition has been difficult for all teachers, but especially the general education teachers, because print-based learners can access the curriculum content (i.e., traditional textbooks). Roberts (2001) reported that teachers do not believe it is their responsibility to teach students with disabilities in the general education classroom. Scruggs, Mastropieri, and Leins (2012) found that teachers report for inclusion practices [with students with disabilities] in the general education classroom, but, at the same time, they report not having the time, training, or support to teach these students. Cochran-Smith and Dudley-Marling (2012) suggested that the lack of a common understanding (i.e., deficit theory versus socio-cultural theory) is the reason for the lack of collaboration and communication and the deep divide between general and special education teachers. They suggested that a new synergy is needed to change the equation.

The quest for an inclusive society and a new synergy demand a profound understanding of two innovative and transformational frameworks that are developing and evolving along parallel tracks: TPACK (Mishra & Koehler, 2006) and UDL (Rose & Meyer, 2002). Both models are forward thinking, creative, and applauded by all stakeholders for their impact on teaching and learning, but teacher educators need to teach both models together, because general education teachers will have students with disabilities and diverse student populations in their classrooms. The blending of technological pedagogical and content knowledge with UDL provides a strong theoretical grounding, supports the beliefs of both general and special education teachers, and enables them to understand that effective integration of technology provides equity and access to groups historically marginalized (e.g., disability, race, ethnicity, language). It can provide a simplistic and logical conceptual framework to hasten the collaboration and communication between these two groups and to increase their efficacy to teach all students, which requires a new mindset and strong validation to integrate technology to teach for student learning.

The intersection of these two innovative frameworks, UDL and TPACK, enables teachers to take ownership and to buy into the belief that the effective integration of technology can impact teaching and learning. UDL is not just a model for the special education teacher and TPACK is not just a model for the general education teacher. The twenty-first century teacher should be teaching *for* student learning, assessing *for* student learning, and engaging *for* student learning, based on the conceptual framework of a UDL infused TPACK model if they expect to teach the full spectrum of diverse, exceptional, and gifted learners in the nation's school (Benton-Borghi, 2012, 2013). Teacher educators and ICT experts need to consider this new approach and to research the impact of this model to narrow the gap in teacher efficacy to teach all students. Teachers cannot be expected to revolutionize their instructional delivery methodologies without programs that include teacher educators modeling effective integration of technology, with specific requirements to demonstrate mastery in knowledge, skills, and dispositions. The professoriate has not failed them. The development of these seminal models has provided teachers with initial frameworks for teaching and learning in the digital age (Benton-Borghi, 2013).

This chapter examines these two innovative frameworks, which were developed along parallel tracks to support the integration of technology by general and special education teachers and provides insights into the impact of their merger. The first model, universal design for leaning (UDL), was developed by Rose and Meyer (2002) for [special education] teachers to integrate technology and enable students with disabilities to access the curriculum content and support their inclusion in the general education classroom. The students with disabilities, and their parents and teachers, embraced this conceptual framework that enables teachers to transition away from the medical model of disability toward the social constructivist model of disability with the removal of barriers to learning that technology affords. The second model is the TPACK model (Angeli & Valanides, 2005, 2009; Mishra & Koehler, 2006) to support the integration of technology by [general education] teachers, who are not transitioning to the digital age. They extended Shulman's (1986) construct of *pedagogical content knowledge* (PCK) to include technology and examined the multiple intersections of teachers' knowledge of content, pedagogy, and technology, and their impact on teaching and student learning (Koehler & Mishra, 2008).

Teacher educators and ICT researchers must consider the fusion of these two models for all teacher preparation programs. Such a change will be transformational and will proactively move teacher preparation from the bifurcated system of education toward a more collaborative system with increased opportunities for an inclusive society, with *all* students having the opportunity, equity, and access for success in the P-12 schools.

Universal Design for Learning Model

The movement to universally design architecture to provide access to the full spectrum of individuals in society (Mace, n.d.) was extended to those who experienced barriers to learning, because of access to learning. Rose and Meyer (2002) approached teaching and learning from this perspective and designed instructional methods and materials that were flexible enough to accommodate learner differences. They developed the concept throughout the 1990s and 2000s, defining UDL in terms of providing multiple means of representation [input], expression [output], and engagement in the classroom (Rose & Meyer, 2002, 2006). These principles, based on Vygotsky's (1978) *Zone of Proximal Development* and advances in neuroscience and brain imaging research, identify three distinct neural networks: recognition, strategic, and affective. This represents a major paradigm shift in how teachers teach and students learn, with teachers considering barriers to all three neural networks in their instructional design *for* student learning (Rose & Meyer, 2006). Technology provides the opportunity for teachers to support learners in all three neural networks. Innovative technology enables students with disabilities, at-risk students, racially, ethnically and linguistically diverse, and gifted students to access the general education curriculum, to express what they know in unique and accessible ways, and to become fully engaged, learning to apply and to integrate technology to learn.

Rose and Meyer (2002) define UDL as "a research-based set of principles that together form a practical framework for using technology to maximize learning opportunities for every student" (p. 5). They believe that curriculum should provide students with different backgrounds, learning styles, abilities and disabilities, and diversity, the flexible and digital options that reduce the need for assistive technology. UDL principles are structured around three sets of learning networks:

- To support recognition networks and to provide multiple means of representation.
- To support strategic networks and to provide multiple means of action and expression.
- To support affective (neural) networks and to provide multiple means of engagement (Rose & Meyer, 2002; Rose, Meyer, & Hitchcock, 2005).

UDL provides a multi-dimensional approach to enable teachers to provide effective learning experiences for all students—but it is more than technology. When applying UDL, teachers will identify solutions to overcome barriers to learning (e.g., students with disabilities, at-risk learners, students with English as a second language) (IDEA, 2004) and will provide multiple ways to have students become engaged in and learn the content, expressing what they know in creative ways situated in the context of the learner supported by technology. These UDL principles do not always require technology, because it depends upon the specific needs of the students, who are increasingly diverse. The universally designed for learning classroom learning profile (CLP) (National Center on Universal Design for Learning, 2009; Rose & Meyer, 2002) was adapted by Benton-Borghi and Chang (2009, 2010, 2012) to prepare pre-service and in-service teachers and provide the equity of access to learning through solutions to barriers in representation, expression, and engagement based on diversity and disability.

Implementation requires a UDL environment supported by the school district and ICT. A universally designed and accessible digital P-12 library model provides support for teachers and learners with the availability of instructional and curriculum content in both print, and flexible, digital, and specialized formats. The implementation of the universally designed Kathyrn Borghi Digital Library (KBDL), in the Upper Arlington City School District in 2002, was recognized by the state of Ohio's legislative body in the United States, and further developed in the New Albany Plain Local School District in 2004 (Benton-Borghi & Dargham, 2009; Dargham & Benton-Borghi, 2009; https://sites.google.com/a/napls.us/kbdl/).

