J. EDUCATIONAL COMPUTING RESEARCH, Vol. 48(2) 199-221, 2013

TECHNOLOGY MAPPING: AN APPROACH FOR DEVELOPING TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE

CHAROULA ANGELI
NICOS VALANIDES
University of Cyprus

ABSTRACT

Technology mapping ™ is proposed as an approach for developing technological pedagogical content knowledge (TPCK). The study discusses in detail instructional design guidelines in relation to the enactment of TM, and reports on empirical findings from a study with 72 pre-service primary teachers within the context of teaching them how to teach with Excel. Repeated Measures MANOVA findings showed that TM was effective and efficient in developing TPCK competencies; however, development of TPCK competencies was directly related to the complexity of the design task, as this was determined by the educational affordances of Excel.

INTRODUCTION

Technological Pedagogical Content Knowledge (TPCK) was introduced to the educational research community as a 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 embraced with enthusiasm the framework and a substantial body of research has been published (Voogt, Fisser, Pareja Roblin, Tondeur, & van Braak, 2013). Nonetheless, a number of issues remain unresolved, and, therefore, any new

doi: http://dx.doi.org/10.2190/EC.48.2.e
http://baywood.com

research efforts that are undertaken to advance the theoretical conceptualization of TPCK, or report data on methods of how to develop and assess TPCK, are fully warranted.

The authors herein revisit some of the theoretical issues about the nature of TPCK that are still debated in the literature, clarify which theoretical stance about TPCK the present study adopts, and discuss technology mapping as a method for developing TPCK. The study also reports on empirical evidence regarding the effectiveness of technology mapping within the context of teaching pre-service primary teachers how to teach with Excel.

CURRENT THEORETICAL CONCEPTIONS OF TPCK

In the literature, there are two dominant theoretical models about the conceptualization of TPCK—the integrative model and the transformative model. The integrative model, as shown in Figure 1, was proposed by Koehler and Mishra (2005), and it conceptualizes TPCK as an integrative body of knowledge defined by the intersections between content and pedagogy, content and technology, and pedagogy and technology. The transformative model, shown in

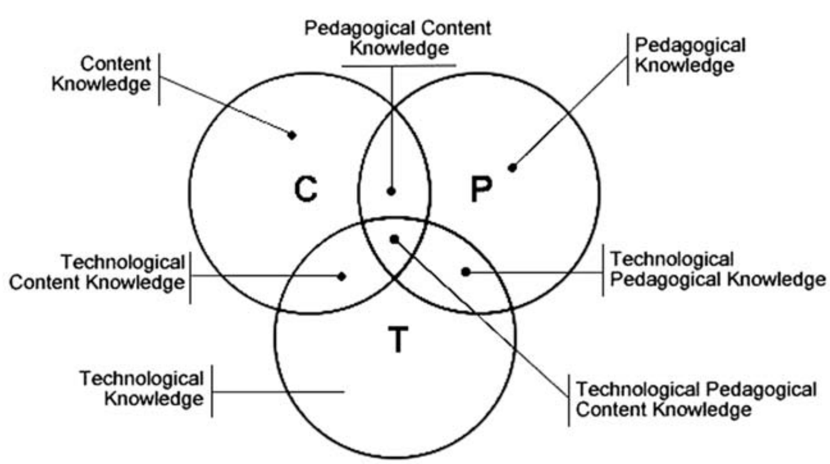

Figure 1. Graphical representation of TPCK (adopted from Mishra & Koehler, 2006).

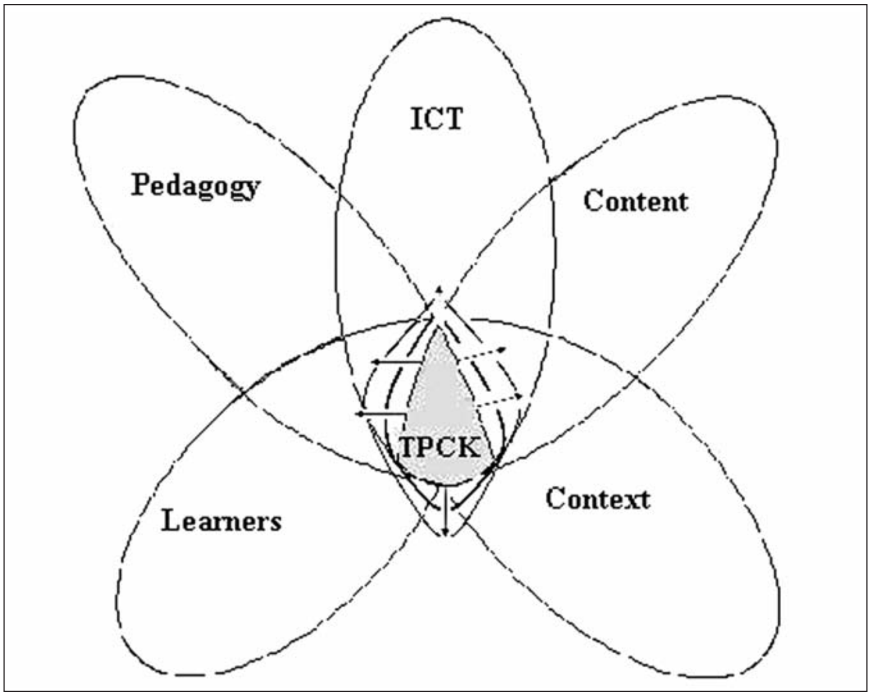

Figure 2. Graphical representation of TPCK as a transformative body of knowledge.

Figure 2, was proposed by Angeli and Valanides (2005), and it conceptualizes TPCK as a unique body of knowledge. In the transformative model, content, pedagogy, learners, technology, and context are regarded as significant contributors to the development of TPCK.

