Chapter 1
The Development of Teachers' Professional Learning and Knowledge

Ying-Shao Hsu

Technology is just a tool. In terms of getting the kids working together and motivating them, the teacher is most important.

Bill Gates

1.1 Background

Living in the world where technology keeps advancing, teaching with technology becomes a must-do for teachers to consider in their instruction of the *Net Generation*. It matters not only for how it helps students construct their current learning but also for how it reinforces citizen's technological literacy and drives technological advances forward. Facing students who are digital natives (getting used to new technology and the explosion of new information), teachers need to be smart about what and how technology-assisted instructional approaches are taken. Successful educational reforms in promoting teaching with technology cannot be achieved without teachers. Teachers are both the agents and the targets of change – leading, supporting, and infusing technology into their classrooms.

In countries where classrooms were supplied with educational technology like the USA, teachers' actual usage of projectors, interactive whiteboards, and digital cameras was low at 72 %, 57 %, and 49 %, respectively, among those who reported having access to the technology, and 40 % rated their or their students' use of computers during instruction as *often* while another 20 % rated their and students' use as *sometimes* (Gray, Thomas, & Lewis, 2010). Survey results from Project Tomorrow (2008), a series of surveys conducted annually since 2007, also revealed that both teachers' and students' technology uses for educational purposes were at a low level (e.g., using computers to type up worksheets or complete assignments). School principals expected newly hired teachers to be proficient in teaching with technology; parents expressed positive attitudes toward digital learning–teaching approaches (e.g., mobile learning tools). Other agents, such as students and aspiring

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teachers, used social networking tools and discussion boards frequently to assist communications in informal learning (Project Tomorrow, 2012, 2013). All of these survey results indicate the urgent demand for teachers' professional knowledge and willingness to use technologies to assist their instruction.

Beyond pursuing the quantity of technology implementation in classrooms, more and more teachers and educators seek content knowledge instruction with appropriate technology implementation. Integrative curriculum, where the borders of subject content are broken, is now becoming a trend for educators to pursue as a near-future or long-term goal. For example, more and more schools in the USA participate in science, technology, engineering, and mathematics (STEM) programs. These programs encourage teachers in these four subject areas to work together at developing an integrative curriculum with the purpose to build up students' ability to solve complex interdisciplinary problems. The appropriateness of teachers' uses of technology to assist their instruction not only determines students' content knowledge comprehension but also develops students' technological literacy (National Research Council [NRC], 2012; Yore, 2011). All these demands would be bounded by teachers' knowledge about enriching curriculum and assisting students' learning with appropriate uses of technology (e.g., knowing what representations are good for teaching certain types of subject content).

In fact, teachers' knowledge is a complex construct blended with their longitudinal input of knowledge and experiences. Besides conflicts between new knowledge to old knowledge systems, teachers' knowledge grows even more complicated with personal experiences or diverse contextual confines. Though teachers' knowledge is personally and dynamically changing, many educational researchers still endeavor to determine what composes teachers' knowledge in instruction. Only when teachers' knowledge is unveiled can teacher education be more effectively designed and implemented. In the following pages, I present the components of teachers' professional knowledge through historical progression and from different perspectives within the past three decades. An introductory discussion is also made to seek future directions for teacher education studies.

1.2 Development of Pedagogical Content Knowledge

Effective teachers possess knowledge to structure and facilitate learning opportunities of specified knowledge in comprehensible ways for the intended learners. Shulman (1986) proposed a teacher knowledge framework that integrated these critical ideas called pedagogical content knowledge (PCK). This integrative framework was composed of teachers' professional knowledge about subject matters called content knowledge (CK) and knowledge of instruction called pedagogical knowledge (PK). Shulman (1987) described PCK as "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). In other words, PCK refers to the *craft knowledge* of content, teaching, learning, and context that teachers rely on when they help their students to construct understanding of a specific idea or domain. The choice of craft knowledge emphasizes that this knowledge flows from experience and practice and not necessarily from theoretical sources.

