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Epistemological and methodological issues for the conceptualization, development, and assessment of ICT–TPCK: Advances in technological pedagogical content knowledge (TPCK)

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ABSTRACT

In this paper, several issues regarding the epistemology of technological pedagogical content knowledge (TPCK) are first raised for the purpose of clarifying the construct. Specifically, the transformative and integrative views are juxtaposed for exploring the epistemology of TPCK, and, at the end, the transformative view is adopted concluding that TPCK is a unique body of knowledge that is constructed from the interaction of its individual contributing knowledge bases. Then, ICT–TPCK is introduced as a strand of TPCK, and is described as the ways knowledge about tools and their 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 technology in ways that signify its added value. One model for the development and another for the assessment of ICT–TPCK are then discussed. Technology Mapping is proposed as a situative methodology for the development of ICT–TPCK, and three forms of assessment, namely, expert assessment, peer assessment, and self-assessment are proposed for assessing teachers' competencies to teach with technology. The paper also reports on the empirical findings of a study that was undertaken to investigate the impact of the proposed models on student learning within the context of two design tasks in a pre-service primary teacher education course. Repeated measures within-subject effects were tested and the results indicated that ICT–TPCK competency significantly improved over the course of a semester. The results of this study clearly show that the theoretical models proposed herein can positively impact the development of ICT–TPCK. Lastly, these results can be used as baseline data in future studies that may be conducted to further validate or improve the proposed models in different contexts.

1. Introduction

We are living in a world that is constantly impacted by rapid developments in the domains of science and information and communication technologies (ICT). Existing knowledge quickly becomes outdated and obsolete, and the acquisition of new knowledge and its innovative applications result in a continuous transformation of our cultural, social, and political environments. Citizens of information-age societies are required to be able to think critically, problem solve, collaborate with others, communicate, use various technologies, take initiatives, and bring diverse perspectives in the learning situation. By virtue of these challenges, Sefton-Green (2006) concluded that the socio–political and educational context of school-aged children is under a period of redefinition and redesign, requiring fundamental transformations in the ways that teachers teach and children learn in schools. Technology has extensive pedagogical affordances and great potential for transforming the teaching and learning environment when it is used appropriately (Cognition & Technology Group at Vanderbilt, 1996; Dede, 1998; President's Committee on Advisors on Science, 1997). Thus, the issue is no longer whether teachers should integrate technology in their existing practices, but how to use technology to transform their teaching with technology and create new opportunities for learning.

The preparation of teachers in the educational uses of technology appears to be a key component in almost every improvement plan for education and educational reform efforts (Davis & Falba, 2002; Dawson, Pringle, & Adams, 2003; International Society for Technology in Education, 2002; National Council for Accreditation of Teacher Education, 1997; Thomas, 1999; Thompson, Schmidt, & Davis, 2003).

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According to Gess-Newsome, Blocher, Clark, Menasco, and Willis (2003), while some issues in education take on the flavor of their social and historical context, some others, such as how to prepare teachers to integrate technology in teaching and learning, remain almost perennial and ill-defined. Essentially, research evidence shows that in spite of the many efforts that researchers and educators invested over the years in preparing teachers in the educational uses of technology, teachers still lack the skills and knowledge needed to be able to teach with technology successfully (Koehler, Mishra, & Yahya, 2007; Rodrigues, 2003).

The failure to adequately prepare teachers to teach with technology can be attributed to various factors. For example, the emphasis of educational technology courses on the acquisition of technical skills is one major contributing factor. As Becker and Riel (2001), and Selinger (2001) explained, although computing skills are important, skills-based courses are not enough for preparing teachers to teach with technology, because they are usually taught in isolation from a subject-specific context. Kenny (2002) stated that the lack of a subject-specific focus in many technology preparation programs remains an issue, but even in those cases where subject applications are discussed, matters of how technology interacts with the content and content-specific pedagogy are not sufficiently explored. As a consequence, the programs fail to adequately prepare teachers in the direction of establishing pedagogical connections between the affordances of technology and the teaching of a particular content domain.