Both models view TPCK as an extension of Shulman's (1986, 1987) pedagogical content knowledge (PCK). PCK identifies the distinctive bodies of knowledge for teaching, and highlights a special amalgam of content, pedagogy, learners, and context (Shulman, 1986). 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. Despite having PCK as their common theoretical basis, the two models are based on different epistemological stances regarding the nature of TPCK.

Mishra and Koehler (2006) used the general term TPCK to include all forms of digital technologies (i.e., internet, digital video), as well as standard technologies (i.e., books, chalk, and blackboard), whereas Angeli and Valanides (2005) used the term ICT-TPCK to put emphasis on the fact that the T in TPCK referred to computer-based technologies only. 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 emphasizes through its letters in the acronym the three kinds of knowledge, namely, **c**ontent, **p**edagogy, and **t**echnology, which are deemed important for successfully integrating technology in teaching and learning. Additionally, according to Thompson and Mishra, TPACK "*captures the fact that these three knowledge domains should not be taken in isolation, but rather that they form an integrated whole, a 'Total PACKage'*" (p. 38). Despite the fact that after 2007 the acronym TPACK has been used considerably in the literature, it has not been widely adopted by everyone (Voogt et al., 2013).

TPACK, as depicted in Figure 1, is represented in terms of three intersecting circles, one for each distinct knowledge base, namely, content, pedagogy, and technology (Mishra & Koehler, 2006), while its subcomponents, i.e., technological content knowledge (TCK), technological pedagogical knowledge (TPK), and pedagogical content knowledge (PCK), are also clearly depicted in the figure. Angeli and Valanides (2009) argued that it was not clear from the initial work of Mishra and Koehler whether TPCK was conceptualized as an integrative or distinct form of knowledge. Later, empirical work by Mishra and Koehler and other researchers who adopted TPACK (e.g., Chai, Kho, Tsai, & Tan, 2011; Harris & Hofer, 2011; Schmidt, Baran, Thompson, Mishra, Koehler, & Shin, 2009) clearly showed that the interest was on identifying and measuring instances of TPACK's subcomponents, for example, TPK and TCK. So far, empirical findings from this line of research have been rather discouraging, because it has proven too difficult to define the boundaries of the different TPACK sub-components (Angeli & Valanides, 2009; Archambault & Crippen, 2009; Graham, 2011; Voogt et al., 2013).

ICT-TPCK (TPCK from now on) as shown in Figure 2, is conceptualized in terms of five distinct knowledge bases, namely, content knowledge, pedagogical knowledge, knowledge of learners, knowledge of educational context, and ICT knowledge (Angeli & Valanides, 2005, 2009). Based on the results of empirical investigations, Valanides and Angeli (2008a, 2008b) concluded that TPCK is a distinct body of knowledge that goes beyond mere integration or accumulation of the constituent knowledge bases, toward transformation of these contributing knowledge bases into something new and unique. For this reason, the authors have not adopted the new term TPACK and opted to continue using TPCK instead, because TPACK appears to be more associated with the integrative view rather than the transformative view.

TPCK AS A TRANSFORMATIVE BODY OF KNOWLEDGE

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 Figure 2, there are a number of individual knowledge bases that contribute to the development of TPCK; however, as was found in a series of empirical studies, growth in the individual contributing knowledge bases alone, without specific instruction exclusively targeting the development of TPCK, does not result in TPCK growth (Angeli, 2005; Angeli & Valanides, 2005; Valanides & Angeli, 2006, 2008a, 2008b). Therefore, research efforts focusing on the development of TPCK as a unique type of knowledge are essential for advancing the field.

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 teach with technology adequately. 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 the TPACK framework 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 implement 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 ™, shown in Figure 3, was first introduced as an approach for developing teachers' TPCK in 2009 (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 pedagogical content knowledge. Angeli and Valanides 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 a tool, content, and pedagogy in relation to learners' content-related difficulties.

TM is a dynamic, situated, and personal design process because teachers' instructional design decisions are guided by a body of knowledge that is highly situated in the context of their real classroom experiences (Carter, 1990; Kagan & Tippins, 1992; Leinhardt, 1988; Moallem, 1998). As shown in Figure 3, context is an overarching factor in the process of designing learning with technology. The process of designing technology-enhanced learning 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 (Abbitt, 2011; Niess, 2005; Ottenbreit-Leftwich, Glazewski, Newby, & Ertmer, 2010). For example, if a teacher has deep-rooted beliefs in teacher-centered learning, then technology integration will most likely be teacher-directed (i.e., the teacher uses the technology to deliver information to students) and not learner-directed (i.e., the students use the technology as a cognitive tool to construct/represent meaning about something). Context is included in the model to promote reflection about the ways context-related factors may impact teachers' designs of technology-enhanced learning. Furthermore, TM allows teachers to bring experiences from their classrooms into the design process, and, specifically, experiences that are related to teachers' PCK, that is, teachers'