Teaching is part of a complex decision-making process in which factors involved in the process of teaching and learning need to be considered carefully before, during, and after the actual event. These reflective practices require anticipatory knowledge for planning the learning–teaching experience, real-time evaluations on actions to monitor and adjust teaching, and post hoc reflections on actions to inform future teaching. For such a process requiring teachers' contemplation in different stages of instruction, Shulman (1987) suggested that PCK could be decomposed into (a) content knowledge, (b) general pedagogical knowledge, (c) curriculum knowledge, (d) knowledge of learners and their characteristics, (e) knowledge of educational contexts, and (f) knowledge of educational goals and intentions. Other researchers have added the importance of teachers' knowledge about context and school culture (Cochran, DeRuiter, & King, 1993; Grossman, 1990), teacher beliefs (Kagan, 1992; Veal, 2004), and experiences (van Driel, Verloop, & de Vos, 1998) to the listing of considerations in PCK. Among these components, CK is viewed as the prerequisite knowledge in teacher development (van Driel et al., 1998; van Driel, De Jong, & Verloop, 2002). Other components and experiences would be those that help teachers envision, enact, and realize instruction in accommodating ways to meet the needs of learners and address the realities of the context. Knowledge about students' misconceptions or alternative concepts would be part of the essence of teachers' TPACK after considering content with pedagogical concerns based on their longitudinal experiences.

Although PCK is viewed as the integration of the knowledge sets previously mentioned, some researchers have argued that PCK is a unified construct and is dynamically changing. Cochran et al. (1993) suggested that PCK should be renamed as pedagogical content knowing (PCKg) to capture the in-the-moment aspect since teachers' knowledge should not only be situated but also student centered and changeable. Gess-Newsome (1999) proposed a framework of PCK, a unitary holistic interpretation, in which teachers' knowledge of subject matter and pedagogy are contextually bounded and cannot be teased apart or deconstructed into individual components. Teachers' experiences become one major source, influencing the activation of necessary knowledge and reinforcement of their further development at the same time. Magnusson, Krajcik, and Borko (1999) suggested that science teachers need to develop knowledge of science curricula, understanding student science learning, instructional strategies, and assessment of scientific literacy and comprehension. All of these knowledge components are functionally and reciprocally nurtured and shaped by teachers' orientations toward and experiences with science teaching. Briefly, teachers' beliefs, values, attitudes, experiences, and teaching goals play important, fundamental roles that determine the development and transformation of teachers' PCK.

Both the integrative and transformative frameworks offer approaches to the development of teachers' PCK from different points of views. The integrative framework emphasizes and identifies the fundamental knowledge subsets contributing to the grand concept of PCK. This view of PCK, as a knowledge integration framework, has major influence on the design of most current teacher education systems since such knowledge can be easily carried out in different subsystems with courses delivered separately, that is, science content in academic department courses, pedagogy in general education courses, and science pedagogy in science education courses and science clinical experiences. However, based on teacher education graduates' criticism that their programs have been fragmented and lack practical relevance (Barone, Berliner, Blanchard, Casanova, & McGowan, 1996; Sandlin, Young, & Karge, 1992) and from a bottom-up point of view, it makes much more sense to view experienced teachers' PCK as the goal for preservice teachers to achieve in the early years of their teaching careers as they become inducted into the teaching profession. Actual teaching experiences and practices would transform teachers' CK and PK into unique PCK since factors of subject matter, individual student needs, curriculum goals, school climate, learning environment, and realities of time and classrooms are contextualized and demand careful considerations. Since preservice teachers' concerns in internship settings are frequently focused on issues of survival, CK, and performance evaluation but not PCK building, the transformative framework of PCK provides teacher educators a unitary holistic view for an organic process that needs time to develop and grow within the teaching contexts.

1.3 Development of Technological Pedagogical Content Knowledge

Discussions regarding PCK and teaching with technology date back to the early 1990s. Dwyer, Ringstaff, and Sandholtz (1991) identified five stages of teachers' evolution in using multimedia to assist their instruction (i.e., entry, adoption, adaptation, appropriation, and invention). Similar developmental progress (i.e., recognizing, accepting, adapting, exploring, and advancing) was also identified from teachers' learning about certain technology to the consolidation of their technological pedagogical content knowledge (TPACK; Niess et al., 2009). Factors that influenced teachers' achievements in teaching with technology include teachers' motivation and commitment, external supports, and access to technology (Hadley & Sheingold, 1993). It was not until a decade later when Pierson (2001) suggested the term *technological pedagogical content knowledge* to emphasize the importance of teachers' technological knowledge connected with the concept of teachers' PCK. Niess (2005) also proposed a similar idea by using the term *technology-enhanced PCK*. Both of these ideas emphasized the instructional use of technologies to improve the comprehensibility of target/abstract concepts, achievement of learning outcomes, and learning–teaching effectiveness.