The IDEA (Individual with Disabilities Education Improvement) Act (2004) mandated UDL principles, the National Instructional Materials Accessibility Standard (NIMAS), and the National Instructional Materials Access Center (NIMAC), supported by the Chafee Amendment (1996) to the U. S. Copyright Law, Section 121. Teachers are able to deliver accessible instructional content in specialized formats to enable students with eligible disabilities (e.g., blind, dyslexic) access to the curriculum content (Rose et al., 2005). These pioneering changes moved the United States closer to equity of access for *all* learners. Yet, even with the technology and access to universally designed digital materials (e.g., NIMACs, Digital libraries in P-12 Schools, Bookshare.org), the UDL framework alone was not sufficient to motivate general and special education teachers to integrate technology and to teach diverse and exceptional students in the general education classroom (Benton-Borghi & Chang, 2009; Dargham & Benton-Borghi, 2009).

A multi-year mixed methodology research project on teacher efficacy and UDL found ongoing resistance to UDL by secondary general education pre-service teachers taking secondary methods courses. After 5 years, this researcher decided to add the TPACK model, teaching UDL infused TPACK, to try to change the dynamic and the attitudes of 18 undergraduate and continuing education secondary pre-service teachers in a private Midwest university. Benton-Borghi submitted a paper with the results of this research at the 2012 annual conference of the Association of Teacher Educators (ATE) in San Antonio, Texas.

The pre-service teachers, enrolled in the secondary general education methods course with field experience, were given pretests and posttests using the UDL-Infused TPACK Inventory adapted from the TPACK instrument developed by Schmidt et al. (2009), and the twenty-first Century Teachers' Sense of Efficacy Inventory. Pre-service teachers received ongoing instruction on the UDL-infused TPACK model throughout the semester. They were required to apply UDL-Infused TPACK knowledge in instructional decision-making and to teach the lesson during the field experience. Initially, these pre-service secondary general education teachers were resistant to UDL [like the others before them, who voiced their belief that UDL was for special education teachers and not for them]. The UDL-Infused TPACK model had a greater impact on their teaching and attitudes.

The gap in teacher efficacy to teach diverse and exceptional students was not significantly reduced, but their teachers' sense of efficacy increased on all three scales from the pretest to the posttest. The Cronbach alpha scores of internal consistency were .93 and .97 on the Twenty-First Century Teachers' Sense of Efficacy Scales (T-TSES), adapted from the robust TSES (Tschannen-Moran & Woolfolk Hoy, 2001), and .89 and .96 on the Diversity Efficacy Scale D-TSES (Benton-Borghi & Chang, 2012), and .89 and .98 on the Inclusion Efficacy Scale I-TSES (Benton-Borghi, 2006). The paired samples *t*-test data included mean differences from .4 to .5 on all three teacher efficacy scales. The data indicated that the pre-service teachers' efficacy to teach all students with diversity and disability increased during the semester.

The TPACK instrument developed by Schmidt et al. (2009) was used and adapted to measure UDL-Infused TPACK knowledge. TPACK had a strong measure of internal consistency with Cronbach's Alpha = .84 and .93 on the posttest, and UDL-Infused TPACK reliability data were equally strong with Cronbach's Alpha = .91 and .95 on the posttest. The paired samples *t*-test data on the 5-point TPACK scale found a .59 mean difference. The data on the 5-point UDL–TPACK scale found a .78 mean difference. Inferential statistics were not reported, because 100 % of the class did not participate in the survey research (Benton-Borghi, 2012).

The opportunity to combine these two frameworks, to teach the UDL-infused TPACK model, and assess the impact on prospective teachers' knowledge, skills, and dispositions informed this teacher educator. These pre-service teachers were more positive in their critical reflexive analysis of their planning and teaching. This researcher believes that the TPACK model combined with UDL made the difference in pre-service teachers' attitudes toward inclusion, and integration of technology to teach every student, and will continue to research the impact of TPACK and a UDL-infused TPACK on the pre-service and in-service teachers' sense of efficacy to teach all students.

Technological Pedagogical Content Knowledge Model

Mishra and Koehler (2006) developed the TPACK model [from a general education perspective] to integrate technology in teaching. Technology provides an opportunity to teach content in a different way. Graham et al. (2009) suggested that several models, or frameworks, to integrate technology have been developed. The TPACK model is grounded on the theoretical framework of Shulman (1986), which defined teacher knowledge at the intersection of pedagogical and content knowledge. Teacher knowledge as PCK has influenced and informed the direction of teacher education research (Shulman & Shulman, 2007). The transition to the digital age and the impact of the electronic modality on student learning led Mishra and Koehler (2006) and other researchers to extend Shulman's model to include technology. At the center of the TPACK model (see Fig. 1) is the tacit and professional knowledge that the expert teacher develops through years of practice in the teaching profession. The domains of technology, pedagogy, and content and their interrelationships are key to the development of this teacher knowledge. This is where all domains overlap and come together, where one finds teacher knowledge—TPACK.

TPACK is an exemplary representation of the teacher's knowledge in the integration of technology and the conceptual framework provides teacher educators with a strong model (Koehler & Mishra, 2007; Mishra & Koehler, 2006). The model includes seven components: Technology Knowledge (TK), Pedagogical Knowledge (PK), Content Knowledge (CK), Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK), Pedagogical Content Knowledge (PCK), and Technological Pedagogical Content Knowledge (TPACK) (see Fig. 1).

Technology knowledge (TK): Refers to technology knowledge.

Content knowledge (CK): Refers to the knowledge about the subject matter that the teacher will teach.

Pedagogical knowledge (PK): Refers to the process of teaching.

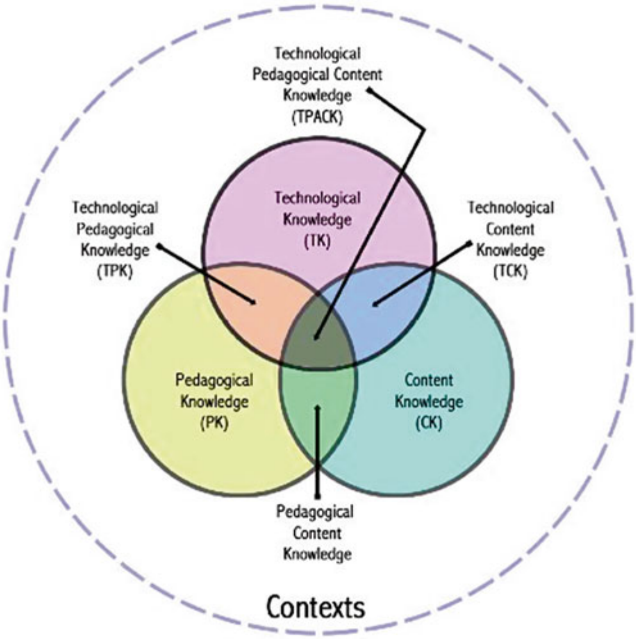

Fig. 1 TPACK. *Source*: http://www.tpack.org

Pedagogical content knowledge (PCK): Refers to the process of teaching based on the content being taught. Shulman's construct (1986) represents the teacher's knowledge of how to teach the specific content.