Most importantly, the lack of theory and conceptual frameworks to inform and guide research in the area of teaching with technology is a major weakness in the educational technology literature (Valanides & Angeli, 2002; Angeli & Valanides, 2005; Angeli, 2005; Koehler & Mishra, 2008; Margerum-Lays & Marx, 2003; Mishra & Koehler, 2006; Niess, 2005; Selfe, 1990; Willis & Mehlinger, 1996; Wilson, 2003; Zhao, 2003). As Selfe (1990) well stated "until we share some theoretical vision of this topic, we will never glimpse the larger picture that could give our everyday classroom efforts direction and meaning" (p. 119).

In view of recognizing the lack of a sound theoretical orientation to guide teacher preparation in technology integration, researchers initiated during the last five years systematic research efforts for the purpose of developing theory and models upon which to ground research in the area of teacher cognition about technology integration (Angeli & Valanides, 2005; Angeli, 2005; Margerum-Lays & Marx, 2003; Mishra & Koehler, 2006; Niess, 2005). These researchers advocate the need to develop a new body of knowledge that constitutes an extension of Shulman's (1986), Shulman's (1987) pedagogical content knowledge (PCK) into the domain of teaching with technology. This extended view of PCK is offered as a framework for revitalizing the study of teacher knowledge and for collecting and organizing data on teacher cognition about technology integration.

A few proposals, suggested mostly by American researchers, of how to extend PCK in the domain of teaching with technology exist in the literature under different labeling schemes. For example, Margerum-Lays and Marx (2003) referred to PCK of educational technology, Slough and Connell (2006) used the term technological content knowledge, and Mishra and Koehler (2006) suggested the term technological pedagogical content knowledge (TPCK) – a comprehensive term that has prevailed in the literature. All existing views are founded on the common principle that effective technology integration presupposes a conceptualization that must be necessarily formulated by considering the interactions among technology, content, and pedagogy.

While the authors of the present paper do acknowledge the important work that has been done on TPCK thus far, here they seek to raise important theoretical, epistemological, and methodological issues relating to TPCK, so that the degree of precision of the construct can be put under scrutiny for the sake of theoretical robustness and clarification. It is also stated from the beginning that the present study will mainly focus on ICT, which, by and large, are currently at the center of scientific interest, exploration, and investigation. Thus, the term ICT–TPCK will be used herein for denoting TPCK that is exclusively related to information and communication technologies. In particular, the paper will first provide answers to the following three questions: (a) Is ICT–TPCK a unique body of knowledge or a body of knowledge that is made of other teacher knowledge bases? (b) How is ICT–TPCK developed? and (c) How is ICT–TPCK assessed? Then, the paper will report on the empirical findings of a study that was undertaken to collect relevant evidence within the context of pre-service teacher education. The empirical findings of this study can also be used as baseline data in future studies that may be conducted within different contexts for validating or improving what is presently known.

2. PCK as a conceptual basis

The concept of PCK was initially introduced by Shulman (1986) who insisted that research on teaching and teacher education did not pay enough attention to the content of the lessons taught. PCK "identifies the distinctive bodies of knowledge for teaching" (Shulman, 1986, p. 8) and refers to teachers' interpretations and transformations of subject matter knowledge for facilitating student learning. The construct of PCK constitutes a special amalgam of content and pedagogy, and is the kind of knowledge that separates an expert teacher in a subject area from a subject area expert. Shulman (1986), Shulman (1987) described PCK as the ways content, pedagogy, and knowledge of learners are blended into an understanding about how particular topics to be taught are represented and adapted to learners' characteristics, interests, and abilities. Specifically, PCK relates to the transformation of several types of knowledge, includes an understanding of what makes the learning of specific concepts easy or difficult, and "embodies the aspects of content most germane to its teachability" (Shulman, 1986, p. 9). Accordingly, PCK encompasses an understanding of students' preconceptions and learning difficulties, and includes the most useful forms of representation, the most powerful analogies, illustrations, examples, explanations, demonstrations, and other ways of representing and formulating the subject in forms that are comprehensible to learners.