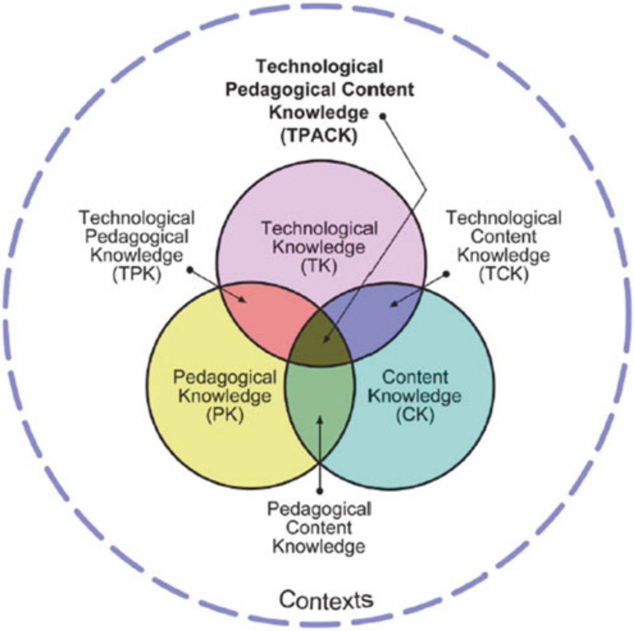

Fig. 1.1 TPACK framework (Koehler & Mishra, 2009, p. 63)

1.3.1 TPACK as an Integrative Framework

In order to decompose what contributes to teachers' knowledge in technology integration, Koehler and Mishra (2005) and Mishra and Koehler (2006) proposed a framework called *technological pedagogical content knowledge* (see Fig. 1.1). Similar to Shulman's idea that PCK is fundamentally an integrated body of knowledge composed of the intersection of CK and PK, TPACK refers to the overlapping area of CK, PK, and technological knowledge (TK). In fact, the composition of teachers' knowledge in technology integration was not as simple as merely adding TK into the PCK framework. The mutually integrated knowledge in the framework, including PCK, technological pedagogical knowledge (TPK), and technological content knowledge (TCK), also points out the knowledge that teachers need to engage in their instruction (Koehler & Mishra, 2009). Viewing TPACK as an extension of PCK, Graham et al. (2009) defined TPACK as the knowledge that teachers possess if they are able to know "a) how technological tools transform their pedagogical strategies and content representation for teaching particular topics, and b) how technological tools and representation impact a student's understanding of these topics" (p. 71).

Mishra and Koehler (2006) did not limit their consideration to technological innovations for instruction – again, not to be confused with engineering and technology as content domains based on design and research and development cycles. *Learning technology by design*, based on a longitudinal, research-based, teacher education method requiring student teachers to design instructional artifacts, has been used as the main approach for student teachers to develop their TPACK. The cyclic process of defining, designing, and refining the artifacts (e.g., instructional software, course design) that are contextualized within different subject topics and learners' needs can help preservice teachers' TPACK to develop, grow, and mature. In other words, the development of TPACK requires teachers to engage the integration of separate knowledge sets in a dynamic process for ensuring the interweaving of the component knowledge.

Following the idea of knowledge integration for TPACK, there are some important sets of knowledge or competencies that teachers who possess TPACK or teach effectively with technology should acquire. Kabakci Yurdakul et al. (2012) proposed that the necessary competencies for teachers with TPACK to develop included the design (i.e., designing instruction), exertion (i.e., implementing instruction), ethics (i.e., ethical awareness), and proficiency (i.e., innovativeness, problem solving, and field specializations). Guzman and Nussbaum (2009) stated that competencies of designing and engaging proper evaluations, setting information communication technology (ICT)-friendly learning environments, and retaining positive personal beliefs should be included in the development of teachers' TPACK. Therefore, it is possible to view the composition of teachers' TPACK with at least two tiers in the notion of knowledge integration. The integrative knowledge body of CK, PK, and TK offers the basis for teachers to carry out their instruction with technology while there are some intervening feedback loops during the enacted teaching that transform these knowledge components and their intersections.

1.3.2 TPACK as a Transformative Framework

Similar to the approaches taken to analyze teachers' PCK from an integrative framework, there are also transformative frameworks when considering the development of teachers' TPACK. Inherent in the transformative conceptualization of teacher education, which needs to be content specific, pedagogical, student centered, and situated (Cochran et al., 1993), the TPACK transformative framework is viewed as a unitary holistic body of knowledge that urges teachers to support content representations, learners, and pedagogy with careful consideration of the technological affordances (Angeli & Valanides, 2009). They proposed and defined the framework ICT–TPCK as:

> knowledge about 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, or difficult to be represented by teachers, can be transformed and taught more effectively with ICT, in ways that signify the added valued of technology. (Angeli & Valanides, 2009, pp. 158–159)

They claimed that functionality maps of instruction and available tools varied with situated contexts and individual students' learning progress. Under this rationale, TPACK is a knowledge construct that transforms with rounds of instructional decisions about what, who, and how to teach with careful consideration of the technological affordances and available technological resources.