Technological content knowledge (TCK): Refers to technological content knowledge, and how to use technology to represent and to teach specific content.

Technological pedagogical knowledge (TPK): Refers to technological pedagogical knowledge and the type of technology best used with specific instructional methodology chosen by the teacher.

Technological pedagogical and content knowledge (TPACK or TPCK): Refers to the intersection of the different types of knowledge (content, technology, pedagogy) required by teachers to integrate technology to teach. "Each and all of these types of teacher knowledge are influenced by contextual factors, such as context or contextual factors of culture, socioeconomic status, and school structures" (Harris & Hofer, 2011, p. 213). The TPACK model guides teachers to integrate ICT in teaching and learning (Angeli & Valanides, 2009; Chai, Ling Koh, Tsai, & Lee Wee Tan, 2011) and provides a robust and theoretically grounded framework to represent the interrelationships between the components of technology, pedagogy, and content for the twenty-first century teachers.

This coherent structure seems almost too simple, but it is the logical progression for teaching and learning in the electronic age. The TPACK model provides a logical representation of knowledge that makes sense to teachers, who must make instructional decisions. Preparing teachers to integrate technology required a move away from the technocentrism (Papert, 1987) because "Technology-related professional development to date has overemphasized hardware and software affordances, awareness, and skills, giving short shrift to usable, customizable strategies for curriculum-based uses for educational technologies" (Harris & Hofer, 2011, p. 227–228). Theory into practice requires that teachers be assessed on their growth in the development of this knowledge known as TPACK. Researchers (Angeli & Valanides, 2009; Cox & Graham, 2009) suggest further clarification of the framework would provide a deeper understanding, construct validity, [and practical measure] of the components of TPACK. Shinas, Yilmaz-Ozden, Mouza, Karchmer-Klein, and Glutting (2013) recommend "…the possibility of adopting a transformative perspective in the examination of TPACK as a unique knowledge body that is more than the sum of its parts" (p. 357).

This researcher found that neither UDL nor TPACK alone, even in the context of the learner, moves us toward equity and inclusivity without both general and special education teachers understanding and applying both transformative conceptual frameworks. Perhaps the infusion of UDL into the TPACK model will add clarity to the conceptual framework and construct validity of the components. TPACK infused with UDL with its multi-dimensional levels enables teacher educators to prepare teachers to teach all students.

NEW VISION: UDL-Infused TPACK Practitioner's Model

A *UDL-Infused TPACK* model provides teachers with a more complete, conceptual foundation essential to teach all students. A technological, pedagogical, content knowledge infused with UDL provides a transformational framework for teacher educators to prepare twenty-first century teachers. Benton-Borghi (2013) posits a UDL-infused TPACK framework will be the impetus to increase teacher integration of technology. Schools, colleges, and departments of education in the United States have high expectations for teacher preparation programs and the integration of technology and application of UDL principles in teaching and learning (CCSS, 2010; Higher Education Opportunity Act, 2008; IDEA, 2004; NCLB, 2002), but it cannot happen without these two theoretical frameworks merged into one practitioner's model. This union improves TPACK expanding it into a three-dimensional model including the three principles of UDL. Teachers and teacher educators will discover and produce greater collaboration and communication for inclusion and equity because the intersection of these two innovative frameworks enables general and special education teachers to better understand the vision and the advantages of integrating technology with its positive impact on student learning. Teacher educators must consider a new approach because doing things the same way has not worked (Kumar & Vigil, 2011) with general education teachers unwilling to implement specialized or differentiated instruction in inclusive classrooms (Scrugges, Brigham, & Mastropieri, 2013) and the result has been the continued pernicious

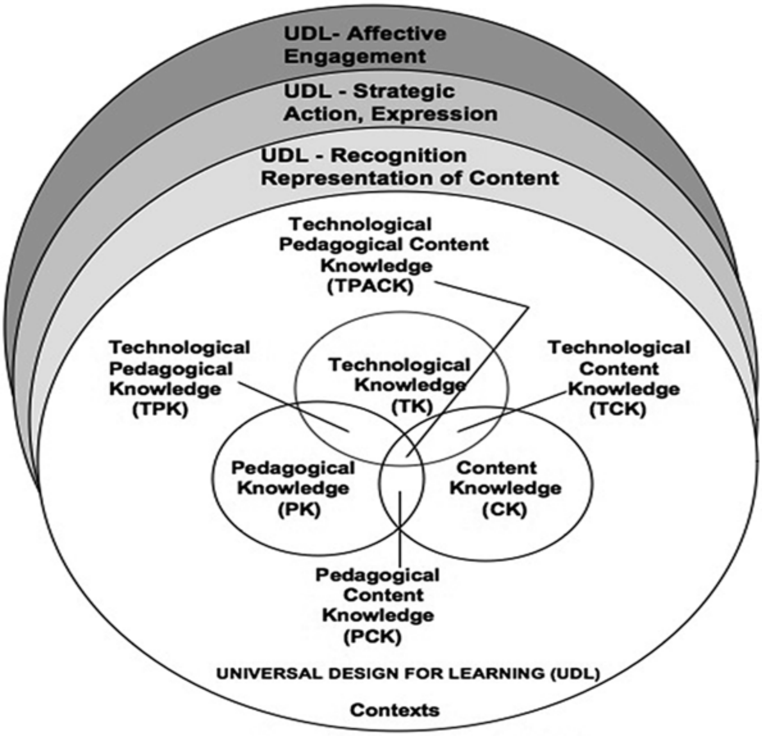

Fig. 2 UDL infused TPACK. Adapted from http://www.TPACK.org

underachievement of students (Edyburn, 2005, 2010), with some calling for a new synergy (Cochran-Smith & Dudley-Marling, 2012). A UDL-infused TPACK practitioner's model will provide teacher educators with that new synergy (see Fig. 2).

UDL is present in the intersections (TCK, TPK, PCK, and TPACK) from three different perspectives: Input (primary representation of content), Output or expression (how the students represent or apply their knowledge of content in a way that demonstrates they understand the content), and Engagement. The TPACK model infused with UDL brings the general education teacher firmly into the equation. Interpreting TPACK through the lens of UDL provides a new way of looking at the model. Teachers will consider how to represent the content, how to engage the students, and how to assess student understanding of content from multiple perspectives. UDL is found at every level of TPACK because these principles are an essential part of pedagogical knowledge (PK) technological knowledge (TK) and are found in varying degrees in all components (CK, TK, PK, TCK, TPK, PCK, and TPACK) of the TPACK model.

