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.solaresearch.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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