The ways teachers' conceptualize TPACK determines the way their knowledge is developed. TPACK in an integrative framework assumes the additive components of knowledge where preservice teachers acquire subsets of knowledge that are applied to the design and development of instructional artifacts as practices for their TPACK integration. However, TPACK in a transformative framework assumes that teachers' TPACK transforms with experiences on designing and delivering content instruction with appropriate uses of technology and that it is the way teacher educators should follow to develop their students' TPACK. Angeli and Valanides, in a series of studies that explored formats for teachers developing TPACK, found that being proficient in one specific knowledge subset (e.g., CK, PK, TK, or TPK) would not ensure the likely development of TPACK (Angeli, 2005; Angeli & Valanides, 2005, 2009; Valanides & Angeli, 2006, 2008a, 2008b, 2008c). Full consideration of content, learners, and technological tools within the actual design would be one of the keys in teachers' TPACK transformation.

The emphasis of teacher education in a transformative framework is the mapping of knowledge of learners, pedagogy, representation, and tool affordances, as shown in Fig. 1.2 (Angeli & Valanides, 2009). This mapping, from constructivist learning theories, urges teachers to design instruction based on students' current knowledge (e.g., alternative concepts) and then engage, challenge, and arouse students' cognitive or sociocognitive conflicts to promote a conceptual change ecology. With this view, it is easier for in-service teachers to start from the alternative concepts that students might have by calling on their previous teaching experiences while preservice teachers would need to seek external information (e.g., experienced teachers' and teacher educators' guidance or information). Assuming that experienced teachers' PCK can be the guidance for preservice teachers, the idea of setting up communities of practice for preservice and in-service teachers where experienced teachers can demonstrate how they design and carry out the instruction could be another method to optimize the transformation of novice teachers' TPACK. According to the collaborative learning framework for teachers (Jang & Chen, 2010), either guided or self-initiated repetitive cycles of use, comprehension, observation, practice, and reflection in teaching with technology would be effective approaches to reinforce teachers' TPACK development in terms of transformative points of views.

Both integrative and transformative frameworks were deemed to be useful for teachers to help students acquire knowledge in a technology-enriched information age as one of the goals for teacher education. Seamless connections between technology and instruction are ideal goals for teachers rather than merely pursuing techno-centric classrooms (Ward & Kushner Benson, 2010). In that way, having a

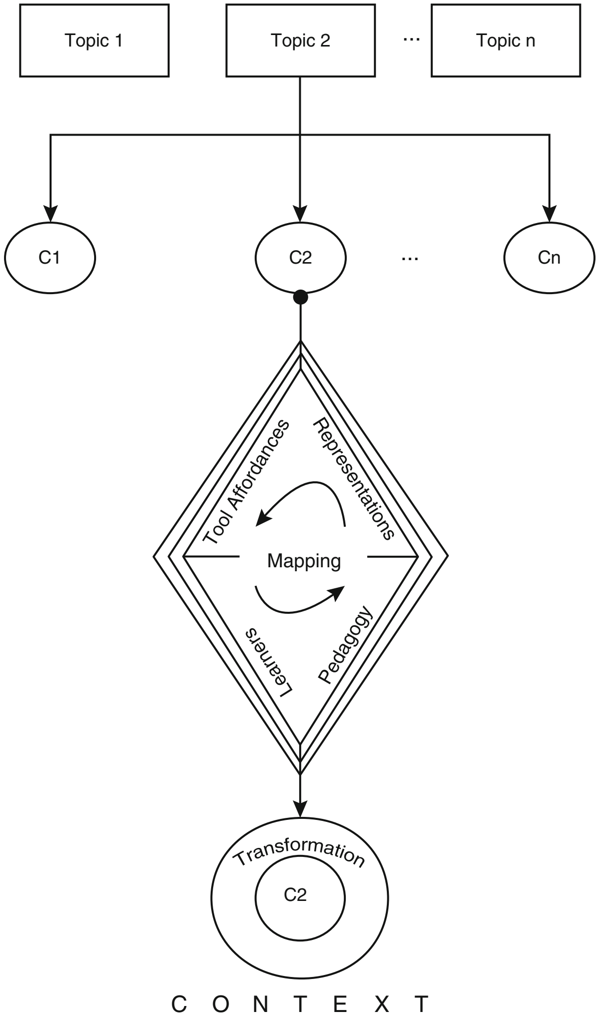

Fig. 1.2 ICT–TPCK in a situative instructional design model (Angeli & Valanides, 2009, p. 160)

technologically literate disposition or habit of mind is the basic requirement for teachers who will need to keep updating themselves so as to know how to use ever-changing hardware and software (Ertmer & Ottenbreit-Leftwich, 2010). The true value of TPACK would be ensuring more effective subject content instruction with consideration of pedagogical needs and use of appropriate technologies for accommodating students' learning needs. Since teacher knowledge is developed for and from teaching practices with technology in classrooms, the development of TPACK is an ongoing journey for preservice teachers, in-service teachers, and teacher educators.