UDL-Infused Technology knowledge (TK): Refers to all technology knowledge (e.g., Geometer's Sketchpad) including assistive technology (e.g., text-to-speech software).

UDL-Infused Content knowledge (CK): Refers to the knowledge about the subject matter that the teacher will teach and providing it in flexible, accessible, digital formats (IDEA, 2004).

UDL-Infused Pedagogical knowledge (PK): Refers to the process of teaching based on the specific content being taught, and teaching for student learning through the application of UDL principles required by the Higher Education Opportunity Act (2008).

UDL-Infused PCK: Refers to the process of teaching based on the content (CK) being taught and the application of UDL principles (PK) as pedagogical knowledge.

The UDL principles as pedagogical knowledge (PK) requires multiple representations of content (PCK), student expression of what they know and how they know the content, and student's engagement in learning and processing the content. General education teachers need to look at content and pedagogy from a different perspective—a UDL perspective in the same way that special education teachers have considered these two concepts—providing equity and access to the content. Twenty-first century pedagogical knowledge (PK) includes UDL principles (Higher Education Opportunity Act, 2008, IDEA, 2004). Burgstahler (2008) posits universal design requires teachers to rethink their instructional decision-making to insure that the choices and implementation of each specific strategy are inclusive and accessible.

The instructional methodology (PK) will be based on the specific content (CK) the teacher is teaching. For example, through the lens of UDL, the teacher using direct instruction strategy to teach mathematics (PK) will consider how to make the content (CK) accessible for students, providing guided notes in text-to-speech formats for some students (e.g., blindness, visual impairment or learning disabilities, ESL). The oral discussion instructional strategy involves students in the development of social and communication skills (PK), but it also creates a new challenge for students with communication disorders. The teacher will consider how to represent the content using the most appropriate instructional delivery model for those who have difficulty with listening skills or social skills or hearing or communication disorders that prevent them from engaging in the oral discussion. Mitchell and DeBay (2012) integrated technology using real life video games through the use of augmented reality and found students can master any content because "Simulations engage students who are typically disengaged in mathematics classrooms, encourage collaboration, allow for differentiation of instruction, and simulate authentic learning" (p. 21).

The intersection of content and pedagogy by definition includes the principles of UDL because all students require access to the curriculum content (e.g., reading disabilities, visual impairment, physical disability). The school district and leadership must support UDL system-wide with instructional content [available through the digital library] for students who require content in multiple, accessible formats. The twenty-first century teacher will consider the specific content (CK) and will integrate the most appropriate instructional methodology (PK) from the UDL perspective and in the context of the learner.

UDL-Infused TCK: Refers to technological content knowledge and how to use technology (TK) to represent specific content (CK) and to provide access to the content.

The universally designed, accessible, digital library model (Benton-Borghi & Dargham, 2009; https://sites.google.com/a/napls.us/kbdl/) provides access to the information and instructional content in the P-12 public schools. It supports teachers and provides a repository for accessible, digital instructional content (TCK) for students, who require technology to access the curriculum (e.g., *Read and Write Gold* software). Digital text readers were innovative in the 1990s and will eventually become ubiquitous. Teachers will provide the content in a way that is accessible to everyone in the classroom, keeping in mind the legal requirement to provide it for students, who need it to access the general education curriculum (e.g., blind, dyslexia, physical disability). The representation of content is no longer static, but is dynamic and infinite with the exponential growth of technology. The teacher will consider curriculum content (CK) through the lens of UDL that requires technology (TK) for students and this intersection is TCK. For example, technology provides access and equity for those who cannot visit the big island of Hawaii to understand volcanic eruptions (e.g., Skype and Google Earth). Technology provides access (e.g., text-to-speech, interactive websites, translators, word predictors, speech synthesizers, concept mapping) to content for all students, but especially those who require it to learn and to express what they have learned (IDEA, 2004). Content has been represented in innovative ways specific to the content (e.g., Khan Academy, gaming, multi-user virtual environments, MUVEs, interactive websites, global collaborative and interactive learning experiences, Edmodo, and VoiceThread).

Technology that becomes ubiquitous is no longer considered TCK by some researchers (Cox & Graham, 2009), and assistive technology that becomes ubiquitous would be viewed the same way. Historically, technology has been viewed differently from a general education and special education perspective. Innovative technologies (e.g., iPad apps for reading) are being effectively integrated into the general education classrooms and are improving student performance (Getting & Swainey, 2012). Equity and access for diverse and exceptional learners must be seen through the application of UDL principles from the premise that teachers will teach the full spectrum of learners in the schools. Teachers will have knowledge of technology even assistive technology for students who require embedded supports for comprehension and expression.

School districts support teachers by providing a dynamic environment that is universally designed—not just the physical architecture, but also ICT. Deb Dargham, the digital rights manager, director of the *Kathryn Borghi Digital Library* and assistive technology consultant in the New Albany City School District in Ohio, found the UDL framework provides content that responds to student learning styles. Technology provides a means to change instruction. Technology (e.g., *Read and Write Gold* and web applications) allows students in the New Albany schools to customize the formats they choose for their own learning needs. Students can use text-to-speech, speech-to-text, change the environment, apply highlighting tools, research tools and other tools for scaffolding, along with dictionaries to assist with vocabulary and word recognition. Decoding and text to speech support features enhance the ability of all students to access challenging grade level content. The translator tool ensures that English Language Learners can check their understanding (Benton-Borghi & Dargham, 2009; Dargham & Benton-Borghi, 2009).

UDL-infused TCK enables teachers to look at content in a new way, and to integrate technology to teach *for* student learning. Cognizant of the full range of technology needed to support all learners, teachers will provide the challenge (different levels of technology and content) and access from the UDL-infused TPACK perspective.

UDL-Infused TPK: Refers to technological pedagogical knowledge and the type of technology used with the specific methodology (e.g., lecture, oral discussion, cooperative learning, project-based learning) chosen by the teacher. The pedagogical knowledge (PK) supports the teacher's instructional decision-making concerning delivery models—and UDL principles are an essential framework mandated for inclusion in teacher preparation programs (Higher Education Opportunity Act, 2008).