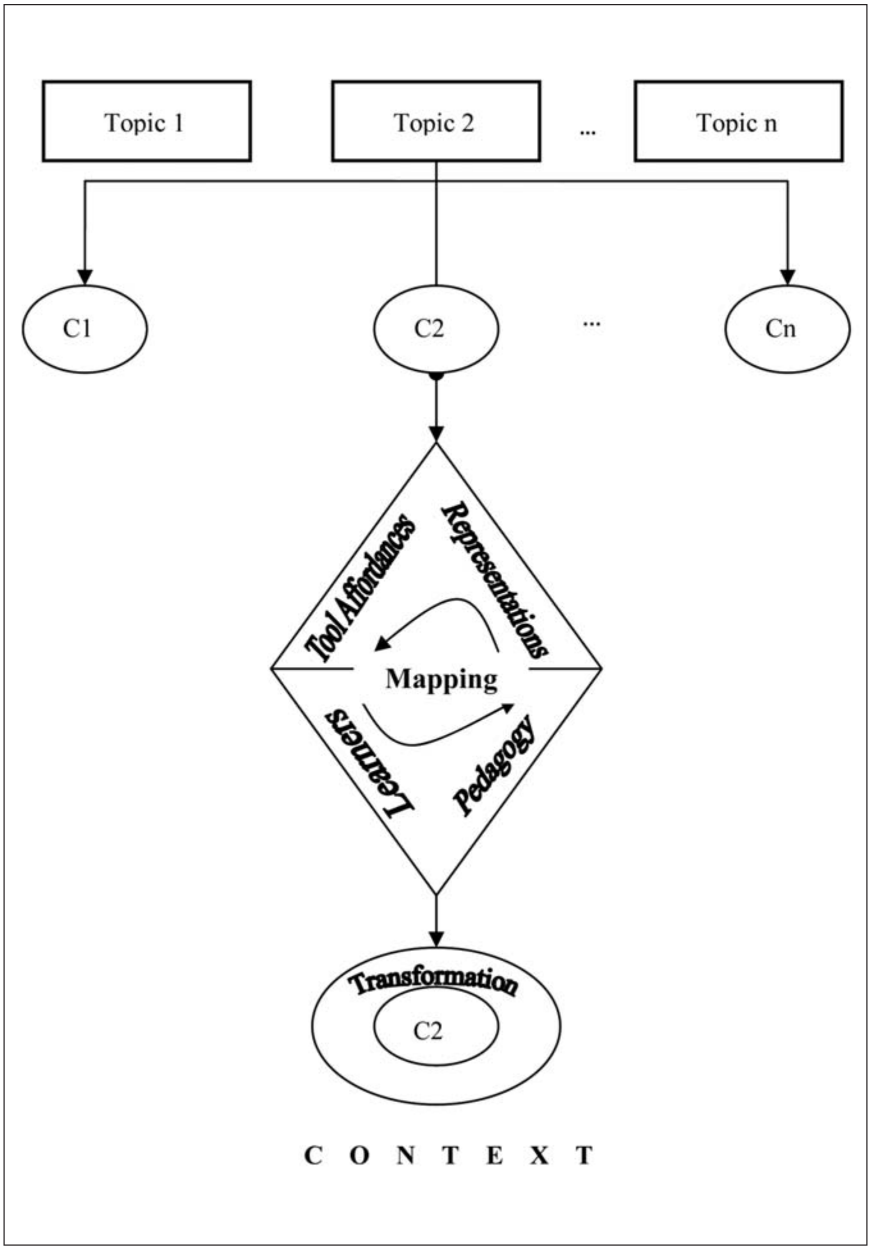

Figure 3. Technology mapping (adopted from Angeli & Valanides, 2009).

understandings of their students' alternative conceptions and learning difficulties in relation to certain curriculum topics, as well as teachers' understandings of their own difficulties in making a specific content teachable and easily learnable for their students.

According to the model depicted in Figure 3, teacher educators ask pre-service or in-service teachers to think about a specific content domain, and, based on their experiences, to indicate their difficulties in making the most challenging aspects of the domain teachable to students, in connection with students' content-related difficulties. Subsequently, for each topic, teachers associate relevant content (represented as circles in Figure 3) 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), how to tailor these representations for 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).

Nonetheless, the authors of the present study recognize that currently in the literature the underlying instructional design processes of TM, encapsulated in the diamond shape in Figure 3, are not explicitly discussed and exemplified. Therefore, the authors aim with the contribution herein to provide teacher educators with specific guidance and examples about how to enact TM.

FROM TECHNICAL FUNCTIONS TO EDUCATIONAL AFFORDANCES

Affordances are properties of the relationship between an agent and its physical environment. These properties allow and facilitate specific types of interaction. Gibson (1977, 1979) defined affordances as all action possibilities latent in the environment, objectively measurable and independent of the individual's experience, knowledge, culture, or ability to recognize them. Norman's (1988, 1990) conceptualization of affordances diverges from Gibson's conceptualization in that Norman defines an affordance as something of both actual and perceived properties. When actual and perceived properties are combined, an affordance emerges as a relationship that holds between the object and the individual that is acting on the object (Norman, 1990).

From the literature on teachers' understandings of technology affordances, it is evident that: (a) teachers do not distinguish between the technical functions of technology and the educational affordances of technology (Angeli, 2013; Angeli & Valanides, 2005; Valanides & Angeli, 2008b); (b) teachers are not always aware of the cognitive processes involved in using the affordances of a particular technology (Yoon, Ho, & Hedberg, 2005); and (c) teachers' formation of mental models of technology affordances largely depends upon their training and their professional development (Angeli, 2013; Krauskopf, Zahn, & Hesse, 2012). Based on these findings, going from knowing how to use a tool to knowing how to teach with a tool, or going from knowing about the technical functions of technology to perceiving the educational affordances of technology, does not occur automatically. Therefore, it becomes imperative that teacher educators make this process explicit during teacher training.

Teaching pre-service or in-service teachers how to teach with technology involves more than just making the educational affordances of technology explicit to them. For example, a course on teaching teachers how to teach with a tool also involves, among other things, teaching the tool itself. In such cases, typically, teacher educators first teach students how to use the tool, and then they illustrate through various examples how the tool can be integrated in classroom teaching. The time devoted to teaching the tools themselves is usually more than the time left to teach students how to teach with the tools. This approach is for the most part fragmented and decontextualized, because the majority of the time is devoted to demonstrating, one by one, the technical functions of the tools, and not on illustrating the educational affordances of the tools in relation to content and pedagogy within the context of a design task. Additionally, an approach that focuses on teaching one at a time the technical functions of technology prevents learners from developing adequate and holistic mental models about the affordances of technology, and the connections among technology, content, pedagogy, and learners. The idea that learners will develop these mental models by themselves can only be characterized as wishful thinking.