Thus, Shulman's (1986) conceptualization of PCK "goes beyond the knowledge of subject matter per se to the dimension of subject matter knowledge for teaching" (p. 9). Teachers' knowledge of representations of subject matter, and their understandings of students' conceptions and content-related difficulties constitute the key elements in Shulman's conception of PCK. The transformation of subject matter, according to Shulman (1986), occurs as the teacher interprets the subject matter, finds multiple ways to represent it, and adapts and tailors the instructional materials to students' prior knowledge and alternative conceptions. PCK implies a transformation of subject matter knowledge, so that it can be effectively and flexibly used in the communication exchange between teachers and learners. Shulman (1987) included PCK in the knowledge base of teaching, which, according to him, consists of three content-related categories (content knowledge, PCK, and curricular knowledge) and four other categories (general pedagogy, learners and their characteristics, educational contexts, and educational purposes). Succinctly, (a) content knowledge includes an understanding of the facts and structures of a content domain, (b) general pedagogical knowledge refers to broad principles and strategies of classroom management and organization that appear to generalize across different subject matter domains, (c) curricular knowledge includes an understanding of the materials for the instruction, alternative texts, visual materials, and laboratory demonstrations, (d) knowledge of learners refers to their characteristics and preconceptions that they bring to a learning situation, (e) knowledge of educational contexts ranges from the workings of the classroom to the governance of the school district, and (f) knowledge of educational values and goals refers to the educational ends and their philosophical underpinnings.

Subsequently, scholars, like Grossman (1990), and Cochran, Derutier, and King (1993), have extended the concept of PCK by including in it some additional elements. For example, Grossman (1990) perceived PCK as consisting of Shulman's two key elements of PCK, namely, transformations of subject matter and teachers' understandings of learners' content-related difficulties, and knowledge and beliefs about the purposes for teaching particular topics, an element that he added. Cochran et al. (1993) proposed a variation to Shulman's notion of PCK based on the constructivist view of learning. They distinguished between knowledge and knowing, and argued that the term knowledge is too static and inconsistent with the constructivist perspective. Thus, they changed PCK to PCKg (Pedagogical Content Knowing) to acknowledge the dynamic nature of PCK development. They defined PCKg as "a teacher's integrated understanding of four components of pedagogy, subject matter content, student characteristics, and the environmental context of learning" (Cochran et al., 1993, p. 266), and emphasized the amalgamated nature of PCK, as the result of the concurrent development of these four components. PCKg also places emphasis on the situatedness of teacher training and the central role that teachers' understandings of their students play in teaching.

According to Cochran et al. (1993) "teacher education should promote learning in contexts where the goals are focused on teaching specific content to specific students in specific contexts" (p. 266). As shown in Fig. 1, the definition of PCKg emphasizes that teachers need to develop their pedagogical knowledge and subject matter knowledge in the context of two other components of teacher knowledge, namely, teachers' understandings of students, and environmental context of learning. The arrows in the model in Fig. 1 represent the growth of PCKg as a result of new experiences and learning activities. From this perspective, the continuing growth of PCK, as a result of new teaching experiences, constitutes its dynamic nature that justifies the change from PCK to PCKg (Angeli & Valanides, 2005).

In general, there is no universally accepted conceptualization of PCK. The main differences among scholars relate to the elements incorporated in PCK and to the specific labels describing these elements. Nevertheless, all scholars include in the construct of PCK both teachers' knowledge of representations of subject matter, and their knowledge of learners' conceptions and content-related difficulties. They also agree that PCK is specifically concerned with the teaching of particular topics, and is distinguished from general knowledge of pedagogy, knowledge of educational purposes, and learner characteristics. Finally, there is universal agreement that PCK is deeply rooted in classroom practice and gradually develops with new teaching experiences. This implies that prospective or even beginning teachers have incomplete and superficial levels of PCK, and that their PCK continually grows with new experiences related to teaching and learning.

3. TPCK: An extended view of PCK

Shulman (1986) incorporated in his definition of curricular knowledge various tools for instruction including computer technology. Specifically, he wrote:

> *The curriculum and its associated materials are the materia medica of pedagogy, the pharmacopeia from which the teacher draws those tools of teaching that present or exemplify particular content and remediate or evaluate the adequacy of student accomplishments. [...] How many individuals whom we prepare for teaching biology, for example, understand well the materials for that instruction, the alternative texts, software, programs, visual materials, single-concept films, laboratory demonstrations, or "invitations to enquiry?"* (Shulman, 1986, p. 10).

In spite of this, Shulman (1986) did not *explicitly* discuss technology and its relationship to content, pedagogy, and learners, and thus PCK in its original form does not specifically explain how teachers use the affordances of technology to transform content and pedagogy for learners.