1.4 TPACK as Twenty-First-Century Instructional Knowledge

TPACK is an integrated set of knowledge, but at the same time, transformation occurs within/between the component knowledge as well as to the overall construct. Some other descriptors like situated, dynamic, and multifaceted (Cox & Graham, 2009; Doering, Veletsianos, & Scharber, 2009; Koehler & Mishra, 2008) imply TPACK is a knowledge construct that varies and matures with contexts and is hard to be generally defined. No matter how complicated it may be in its development, it is undeniable that TPACK is born and elaborated for satisfying student learning needs. Who to be taught (i.e., students) has great influence on what to teach (e.g., subject content) and how to teach (e.g., pedagogy, technological tools) while how to teach will play a supportive role to the instructional target (i.e., learning goals). Furthermore, it becomes more complicated when TPACK is expected to be a knowledge framework that teachers rely on to develop students' twenty-first-century skills and competencies. Some researchers have proposed that the TPACK framework needs to be *transdisciplinary* (Kereluik, Mishra, & Koehler, 2010; Mishra, Koehler, & Henriksen, 2010). Besides CK learning, considering actual practices that teachers engage to enhance students' cognitive skills like problem solving and critical thinking is important for twenty-first-century education. By recapitulating the importance of accommodating student learning needs, TPACK should be student driven, content bound, and technology required but not technology prioritized.

Science teaching is a field that demands higher quality of teachers' TPACK. In contemporary views, science learning is involved with knowledge construction (Driver, Asoko, Leach, Scott, & Mortimer, 1994), conceptual change (Carey, 2000; Duit & Treagust, 2003), inquiry ability construction (Cuevas, Lee, Hart, & Deaktor, 2005; White & Frederiksen, 1998), and so on. Since misconceptions are common in science learning (Gil-Perez & Carrascosa, 1990; Gilbert & Watts, 1983), individual and social explorations of natural phenomena or data become necessary when students construct their science knowledge. Unobservable natural phenomena or abstract concepts have to be represented for students to visualize. Therefore, technology with different affordances can be helpful to student knowledge construction: multimedia for science phenomena presentation, predefined simulation software for students' modeling, and communication tools or platforms for collaborative learning. These science-specific disciplinary features make TPACK especially critical to science teachers since meaningful technological support and implementation can afford authentic science and engineering practices and scientific thinking in classrooms where the teacher-directed approach is pursued most of the time.

In the past few decades, science education researchers have devoted much time developing technologically assisted curricula or microcomputer-based experiments for helping students construct science CK and achieving scientific literacy. It was not until 2000 that researchers started paying attention to TPACK with regard to domain-specific content in science. Jimoyiannis (2010) in his technological pedagogical science knowledge (TPASK) pointed out content-specific knowledge components that science teachers are expected to develop, like "fostering scientific inquiry with ICT [and] student scaffolding" (p. 1263). Researchers spent more time on examining science teachers' proficiency in TPACK (Graham et al., 2009; Lin, Tsai, Chai, & Lee, 2013), but comparatively fewer studies have been conducted about the development of science teachers' knowledge and uses of certain technological devices (Jang & Tsai, 2012). Either specific competencies (e.g., science literacy, inquiry) or specific contents (e.g., plate movement, molecular collision) deserve quality technology-implemented instruction. Experienced science teachers' ideas can be good resources when designing learning tools or software that promotes students' science learning. Their meaningful and flexible uses of technology to assist science instruction can be practical exemplars for novice teachers to learn and observe. Networking among teacher communities comprised of individuals possessing varied scientific competencies can be another good approach to encourage sharing of science teachers' teaching materials in diverse formats and learning goals. Investigations on the nature and approaches to develop general TPACK (interdisciplinary) are important, but domain-specific TPACK within other disciplines should be emphasized as well in science education. After all, discussions become more consolidated once real teaching contexts (e.g., target content and students' learning progress) are considered.

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