Technology mapping is about making the educational affordances of the tools explicit within the context of an authentic design task, while, at the same time, students also learn how to use the technology itself. In particular, the authors developed the following seven instructional design guidelines to facilitate the enactment of the TM process. These guidelines are intended to be used by teacher educators or teacher trainers after selecting appropriate topics and content to be taught with technology. The guidelines are provided as an expansion or elaboration of the diamond shape in Figure 3, and they are proposed as a way to help teachers construct mental models of technology affordances within the context of an authentic design task directly related to the curriculum. They include:

1. Discuss, in a sequence from simple to complex, the educational affordances of a tool for the specific target group of students.
2. Demonstrate each educational affordance, with a worked-out design task, using a series of technical functions within the context of an appropriate real curriculum topic.

3. Discuss and explain the structure of the worked-out design task in terms of its underlying instructional design (i.e., objectives, design of an instructional sequence of activities, etc.).
4. Let students practice with the affordance using a new design task, and by introducing gradually more and more technical functions, as needed.
5. Repeat steps 2 to 4 as many times as instructional/classroom time allows according to one's discretion, moving gradually from worked-out design tasks to semi-completed design tasks, to new design tasks.
6. Continue with a new educational affordance and repeat steps 2 to 5 until all educational affordances are discussed, illustrated, and practiced.
7. Select a new tool, and repeat steps 1 to 6.

The authors maintain that the TM guidelines promote a spiral approach to learning how to use a computer tool. The spiral approach is a method where first the basic facts of a subject are learned, and gradually as learning progresses, more and more details are introduced while, at the same time, the basics are revisited (Bruner, 1960; Duncan & Hmelo-Silver, 2009). Respectively, the TM guidelines promote teaching the basic functions of a tool first, followed by the more complex. It is not the aim of TM to exhaustively teach all technical functions of a tool in one particular course.

In general, the TM guidelines reflect a holistic approach to developing all competencies teachers need to teach with technology. A holistic design approach is successful in preventing compartmentalization and fragmentation (van Merrienboer & Kirschner, 2007). Compartmentalization refers to the separation of a whole into distinct parts. This approach leads to a piecemeal approach of aquiring knowledge, seriously limiting one's ability to develop an integrated body of knowledge which includes skills, facts, procedures, principles, attitudes, beliefs, and dispositions. Fragmentation is the process of breaking something into small or isolated parts (van Merrienboer, Clark, & de Croock, 2002). The implications of such an approach is that learning objectives are taught in isolation, one at a time, and not in coordination with each other, leading to a highly fragmented body of knowledge.

In particular, the TM guidelines represent an instructional design model that is rooted in van Merrienboers' four-component instructional design theory (van Merrienboer, 1997) which can be described as consisting of learning tasks, supportive information, procedural information, and part-task practice. Learning tasks are in this case design tasks that aim at integrating design skills, knowledge of content, pedagogy, technology, and learners, and beliefs about the role of technology in teaching and learning. These design tasks are organized in easy-to-difficult task classes and have diminishing support in each task class. This is realized by presenting students with design tasks ranging from worked-out design tasks to semi-completed design tasks and to new design tasks. Supportive information is specified for each design-task class and is related to the instructional design of each task contingent upon a particular technology affordance. Then, for the routine aspects of each design task, procedural information is provided when needed, to specify exactly how to perform the routine aspects of the task. Part-task (practice) items are provided to help learners reach a high level of automaticity for selected routine aspects of a design task, such as, for example, practicing a set of technology functions pertinent to a particular design task.

METHODOLOGY

Participants

Seventy-two juniors from a teacher education department participated in the study. At the time, students were enrolled in three sections of an instructional technology course to learn how to design and develop learning activities with Excel appropriate for young learners. The duration of the course was 13 weeks. Each section met once a week in a computer laboratory for 2.5 hours. The challenge in teaching the course was threefold, as students needed to learn: (a) how to use the technical functions of Excel; (b) about the educational affordances of Excel; and (c) how to design technology-enhanced learning activities with Excel for young learners.

Assessment Tasks

Students' TPCK was assessed based on their performance on five design tasks, one for each of the five educational affordances of Excel that were discussed in the course during the semester. The time allotted for completing and submitting a design task for grading was 2 weeks. Students completed their first design task in the 3rd week of the course, and their fifth design task in the 11th week of the course. Pre-service teachers were specifically instructed to submit, along with a CD with their Excel activities, a five-page word document for each design task addressing the following elements:

1. description of a topic to be taught with Excel in ways that exploit the added value of Excel;
2. identification of appropriate Excel representations for transforming the content to be taught into forms that are comprehensible to learners and difficult to support by traditional means;
3. identification of teaching strategies with Excel, which are difficult or impossible to implement by traditional means;
4. design of appropriate computer-based learning activities that exemplify adequately the educational affordances of Excel; and
5. infusion of the Excel activities in a classroom lesson with learner-centered strategies.

Participants' design tasks constituted the unit of analysis. Performance on each design task was assessed using the evaluation criteria for TPCK competencies shown in Table 1, and the evaluation criteria for each educational affordance of Excel shown analytically in Table 2. The maximum score for each design element was 20, thus the highest assessment score possible for each design task was 100. Two raters, one of the researchers and a doctoral candidate in instructional technology who was also the teaching assistant for the course, rated students' performance on the five design tasks. The inter-rater reliability was found to be .91, .88, .85, .87, and .84, for the first, second, third, fourth, and fifth design tasks, respectively. Observed disagreements were resolved constructively after discussion.