Pedagogical decisions naturally intersect with technological knowledge empowering the teacher to choose wisely among the myriad of technological options available (e.g., Skype, Edmodo). Technology knowledge (TK) depends upon the content first and foremost (e.g., Chemistry, Mathematics), but it is also informed by the specific instructional methodology (PK) chosen to teach the specific content. The pedagogical knowledge (PK) includes the most appropriate delivery format for teaching the specific content through the lens of UDL (IDEA, 2004; NCLB, 2002) and technological knowledge (TK) includes all technology, including assistive technology. For example, the pedagogy of a flipped classroom might use the technology of *Khan Academy* and *Geogebra* to support student learning in Geometry and Algebra UDL infused in TPK will impact how content is represented (digitally) as well as how to represent the content for someone unable to access the content in traditional format. For example, the teacher may choose cooperative learning (PK) with digital storytelling. The CAST UDL Bookbuilder (http://bookbuilder.cast.org) with its multi-lingual pedagogical coaches and other embedded supports (TK) will provide students the flexible representation, expression, and engagement needed to meet the needs of exceptional and diverse students (TPK).

UDL-infused technological pedagogical (TPK) may require technology with embedded supports for students with decoding problems in reading. Teaching reading in cooperative or independent learning groups may require technology to support certain readers. The learning tools (e.g., Thinking Reader software) found at the CAST website (http://www.cast.org/learningtools/index.html) provide multiple levels of support for students with different needs (e.g., reading, decoding, background information, attention deficit). Technology supports the specific instructional model (e.g., lecture, mnemonics, PBL, cooperative learning), based on UDL principles, and enables teachers to meet the needs of all students in all three dimensions.

UDL-Infused TPACK: Refers to the intersection of TPK, TCK, and PCK contextually situated by the teacher in the world of the learner. The teacher will design a PBL unit of instruction and will automatically apply knowledge of TCK, TPK, and PCK in the context of the learner but infused with UDL—including disability as an integral part of diversity. Equity and inclusion cannot be achieved without access to learning (Benton-Borghi & Chang, 2009, 2010).

A *UDL-Infused TPACK* practitioner will consider access to the curriculum content through the integration of flexible digital technology to represent content, to empower student expression (assessment) of learning through flexible methods of expression, mastery, and apprenticeship, and to engage the student through multiple, flexible options for engagement.

A UDL-Infused TPACK practitioner's model will enable all teachers to reduce the barriers to learning for the students they teach and to increase the collaboration and communication between general and special education teachers. The digital age provides teachers with the opportunity to teach from a global twenty-first century perspective and with access to learning for all, and it demands the merger of these two innovative and transformational models in teacher preparation programs if the goal is to prepare highly efficacious, exemplary, collaborative teachers to work within a community of practice that supports the teaching of *every* student.

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Introducing e-TPCK: An Adaptive E-Learning Technology for the Development of Teachers' Technological Pedagogical Content Knowledge

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Introduction

Technological Pedagogical Content Knowledge (TPCK) has been introduced to the educational research community during the last decade to address the perennial issue of what teachers need to know to teach effectively with ICT in their respective classrooms (Angeli & Valanides, 2005, 2009; Mishra & Koehler, 2006; Niess, 2005). While systematic and worthwhile research efforts have been undertaken regarding the conceptualization, development, and assessment of TPCK within the context of face-to-face learning experiences in higher education and teacher professional development settings (Archambault & Barnett, 2010; Guzey & Roehrig, 2009; Harris, 2008), the authors herein posit that the framework of TPCK requires a complementary technological solution. The limited amount of time that is usually devoted in conventional teacher education courses and one-time only ICT training courses, as well as teachers' different needs, skills, knowledge, expectations, expertise, subject-matter area and in general readiness, render traditional face-to-face learning experiences inadequate for providing ongoing TPCK development. In this chapter, the authors introduce the design and development of e-TPCK, an adaptive electronic learning environment that teacher educators, teacher trainers, and

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in-service and pre-service teachers can use to foster ongoing TPCK development, or the gradual development of their TPCK knowledge.

Specifically, the purpose of the chapter is to: (a) examine the challenges related to teaching teachers how to teach with technology, (b) present the concept of TPCK in conjunction with the need for developing the e-TPCK system, and (c) discuss the gradual development of the e-TPCK system through the lens of the design-based research (DBR) methodology with a focus on adaptive scaffolding to better meet teachers' needs.

Challenges in Preparing Teachers to Teach with Technology

Research evidence shows that in spite of the numerous efforts researchers and educators have undertaken over the years in preparing teachers to teach with technology, teachers still lack the skills and knowledge needed to enable them to competently teach with technology (Bork, 2003; Chai, Koh, & Tsai, 2010; Niess, 2005). The failure to adequately prepare teachers to teach with technology can be attributed to either the emphasis that is usually given in many teacher education courses on teaching technical skills or to the limited amount of time that is usually devoted to matters of how technology interacts with subject matter, pedagogy, and learners' conceptions about a specific content domain. The failure can be also attributed to the fact that traditional one-size-fits-all courses fail to equally benefit all teachers, because teachers' needs, beliefs, skills, knowledge, expectations, and subject-matter expertise are diverse.

In view of recognizing these challenges, researchers, during the last decade, initiated systematic research efforts for the purpose of developing theory and frameworks to ground research in the area of teaching with technology (Angeli & Valanides, 2005; Mishra & Koehler, 2006; Niess, 2005). These researchers advocate that teachers need to develop TPCK, a new body of knowledge that constitutes an extension to Shulmans' (1986, 1987) pedagogical content knowledge (PCK). Since 2005, researchers invested systematic research efforts for the purpose of extending PCK to TPCK in order to educate teachers in the pedagogical uses of technology, so that teachers become competent to teach with technology in their classrooms (Angeli & Valanides, 2005; Mishra & Koehler, 2006; Niess, 2005).

Currently, in the literature there are two theoretical conceptualizations of TPCK: the integrative view proposed by Mishra and Koehler (2006), and the transformative view proposed by Angeli and Valanides (2005, 2009). Research on the integrative view of TPCK revealed difficulties in terms of robustly measuring TPCK development, while research on the transformative view of TPCK resulted in more reliable empirical evidence of TPCK development (Graham, 2011). Therefore, the authors herein adopt the transformative conceptualization of TPCK, according to which TPCK constitutes a special amalgam of several sources of teachers' knowledge bases including pedagogical knowledge, subject-matter knowledge, knowledge of students, knowledge of context, and ICT knowledge (Angeli & Valanides, 2009).

ICT knowledge is defined as knowing how to operate a computer, knowing how to use a multitude of tools/software, and knowing about tool affordances. TPCK is the form of knowledge that makes a teacher competent to teach with ICT and can be described as the ways knowledge about tools and their affordances, pedagogy, content, learners, and context are synthesized into an understanding of how particular topics can be taught with ICT, for specific learners, in specific contexts, and in ways that signify the added value of ICT.