Today with the continual increase of computers in schools and the numerous applications of ICT, the construct of PCK needs to be extended to account for the need to study and understand teacher cognition about the educational uses of computers. Recently, the

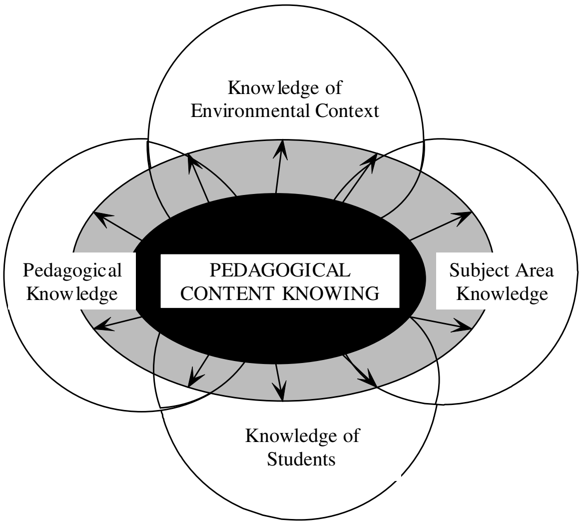

Fig. 1. A model of pedagogical content knowing (PCKg) adopted from Cochran et al. (1993).

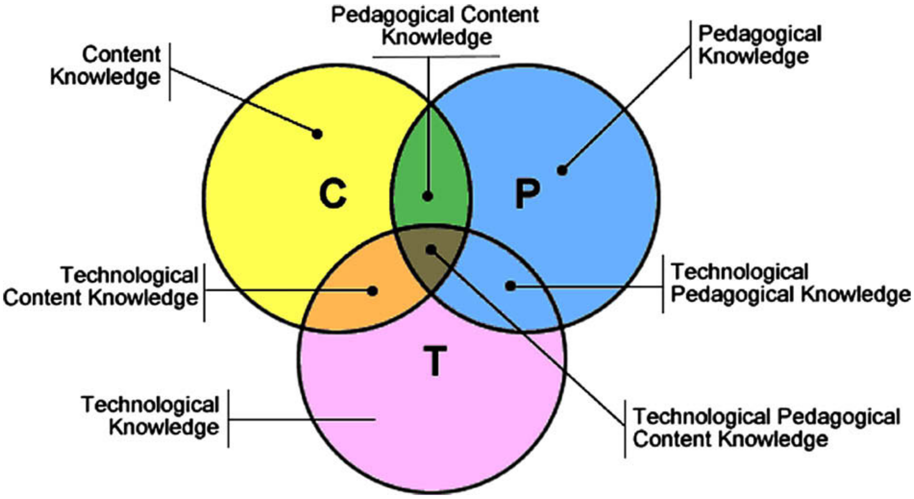

Fig. 2. Technological pedagogical content knowledge (TPCK) adopted from Koehler et al. (2007).

question of what teachers need to know to be able to teach with technology has received a great deal of attention (International Society for Technology in Education, 2002; Zhao, 2003). One thing that has become clear is that the mere introduction of technology in schools will not have the desirable outcomes, that is, technology in and of itself is not a transformative mechanism or a vehicle for change. Rather, it is a tool invoked by its users to reconstruct the subject matter from the knowledge of the teacher into the content of instruction. As Mehan (1989) explicitly stated "it is what people do with the machine, not the machine itself that makes a difference" (p. 19).

PCK constitutes the conceptual basis for Mishra and Koehler's (2006) construct of TPCK that is conceptualized as a situated form of knowledge deeply rooted in the interactions of subject matter, pedagogy, and technology. Koehler et al. (2007), in a recent article in *Computers & Education*, stated that TPCK is a situated form of knowledge that is required for the intelligent uses of technology in teaching and learning.

> *At the heart of TPCK is the dynamic, transactional relationship between content, pedagogy, and technology. Good teaching with technology requires understanding the mutually reinforcing relationships between all three elements taken together to develop appropriate, context-specific, strategies and representations* (Koehler et al., 2007, p. 741).

As it is shown in Fig. 2, Koehler et al.'s (2007) conceptualization of TPCK goes beyond seeing content, pedagogy, and technology as constructs in and of themselves. Specifically, their approach considers all possible interactions between any two constructs, namely, Pedagogical content knowledge, Technological content knowledge, and Technological pedagogical knowledge.