Research Procedures

The course instructor, who was the same for all three sections, first discussed in class the philosophy behind teaching with technology. The departure from technologies as media for transferring facts and information to technologies as cognitive tools for constructing meaning and representing understanding was emphasized. Then, students were asked to think about topics that traditionally were regarded as difficult to understand or teach. Students were able to recall from their other teacher education courses and identified a number of suitable topics. Then, the course instructor introduced Excel as a tool with certain educational affordances for teaching and learning. Specifically, the course instructor discussed five distinct educational affordances of Excel in a sequence from simple to complex, as follows: (a) Excel as a tool for organizing information; (b) Excel as a tool for giving feedback; (c) Excel as a tool for creating a hypertext story; (d) Excel as a tool for performing calculations; and (e) Excel as a modeling tool. Then, for each educational affordance, the course instructor, with the help of the participants, chose curriculum topics and determined content suitable to be taught with Excel. For example, to illustrate the use of Excel as a modeling tool, the course instructor demonstrated how Excel could be used to model the phenomenon of the growth of plants, and the water cycle. Subsequently, the course instructor demonstrated each educational affordance with the application of a series of technical functions within the context of a simple real curriculum example. Students were allowed to practice the same affordance with a new design task, while new technical functions were also introduced accordingly as needed. This process continued with providing more examples of design tasks, albeit of diminishing support, until a new affordance was introduced.

RESULTS

Table 3 shows descriptive statistics of pre-service teachers' performance on the five design tasks for each TPCK competency. The first design task was about utilizing Excel as a tool for organizing data, the second about utilizing Excel as a tool for giving feedback, the third about Excel as a tool for creating a hypertext story, the fourth about Excel as a tool for performing calculations, and the fifth was about Excel as a modeling tool. Each design task was progressively more complex than the previous one(s), in terms of the underlying instructional design of the learning activities with Excel relative to the five affordances.

As the results show in Table 3, students' performance on the first design task was consistently high across all five TPCK competencies. Students' performance on the second design task was high for the first two competencies and relatively high for the last three competencies. Students' performance on the remaining three design tasks was much lower than students' performance on the first two design tasks. In fact, students' performance after the second design task progressively dropped, so that students' scores on the third design task for each TPCK competency were much lower than students' scores on the second design task. Similarly, students' scores on the fourth design task were much lower than students' scores on the third design task, and students' scores on the fifth design task were much lower than students' scores on the fourth design task. Obviously, as the findings showed, thinking about how to use Excel to model a phenomenon had inherently a higher degree of difficulty compared to using the tool as a means for organizing information, or providing feedback, or creating a hypertext story, implying that more time and effort should be devoted to teaching students about modeling and how Excel can be used as a modeling tool.

Repeated Measures MANOVA was performed to identify differences in TPCK competencies across the five design tasks. The results showed statistically significant differences for all five TPCK competencies across all five design tasks as follows: (a) identification of topics to be taught with Excel, $F(4, 67) = 16.84$, $p < 0.01$, partial $\eta^2 = .16$; (b) identification of representations for transforming the content into appropriate forms, $F(4, 67) = 15.87$, $p < 0.01$, partial $\eta^2 = .15$; (c) identification of teaching strategies, which are difficult or impossible to be implemented by traditional means, $F(4, 67) = 16.36$, $p < 0.01$, partial $\eta^2 = .14$; (d) pedagogical utilization of the affordances of Excel, $F(4, 67) = 13.98$, $p < 0.01$, partial $\eta^2 = .14$; and (e) identification of learner-centered strategies for the infusion of Excel in the classroom, $F(4, 67) = 15.10$, $p < 0.01$, partial $\eta^2 = .15$. Post hoc comparisons using the Tukey HSD method showed significant differences regarding students' scores on the first TPCK competency between: (a) the first design task and the third, fourth, and fifth design tasks; and (b) the second design task and the third, fourth, and fifth design tasks as well. No significant differences were detected between the first and second tasks regarding the first TPCK competency. Regarding the second TPCK competency, significant differences were found between: (a) the first design task and the third, fourth, and fifth design tasks; (b) the second design task and the fourth and fifth design tasks; and (c) the third and fifth design tasks. Similarly, concerning the third TPCK competency, significant differences were found between: (a) the first design task

Table 1. Evaluation Criteria for Assessing TPCK Competencies

TPCK competency	Evaluation criteria
1. Identification of topics to be taught with technology in ways that signify the added value of tools, such as topics that students cannot easily comprehend, or topics that teachers face difficulties in teaching them effectively in class.	1. Abstract concepts (i.e., cells in biology) that need to be visualized. 2. Phenomena from the physical and social sciences which consist of certain events and need to be animated (i.e., water cycle, immigration, butterfly life cycle). 3. Complex systems (i.e., ecosystems, organizations) in which certain factors function systemically and need to be simulated or modeled. 4. Topics that require multimodal representations (i.e., textual, iconic, auditory) such as phonics and language learning.
2. Identification of representations for transforming the content to be taught into forms that are comprehensible to learners and difficult to be supported by traditional means.	1. Interactive representations. 2. Dynamic transformation of data. 3. Dynamic processing of data. 4. Multiple simultaneous representations of data. 5. Multimodal representations of data.
3. Identification of teaching strategies, which are difficult or impossible to be implemented by traditional means.	1. Exploration and discovery in virtual worlds. 2. Virtual visits (i.e., virtual museums). 3. Testing of hypotheses and/or application of ideas into contexts not possible to be experienced in real life. 4. Modeling. 5. Complex decision-making.