Adaptive Educational Technologies

Adaptation attempts to create personalized educational experiences optimized for each individual student, or groups of students with similar characteristics, and shows promise for enabling powerful educational experiences (Shute & Towle, 2003). According to Shute and Towle (2003), the main idea behind adaptive systems is that effective instruction should capitalize on relevant learner characteristics, such as, knowledge and skills, cognitive abilities, and style. Succinctly, adaptive e-learning systems are those that have the ability to modify e-learning lessons using different parameters (that touch upon relevant learner characteristics) and a set of pre-defined rules, while adaptable personalized e-learning systems are those systems in which learners can intervene and personalize an e-learning lesson for themselves (Burgos, Tattersall, & Koper, 2006). In essence, these two e-learning approaches to personalized learning go from machine-centered adaptivity to user-centered adaptability. In practice, it is quite difficult to isolate one from the other due to their close relationship. In this chapter, the authors discuss a personalized e-learning system that is both adaptive and adaptable, while the control of the adaptation process is shared between the users and the system. Adaptation can be achieved in terms of providing a more personalized learning environment pertaining to: (a) tailoring content (Hook et al., 1998), (b) problem-solving support (Melis et al., 2001), (c) grouping and collaboration (Greer et al., 1998), (d) interface and navigation (Kavcic, Privosnik, Marolt, & Divjak, 2002), (e) learning flow and sequencing of learning activities (Gilbert & Han, 1999), and (f) information filtering (De Bra & Calvi, 1998). The principles of the adaptation strategy implemented in the e-TPCK system are described in the next two sections of this chapter.

The Need for e-TPCK

Teaching teachers how to teach with technology is undoubtedly a complex task, as it demands the application of various bodies of teacher knowledge. At the same time, in formal education development settings, either within the context of preservice or in-service education, teachers bring different experiences, prior knowledge, skills, and in general readiness. These differences among teachers render the process of teaching them how to teach with technology difficult requiring constant adaptation and personalization of teaching procedures and materials.

To this end, the authors herein aim to introduce e-TPCK as an adaptive interactive technology, which has been designed and developed specifically for promoting teachers' ongoing advancement of TPCK in a self-paced and personalized manner. It is emphasized that e-TPCK was not designed to be an electronic system for delivering content to the user, but a cognitive partner for scaffolding teachers' learning enabling them to reach the next levels of TPCK development (Angeli & Veletsianos, 2010). Therefore, adjusting the difficulty level of the learning tasks, as well as giving teachers control over task selection was some of the design strategies that were used to adapt instruction. In the next section, the authors discuss in detail the design and development of e-TPCK.

Design-Based Research for the Iterative Design of e-TPCK

In DBR, development and research take place through iterative cycles of design, enactment, analysis, and redesign (Barab & Squire, 2004; Brown, 1992; Collins, Joseph, & Bielaczyc, 2004; Design-Based Research Collective, 2003; Wang & Hannafin, 2005). Edelson (2002) stated that DBR is conducted "through a parallel and retrospective process of reflection upon the design and its outcomes; the design researchers elaborate upon their initial hypotheses and principles, refining, adding, and discarding - gradually knitting together a coherent theory that reflects their understanding of the design experience" (p. 106). The aim of the e-TPCK system, discussed herein, is to promote teachers' ongoing TPCK development by personalizing the content presented to them in the form of ICT-infused design scenarios. The goal of each design scenario is to guide in-service or pre-service teachers through a sequence of instructional design decisions about how to teach a particular topic using specific ICT tools. Concerning the difficulty level of the design scenarios, there are three different categories of design scenarios: completed (worked-out) design scenarios, semi-completed design scenarios, and new design scenarios that teachers need to develop from scratch. There are four different types of semi-completed scenarios, which differ in the amount of scaffolding that is provided by the system to the teacher in order to complete a design task. In particular, each design scenario contains information about the learning context for which it is intended and is based on a constructivist learning model comprised of six phases, which describe in chronological order all learning activities. Specifically, the structure of each ICT-infused learning design scenario is as follows:

1. Rationale of topic selection. It is aligned with the TPCK guidelines, i.e., a prerequisite action is the identification of topics that signify the added value of the specific ICT tool used in the scenario.
2. Brief subject-matter content description, including connections with the curriculum.
3. Learning objectives (lower-order learning objectives, higher-order learning objectives, ICT-related objectives).

4. Classroom/Lab organization.
5. Sequence of classroom activities:
   (a) Phase 1: Gain attention/attract student interest.
   (b) Phase 2: Identification/diagnosis of learners' initial perceptions or misconceptions/alternative conceptions.
   (c) Phase 3: Destabilization of initial perceptions through the induction of cognitive conflict.
   (d) Phase 4: Construction of new knowledge and active engagement of learners in the knowledge construction process.
   (e) Phase 5: Application of new knowledge in a new context.
   (f) Phase 6: Revision and comparison with initial ideas.

Four types of semi-completed design scenarios, as already mentioned, exist in the system. The first type has phase 2 missing, the second type has phase 2 and phase 3 missing, the third type has phase 2, phase 3, and phase 4 missing, and the fourth type has phase 2, phase 3, phase 4, and phase 5 missing. All missing phases in all design scenarios need to be completed by the teachers.

Through the DBR iterative cycles, system prototypes were created with enhanced design features, more sophisticated functionality, and less complexity. e-TPCK adapts the learning path of its users based on subjective ratings concerning learners' perceived cognitive effort about a design scenario, their preference on the technology tools used in the design scenario, and the difficulty level of the design scenario as decided by the system. The whole process of the system enhancement has been driven by the continuous elaboration and fine-tuning of our research questions. In particular, with regard to adaptive scaffolding (provided by a machine tutor), as was handled in the first version of the system, it was implemented in terms of adapting (a) the learning path of its users based on ratings concerning learners' perceived mental effort about a design scenario, (b) learners' preference on the technology tools used in the design scenario, and (c) the difficulty level of the design scenario. That is, the adaptation strategy that was followed for developing the first version of the system was comprised of the following constituent elements: (1) Adaptation Parameters, such as, learners' perceived cognitive load, choice of ICT tools used in the design scenario, and the difficulty level of the ICT-infused scenario as decided by the lead instructional designers of e-TPCK and the supporting research team. (2) Adaptation Type, namely, tailoring content, learning flow, and sequencing of activities. (3) Adaptation Rules, such as, conditional rules that assign and implement shared control between the system and the end user.