	6. Creation of cognitive conflict. 7. Long distance communication and collaboration with experts. 8. Long distance communication and collaboration with peers. 9. Personalized learning. 10. Adaptive learning.
4. Selection of an ICT tool and pedagogical utilization of its affordances.	Evaluation criteria are presented in Table 2 (the criteria are specific for each affordance of Excel).
5. Identification of learner-centered strategies for the infusion of technology in the classroom.	Any strategy that puts the learner at the center of the learning process in order to: 1. express a point of view, 2. explore, 3. observe, 4. discover, 5. inquire, 6. collaborate with others, 7. resolve cognitive conflict, and 8. problem solve.

Table 2. Educational Affordances of Excel, Technical Functions, and Evaluation Criteria for Each Affordance

Affordance (sequenced) from simple to complex)	Excel technical functions	Evaluation criteria
1. Excel as a tool for organizing data.	1. File – New/Open/Close/Save/Save as/Page setup/Print area/Print preview/Print/Send to. 2. Edit – Cut/Copy/Paste/Fill/Clear/Delete/Delete sheet/Move or copy sheet/Find/Replace. 3. Insert – Cells/Rows/Columns/Worksheet/Chart Pictures. 4. Format – Cells/Row/Column/Sheet/Style. 5. Tools – Spelling/Speech/Protection. 6. Data – Sort/Text to columns/Group and outline.	1. Meaningful and clear organization of data. 2. Attractive and intuitive organization of data. 3. Appropriate selection of visualizations for young learners. 4. Integrated presentations of pictures, text, numbers, and spoken word. 5. Appropriate symbols to promote emergent literacy.
2. Excel as aa tool for providing context-sensitive feedback.	1. Insert – Function/IF.	1. Function is correctly utilized. 2. Feedback is provided in different modalities taking into consideration students' current level of literacy skills.

3. Excel as a tool for creating a hypertext story.	1. Insert – Hyperlink.	1. The story is presented from the perspectives of multiple characters. 2. The story has multiple possible entry points. 3. The story has many internal threads. 4. The story constitutes an integrated whole. 5. Easy navigation and learner control.
4. Excel as a tool for performing calculations.	1. View – Formula bar. 2. Insert – Function/Sum/Average/Count/Max.	1. Functions such as SUM( ), AVERAGE ( ), etc. are correctly utilized. 2. Formulae are correct.
5. Excel as a modeling tool.	1. All of the above as needed.	1. Children see clearly how their decisions/actions affect the outcomes. 2. Children add or remove objects and observe the consequences. 3. The results of an action or decision are communicated with the use of appropriate visualizations when possible. 4. Aesthetic appeal.

Table 3. Descriptive Statistics of Learners' Performance on the TPCK Competencies for the Five Design Tasks (N = 72)

	Design Task I		Design Task II		Design Task III		Design Task IV		Design Task V	
TPCK competencies	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
1. Identification of topics to be taught with technology in ways that signify the added value of tools, such as topics that students cannot easily comprehend, or topics that teachers face difficulties in teaching them effectively in class.	19.92	.40	19.25	2.52	17.29	3.28	16.50	4.79	15.70	5.35
2. Identification of representations for transforming the content to be taught into forms that are comprehensible to learners and difficult to be supported by traditional means.	19.83	.80	19.08	3.08	17.29	3.26	16.29	5.01	15.04	6.49
3. Identification of teaching strategies, which are difficult or impossible to be implemented by traditional means.	19.83	.80	18.92	3.90	17.25	3.34	16.29	5.04	15.00	6.55
4. Selection of an ICT tool and pedagogical utilization of its affordances.	19.67	1.61	18.50	5.01	17.42	3.13	16.50	4.84	13.92	7.88
5. Identification of learner-centered strategies for the infusion of technology in the classroom.	19.79	1.01	18.96	3.55	17.38	3.20	16.08	5.28	15.17	6.06

and the third, fourth, and fifth design tasks; (b) the second design task and the fourth and fifth design tasks; and (c) the third and fifth design tasks. Regarding the fourth TPCK competency, significant differences were found between: (a) the first design task and the fourth and fifth design tasks; (b) the second design task and the fifth design task; (c) the third and fifth design tasks; and (d) the fourth and fifth design tasks. Lastly, regarding the fifth TPCK competency, significant differences were found between: (a) the first design task and the third, fourth, and fifth design tasks; (b) the second design task and the fourth and fifth design tasks; (c) the third and fifth design tasks; and (d) the fourth and fifth design tasks.

Students were also asked to comment on their design experiences with Excel. All students said that their experiences, prior to taking this course, with learning how to use a computer program were limited to learning how to use the tool in a decontextualized way with a focus on learning to use the technical functions of the tool only. Such an approach, students added, was very limiting, because it did not demonstrate the educational affordances of the tool in teaching and learning a particular subject matter. In addition, the majority of the participants stated that a teacher may know how to use a tool, but he or she may not know how to utilize the tool pedagogically in the classroom in ways that exploit the distinct educational affordances of the tool. As a consequence, students strongly pointed out that the educational affordances of a tool must always be made explicit by teacher educators, because often times teachers' ignorance about the educational affordances may lead to the misuse of the tool in the classroom. When students were asked to self-evaluate their TPCK, all of them stated that the course added to the development of their TPCK, because they now had a better understanding about how to use Excel to transform content into powerful representations. This was more evident in the case about utilizing Excel as a modeling tool, because, as students mentioned, they had to think hard about a topic that was appropriate for young learners to understand and at the same time complex enough to be taught with models. Students also mentioned that they no longer struggled over the selection of an appropriate topic to be taught with technology, but rather to understand in creative ways the educational affordances of a computer tool, and to map tool affordances onto content and pedagogy. In asking the students to suggest ways of how their TPCK could be further developed, all students expressed the need to be explicitly taught about the educational affordances of tools in their remaining teacher education courses, as well as to practice identifying the educational affordances of tools within the context of authentic design tasks across their undergraduate curriculum.

DISCUSSION

Teaching how to teach with technology is a complex task, because on the one hand teacher educators need to teach the tool, and on the other hand, they need to teach how to design learning activities with the tool. In this article, TM was proposed as a holistic approach for developing TPCK competencies, so that knowledge about the affordances of tools, content, pedagogy, and learners is used concurrently in an iterative instructional design process. Based on the findings of the study, TPCK can be developed as a unique body of knowledge in powerful learning environments where technology teaching is situated in real and authentic design tasks, and in ways that teacher educators explicitly teach about the educational affordances of tools.

According to the data presented in Table 3 and the results of the repeated measures MANOVA, students' development of TPCK competencies was directly related to the complexity of the task, as this was determined by the educational affordances of Excel. For example, the task related to the design of activities for utilizing Excel as a tool for organizing data or as a tool for providing feedback was simpler than the task related to the design of activities for utilizing Excel as a tool for creating a hypertext story, or performing calculations, or modeling a phenomenon. In fact, the task related to the design of activities for utilizing Excel as a modeling tool had a higher degree of difficulty than all other affordances of Excel. While the average performance on the third, fourth, and fifth design tasks for each TPCK competency together with the corresponding standard deviation indicated that there was still space for improvement, albeit in different variations, students' development of all TPCK competencies across all five design tasks over the duration of a 13-week course was more than satisfactory. These results indicate that TM is both an efficient and effective approach for the development of TPCK. Additionally, TM proved to be an economical approach as students concurrently developed technical skills and pedagogical skills regarding the educational uses of Excel in teaching in learning.

Based on the participants' qualitative comments, teacher education courses must invest time and effort in helping students develop their TPCK competencies, so that students are able to perceive their courses as a connected whole such that the development of integrated mental models about what to teach, how to teach, for whom, by what means, and under what conditions is effectively and efficiently facilitated. Accordingly, the results of the study showed that TM was also effective in terms of organizing fragmented pieces of knowledge into meaningful wholes.

Additionally, the instructional design guidelines about how to teach Excel can be applied to teaching other computer applications as well; thus, this study may inform ongoing debates in informatics education about how computer applications can be taught in contextualized ways across the disciplines (ACM K–12 Task Force Curriculum Committee, 2003). In particular, teachers who teach informatics constitute a special group of teachers, because they are technology experts by training, and technology is what they teach. However, their expertise oftentimes is limited to the mere technical use of the tools themselves and does not entail the necessary pedagogical skills that will allow them to teach the tools in powerful pedagogical ways (ACM K–12 Task Force Curriculum Committee). The TPCK framework can delineate the knowledge that informatics teachers need to develop in order to teach computer applications in optimal ways, and the TM guidelines can facilitate their instructional design efforts in terms of teaching computer applications meaningfully and not in fragmented and compartmentalized ways.

CONCLUDING REMARKS

In conclusion, the study has theoretical significance related to the enactment of the TM approach, and consequently the development of TPCK as a unique body of knowledge. Furthermore, it provides empirical data about the effectiveness of TM, and thus it contributes to the ongoing discussions about how TPCK can be developed. Additionally, the study has practical significance as it provides step-by-step instructional design guidelines about how teacher educators can teach Excel, as well as how to teach with Excel. Undoubtedly, it would be beneficial and valuable if more and more educational researchers made use of the TM methodology in order to develop coherent theories of how TPCK development should be approached. The findings of this study can be used as baseline data for comparison purposes in future studies that may be conducted to further validate or modify TM.

REFERENCES

Abbitt, J. (2011). An investigation of the relationship between self-efficacy beliefs about technology integration and technological pedagogical content knowledge (TPACK) among preservice teachers. *Journal of Digital Learning in Teacher Education*, *27*(4), 134-143.

ACM K–12 Task Force Curriculum Committee. (2003). *A model curriculum for K–12 computer science*. New York, NY: Computer Science Teacher Association.

Angeli, C. (2005). Transforming a teacher education method course through technology: Effects on pre-service teachers' technology competency. *Computers & Education*, *45*(4), 383-398.

Angeli, C. (2013). Teaching spreadsheets: A TPCK perspective. In D. Kadijevich, C. Angeli, & C. Schulte (Eds.), *Improving computer science education*. New York, NY: Routledge.

Angeli, C., & Valanides, N. (2005). Pre-service teachers as ICT designers: An instructional design model based on an expanded view of pedagogical content knowledge. *Journal of Computer-Assisted Learning*, *21*(4), 292-302.

Angeli, C., & Valanides, N. (2009). Epistemological and methodological issues for the conceptualization, development, and assessment of ICT-TPCK: Advances in technological pedagogical content knowledge (TPCK). *Computers & Education*, *52*(1), 154-168.

Archambault, L. M., & Barnett, J. H. (2010). Revisiting technological pedagogical content knowledge: Exploring the TPACK framework. *Computers & Education*, *55*(4), 1656-1662.

Archambault, L., & Crippen, K. (2009). Examining TPACK among K-12 online distance educators in the United States. *Contemporary Issues in Technology and Teacher Education*, *9*(1), 71-88.

Bruner, J. (1960). *The process of education*. Cambridge, MA: Harvard University Press.

Carter, K. (1990). Teachers' knowledge and learning to teach. In W. R. Houston, M. Haberman, & J. Sikula (Eds.), *Handbook of research on teacher education* (pp. 291-310). New York, NY: Macmillan.