Succinctly, the teacher-system interaction can be summarized as follows. When a teacher logs into the system, he or she is asked to select a computer tool and the difficulty level of a design scenario. The amount of scaffolding provided to the teacher is directly related to the number of phases that the system describes in the design scenario, and thus to the number of phases that the teacher needs to complete. Every 15 min, the system asks the teacher to rate the amount of mental effort that he or she currently experiences. The ratings of teachers' perceived cognitive effort are measured with a 7-point Likert scale ranging from very very small mental effort to very very high mental effort. Rating scale techniques assume that people can introspect on their cognitive processes and report the amount of their cognitive effort. Paas, Tuovinen, Tabbers, and Van Gerven (2003) mention that self-ratings may appear questionable, but it has been demonstrated that people are able in giving a numerical indication of their perceived mental effort. The issue of system-learner shared control was implemented in terms of giving the learner the opportunity to choose his or her next step from a list of options as specified by the system. Specifically, in the case where a learner indicates a low cognitive effort the system asks if (a) the learner wants to select a more demanding (difficult) design scenario, which involves the same tool or a different tool, or (b) if the learner wants to continue with the same design scenario. In the case where a learner indicates a high mental effort the system asks whether (a) the learner wants to select a less demanding (difficult) design scenario, which involves the same tool or a different tool, or (b) if the learner wants to continue with the same design scenario. In essence, e-TPCK includes instances of shared instructional control, where adaptive behavior is controlled both by the learner and the system. System-controlled adaptation includes rules to determine task-selection as mentioned above. The learner can select a task from a set of options given by the system according to his or her self-reported mental effort rating.

In the second version of the e-TPCK system, learning analytics were incorporated for tracking and reporting learner activity. The Society for Learning Analytics Research defines learning analytics as "the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs" (http://www.sola-research.org/mission/about/). Succinctly, the idea to encompass learning analytics in the e-TPCK system involves the presentation of the learning path to the teachers in a textual format, which basically describes using keywords the path of the learner during a learning session. The underlying principle is that learning analytics could trigger reflection about learners' progress and serve as a metacognitive scaffold for them. In practical terms, teachers are presented with their learning trajectory through a dedicated design element in the user interface of e-TPCK, literally with the press of a button which propels teachers to check their progress (i.e., the "Check your progress" button).

The second version of e-TPCK was pilot tested with 53 pre-service teachers who participated in a two-hour session during which they used e-TPCK, and then they completed an online survey about their perceptions regarding the design and ease of use of e-TPCK. The survey included the following items: (1) The design scenarios in e-TPCK are useful to me; (2) It is easy to install e-TPCK; (3) It is easy to use e-TPCK; (4) The cognitive load question is useful for deciding what to do next; (5) The number of design scenarios is not enough; (6) I found the user manual difficult to use; (7) Please specify any other feature you would like to have implemented in the e-TPCK system.

Responses to the first question were evaluated with a 5-item Likert type scale ranging from 1 [not at all] to 5 [very useful]. According to the collected data, students found the design scenarios useful (mean = 4.3; standard deviation = 0.9).

Regarding the second question, the answer items ranged from 1 [very complicated] to 5 [very simple]. Students found the system somewhat difficult to access and often complained for the difficulty they faced during installing e-TPCK in their personal computers (mean = 2.7, standard deviation = 1.2). The third question was assessed with a 5-item Likert type scale with values ranging from 1 [very complicated] to 5 [very easy]. According to the results, students found the system somewhat difficult to use (mean = 2.7, standard deviation = 1.1). Regarding the fourth question about the cognitive load, the options ranged from 1 [I completely disagree] to 5 [I completely agree]. Students in general found the question useful (mean = 3.3, standard deviation = 1.1), but some of them stated that the question needed to be asked not every 15 min but earlier in case a student wanted to change scenarios much earlier than that. The options for the fifth question ranged from 1 [I completely disagree] to 5 [I completely agree]. Students found the number of design scenarios adequate (mean = 3.5, standard deviation = 1.1), even though some of them stated that it would be useful if more design scenarios could be made available. Options for the answers regarding the sixth question ranged from 1 [I completely disagree] to 5 [I completely agree]. Students spent a good amount of time trying to understand the user manual in order to learn how to use the system and expressed the need to make it easier to use (mean = 3.6, standard deviation = 0.9).

Based on students' answers the authors are currently in the process of making changes to the functionality of the system in addition to creating new design scenarios. Most importantly, the authors took into consideration students' suggestions for adding new system features (item 7 on the survey), such as, for example adaptive feedback for each design scenario in order to provide scaffolding to those users who despite experiencing high cognitive load with a design scenario do not choose to switch to a simpler one.

The third version of the e-TPCK system is currently under development and the emphasis is on implementing adaptive scaffolding to foster students' Self-Regulated Learning (SRL). Through the study of the SRL framework it was possible to investigate ways to appropriately assist the SRL processes, with regard to e-TPCK's context.

Self-Regulated Learning (SRL)

SRL is generally acknowledged as an active and constructive learning process, within which learners set goals for their learning and then attempt to monitor, regulate, and control certain aspects of their cognition, motivation, and behavior, directed and restricted by the attainment of the desired goals and the contextual characteristics of the learning task (Pintrich, 2000; Zimmerman, 2001). Whereas in traditional face-to-face classroom settings, the instructor exercises great control over the learning procedure and monitors learners' attention and progress, in student-centered Computer-Based Learning Environments (CBLEs), learners have to firstly cope with the physical absence of the instructor, and secondly, with the inherent systemic characteristics and demands of such learning environments (Dabbagh & Kitsantas, 2004; Devolder, van Braak, & Tondeur, 2012). Therefore, learners are likely to benefit from the potential of CBLEs, only if they develop SRL processes (Winters, Greene, & Costich, 2008).

In the literature, there are three central theoretical models about SRL within the context of CBLEs that share important similarities, namely, (a) Zimmerman's (2000, 2001) model, (b) Winne and Hadwin's (1998) model, and (c) Pintrich's (2000) framework of SRL. All three models suggest four areas of self-regulatory activity. The first area is that of cognition, which is related to the cognitive strategies that learners might apply during the learning process. Second, is the area of behavior that represents learners' effort to seek help and persist towards the accomplishment of a task. This area also represents the choices learners are compelled to make in order to determine their behavior. The third is the area of motivation, which includes the motivational beliefs, task values, interests, and affective reactions that learners possess regarding themselves and the task. Additionally, this area involves the strategies that learners deploy in order to control and regulate motivation. Finally, the area of context refers to the control and regulation of the learning environment. In essence, all three theoretical models describe SRL as an activity that consists of a number of phases, which are not fixed hierarchically in a sequence, that learners go through as they strive to complete a task (Winters et al., 2008). According to Devolder et al. (2012), in Zimmerman's, Winne, and Hadwin's, and Pintrich's models, a SRL activity consists of the following four phases: (1) Task definition and planning. This phase involves planning and goal setting, as well as the activation of prior knowledge and perceptions of the task, the context and the self in relation to the task. (2) Monitoring. During the second phase, learners engage in metacognitive monitoring of their learning process that represents metacognitive awareness of different aspects of the self and the task or the context. Essential to this phase, the feeling of knowing (FOK), the judgment of learning (JOL) as well as monitoring one's progress toward his/her goals are particularly crucial to learning (Winne, 2001; Winne & Hadwin, 1998). On the other hand, students' content evaluation, identifying the adequacy of information and evaluating the content as the answer to a goal, are associated with lower learning outcomes. (3) Control. Monitoring prompts learners to the third phase, where they control their learning processes by attempting changes within any of the four areas of self-regulation. For instance, a learner may abandon a particular strategy that does not seem to be leading to the attainment of the goals (i.e., understanding of the material or retention) and apply a more efficient one. (4) Reaction and reflection. The fourth phase involves different reactive and reflective processes on the self, the task, or the context. The performance is evaluated and often leads to adaptations to learners' self-beliefs, beliefs about learning strategies and the learning context. According to Winters et al. (2008), these adaptations may then affect future learning activities. There is also a possibility for learners to recycle back through previous stages over the learning process, especially when monitoring reveals that the strategies being used are not that successful. However, this recycling activity occurs only until the student has well-developed regulatory skills.

The Interplay Between SRL and Scaffolding

The key for fostering self-regulation seems to lie in the concept of scaffolding (Devolder et al., 2012). Summarizing up, Lepper, Drake, and O'Donnell-Johnson (1997) allege that scaffolding assists learners in the accomplishment of tasks beyond their unaided efforts. When assistance is withdrawn, learners continue to function independently. Removing the assistance does not diminish learning or functioning; instead, learners continue to function at the elevated plane reached via scaffolding. Particularly, Lepper et al. (1997) equated scaffolding with the interim structures that support the construction of an arch or a bridge; when the scaffolding is removed, the structure continues to stand unsupported.

The theorization of scaffolding was firstly linked to Vygotsky's sociocultural theory (Stone, 1998). A fundamental tenet of sociocultural theory is that cognitive development/learning is a social construct. According to Vygotsky, a child, or a novice, learns with an adult or a more capable peer with learning occurring within the child's or novice's zone of proximal development (ZPD). The learner can bridge the distance between an actual and a potential level of development, depending on the resources or support given (Tabak & Reiser, 1997). Apparently, both of the constructs, scaffolding and ZPD, comprise interactions between an expert (i.e., tutor) and a novice (i.e., learner) in which the first assists the latter in completing a particular task beyond his or her unassisted efforts. Ever since, the metaphor of scaffolding has been used to give implications on how teachers can successfully support learners within the ZPD; to prompt them forward until they can independently function and apply a newly acquired skill, strategy, or process (Jadallah et al., 2011). Furthermore, the notion of ZPD broadened the concept of scaffolding as to include the fading of expert support, distinguishing scaffolding from other forms of support. Therefore, scaffolding operationalizes ZPD's relationship between teaching and psychological development by providing a conceptual framework for the design, operation, and study of scaffolding for the support of a particular form of learning (Sharma & Hannafin, 2007).

Scaffolds have recently been defined as tools, strategies, or guides given by human and computer tutors, teachers, and animated pedagogical agents during learning, in order to help students reach higher levels of understanding, which would be impossible to do if they worked on their own (Azevedo & Hadwin, 2005; Hannafin, Land, & Oliver, 1999; Saye & Brush, 2002). Evidence from scaffolding research on CBLEs poses a major challenge to instructional designers and teachers: to provide a well-designed environment that can enable students to enhance their self-regulatory skills for achieving optimal learning and academic success (Bernacki, Aguilar, & Byrnes, 2011; Devolder et al., 2012). This implies that apart from the inherent features of the system, other design features and technology-mediated support should be developed as scaffolds in order to facilitate SRL processes and assist students engaged in this type of learning (Dabbagh & Kitsantas, 2005; Devolder et al., 2012; Schraw, 2007; Sharma & Hannafin, 2007).

Guidelines for Designing Scaffolds to Foster Students' SRL in e-TPCK

Based on these theoretical perspectives as well as the suggestions of the pre-service teachers who have pilot-tested the second version of the e-TPCK system, this section of the chapter discusses future research directions regarding the development of e-TPCK by proposing scaffolds for the first three phases of SRL.

Scaffolds for the First Phase (Task Definition and Planning)

1. Before introducing students to the electronic learning environment and engaging them in the instructional design activity, it is advisable to provide orientation regarding the functionality of all available scaffolds built into the e-TPCK system. The use of scaffolds is likely to increase, when scaffolding tools are explicitly identified and their functions clarified (Slotta & Linn, 2000). For example, pop-up windows, rollovers, and pedagogical agents can be added to indicate utility and importance for the underlying learning task.
2. A planning net could be included to engage students in activity scheduling. This scaffold can help learners to monitor their progress toward goals. The monitoring mechanism can display a list of goals, marking those that have not been completed within the available time. Providing students with a planning interface, similar to a management timeline with listed activity names and completion times, is a way to provide a learning analytics dashboard that learners can refer to for checking their progress toward the attainment of goals.
3. Scaffolds that will provide guidance, clarification, and explanation about the design of the learning scenarios including the steps/phases of the learning model that is adopted in each design scenario.

Scaffolds for the Second and Third Phases

1. Socratic questioning can be added as a metacognitive scaffold for each design scenario. Students will be prompted to expose the logic of their thoughts. It will not be focused as much on drawing out information as on prompting reflective analysis (Paul, 1990). Hunkins (1995) described the importance of encouraging students to "*dialogue with themselves and the material*" (p. 6), in order to discern individual value and utility of information.
2. Adaptive scaffolding can be implemented by prompting students regularly for the purpose of using FOK and JOL, as well as monitoring their progress every time they switch to a new topic or subtopic.
3. Prompts and feedback can be designed to assist with the instructional design and development of new design scenarios per teachers' needs. This can also be another way of providing adaptive scaffolding.

4. A built-in database with all teachers' questions can be implemented. Each of these questions can be coupled with a set of corresponding scaffolds. During learning, teachers will be able to type in a question and the system through pattern matching will be able to match the new question with one already present in the database, if any. Consequently, this matching will fire a production rule associated with the corresponding scaffold(s).
5. Fading of scaffolding can be accomplished through a simple mechanism, such as, for example, an option like "Stop Reminding Me" that teachers' can choose, when they feel they do not need the hint or support. In essence, fading will be available upon request.

Final Remarks

The present chapter discussed the design and development of e-TPCK, an adaptive e-learning system developed at the University of Cyprus, for the ongoing development of teachers' TPCK. The methodology of DBR has been adopted for the development of the system, leading to three iterations of refinement adding each time new features for the purpose of scaffolding teachers' gradual development of TPCK. Currently, the focus is on enhancing the system with adaptive scaffolds for the purpose of promoting teachers' self-regulatory processes during learning with e-TPCK.

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