Chai, C. S., Koh, J. H. L., Tsai, C-C., & Tan, L. L. W. (2011). Modeling primary school pre-service teachers' technological pedagogical content knowledge (TPACK) for meaningful learning with information and communication technology (ICT). *Computers & Education*, *57*(1), 1184-1193.

Cox, S., & Graham, C. R. (2009). Diagramming TPACK in practice: Using an elaborated model of the TPACK framework to analyze and depict teacher knowledge. *TechTrends*, *53*(5), 60-69.

Duncan, R. G., & Hmelo-Silver, C. E. (2009). Learning progressions: Aligning curriculum, instruction, and assessment. *Journal of Research in Science Teaching*, *46*(6), 606-609.

Gibson, J. J. (1977). The theory of affordances. In R. Shaw & J. Bransford (Eds.), *Perceiving, acting, and knowing: Toward an ecological psychology* (pp. 67-82). Hillsdale, NJ: Erlbaum.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston, MA: Houghton Mifflin.

Graham, C. R. (2011). Theoretical considerations for understanding technological pedagogical content knowledge (TPACK). *Computers & Education*, *57*(3), 1953-1960.

Harris, J. B., & Hofer, M. J. (2011). Technological pedagogical content knowledge in action: A descriptive study of secondary teachers' curriculum-based, technology-related instructional planning. *Journal of Research on Technology in Education*, *43*(3), 211-229.

Kagan, D., & Tippins, D. (1992). The evolution of functional lessons among twelve elementary and secondary student teachers. *Elementary School Journal*, *92*(4), 477-489.

Koehler, M., & Mishra, P. (2005). What happens when teachers design educational technology? The development of technological pedagogical content knowledge. *Journal of Educational Computing Research*, *32*(2), 131-152.

Krauskopf, K., Zahn, C., & Hesse, F. W. (2012). Leveraging the affordances of YouTube: The role of pedagogical knowledge and mental models of technology functions for lesson planning with technology. *Computers & Education*, *58*(4), 1194-1206.

Leinhardt, G. (1988). Situated knowledge and expertise in teaching. In J. Calderhead (Ed.), *Teachers' professional learning* (pp. 146-168). London: Falmer.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A new framework for teacher knowledge. *Teachers College Record*, *108*(6), 1017-1054.

Moallem, M. (1998). An expert teacher's thinking and teaching and instructional design models and principles: An ethnographic study. *Educational Technology Research and Development*, *46*(2), 37-64.

Niess, M. L. (2005). Preparing teachers to teach science and mathematics with technology: Developing a technology pedagogical content knowledge. *Teaching and Teacher Education, 21,* 509-523.

Niess, M. L. (2011). Investigating TPACK: Knowledge growth in teaching with technology. *Journal of Educational Computing Research*, *44*(3), 299-317.

Norman, D. A. (1988). *The psychology of everyday things*. New York, NY: Basic Books.

Norman, D. A. (1990). *The design of everyday things*. New York, NY: Doubleday.

Ottenbreit-Leftwich, A., Glazewski, K., Newby, T., & Ertmer, P. (2010). Teacher value beliefs associated with using technology: Addressing professional and student needs. *Computers & Education, 55*, 1321-1335.

Pierson, M. (2001). Technology integration as a function of pedagogical expertise. *Journal of Research on Computing in Education*, *33*(4), 413-430.

Schmidt, D. A., Baran, E., Thompson, A. D., Mishra, P., Koehler, M. J., & Shin, T. S. (2009). Technological pedagogical content knowledge (TPACK): The development and validation of an assessment instrument for preservice teachers. *Journal of Research on Technology in Education*, *42*(2), 123-149.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, *57*, 1-22.

Thompson, A., & Mishra, P. (2007). Breaking news: TPCK becomes TPACK! *Journal of Computing in Teacher Education, 24*(2), 38-64.

Valanides, N., & Angeli, C. (2006). Preparing pre-service elementary teachers to teach science through computer models. *Contemporary Issues in Technology and Teacher Education—Science*, *6*(1), 87-98.

Valanides, N., & Angeli, C. (2008a). Learning and teaching about scientific models with a computer modeling tool. *Computers in Human Behavior*, *24*(2), 220-233.

Valanides, N., & Angeli, C. (2008b). Professional development for computer-enhanced learning: A case study with science teachers. *Research in Science and Technological Education*, *26*(1), 3-12.

Van Merriënboer, J. J. G. (1997). *Training complex cognitive skills: A four-component instructional design model for technical training.* Englewood Cliffs, NJ: Educational Technology Publications.

Van Merriënboer, J. J. G., Clark, R. E., & de Croock, M. B. M. (2002). Blueprints for complex learning: The 4C/ID-model. *Educational Technology, Research and Development*, *50*(2), 39-64.

Van Merriënboer, J. J. G., & Kirschner, P. A. (2007). *Ten steps to complex learning*. Mahwah, NJ: Erlbaum.

Voogt, J., Fisser, P., Pareja Roblin, N., Tondeur, J., & van Braak, J. (2013). Technological pedagogical content knowledge—A review of the literature. *Journal of Computer-Assisted Learning, 29*(2), 109-121. doi: 10.1111/j.1365-2729.2012.00487.x

Yoon, F. S., Ho, J., & Hedberg, J. G. (2005). Teacher understandings of technology affordances and their impact on the design of engaging learning experiences. *Educational Media International, 42*(4), 297-316.

Direct reprint requests to

Dr. Charoula Angeli
11-13 Dramas St.
Dept. of Education
University of Cyprus
Nicosia 1678, Cyprus
e-mail: cangeli@ucy.ac.cy