While Koehler et al. (2007) do emphasize that students need to be engaged in rich design activities in order to understand the interrelationships among content, pedagogy, and technology, the authors of this paper do believe that Koehler et al.'s (2007) conceptualization of TPCK needs further theoretical clarity. It is argued that if TPCK is to be considered as an analytical theoretical framework for guiding and explaining teachers' thinking about technology integration in teaching and learning, then TPCK's degree of precision needs to be put under scrutiny. The degree of precision of a construct refers to the discriminating value of the construct and has important implications for its development and assessment.

For example, it is not clear from Koehler et al.'s (2007) empirical findings whether TPCK is a distinct form of knowledge or whether growth in TPCK simply means growth in any of the related constructs (i.e., Pedagogical content knowledge, Technological content knowledge, Technological pedagogical knowledge, or even the initial elements of Pedagogy, Content, and Technology). Furthermore, the boundaries between some components of TPCK, such as, for example, what they define as Technological content knowledge and Technological pedagogical knowledge, are fuzzy indicating a weakness in accurate knowledge categorization or discrimination, and, consequently, a lack of precision in the framework. Furthermore, TPCK, in its current form, appears to be too general, primarily because it does not deal explicitly with the role of tool affordances in learning. Essentially, while Koehler et al. (2007) do assert that at the heart of TPCK is the dynamic, transactional relationship among content, pedagogy, and technology, and that "good teaching with technology requires understanding the mutually reinforcing relationships between all three elements taken together to develop appropriate, context-specific, strategies and representations" (p. 741), the framework does not make explicit the connections among content, pedagogy, and technology.

While it is perfectly understood that the preference for a general model might be directly related to its potential wide applicability in different contexts, the lack of specificity is problematic, because the very important issue of how tool affordances can transform content and pedagogy is not addressed. Also, the framework in its present form does not take into consideration other factors beyond content, pedagogy, and technology, such as, for example, teachers' epistemic beliefs and values about teaching and learning that may be also important to take into account. This simplified or general view, one might argue, may lead to possible erroneous, simplistic, and naïve perceptions about the nature of integrating technology in teaching and learning.

Therefore, the purpose of this paper is (a) to productively contribute to the further theoretical refinement of TPCK, (b) to introduce ICT–TPCK as a strand of TPCK, and (c) to empirically examine the impact of the models proposed herein for the development and assessment of ICT–TPCK on student learning. The conceptualization of ICT–TPCK seeks to systematically address the specificity that is currently missing from the current conceptualization of TPCK regarding the dynamic and transactional relationship among content, pedagogy, and various technology affordances, and to address from a methodological point of view various issues related to the development and assessment of ICT–TPCK.

4. Theoretical and epistemological considerations about TPCK

Koehler et al.’s (2007) discussed TPCK as a distinct area of teacher knowledge and framed questions about TPCK. In their methodology and data collection, they only dealt with the “contributing” knowledge bases of TPCK, such as, Content knowledge, Pedagogical knowledge, Technological knowledge, Technological content knowledge, Technological pedagogical knowledge, and Pedagogical content knowledge. In other words, they never really measured or proposed instances of TPCK, despite the fact that in their discussion they drew conclusions about TPCK. One may thus argue that Koehler et al. (2007) should not refer to TPCK at all, because they have not shown TPCK to be a unique body of teacher knowledge.

Obviously, if the epistemological aspect of TPCK is not considered in the development of its theoretical framework, then there will be confusion about the theoretical conceptualization of the construct, and, thereafter, confusion about its growth and assessment. The unresolved issue that researchers neglected to consider about TPCK is whether TPCK is a distinct or unique body of knowledge that is constructed from other forms of teacher knowledge – the transformative view, or whether TPCK is not a distinct form of knowledge, but is integrated from other forms of teacher knowledge “on the spot” during teaching – the integrative view. Each of these views has important research implications about the nature of the questions to be raised and the data to be collected. For example, research questions framed from the transformative view focus on TPCK itself, the methodology is designed to obtain data about TPCK, and conclusions are drawn in terms of TPCK. In the same way, research questions framed from the integrative view focus on the contributing forms of teacher knowledge, the methodology is designed to obtain data about the contributing knowledge bases, and conclusions are reached in terms of them. In other words, the data do not show evidence of TPCK, instead they relate to TPCK’s constituent components.

From the current body of literature on TPCK, it seems that most researchers believe that growth in any of the related constructs (i.e., content, technology, pedagogy) automatically contributes to growth in TPCK (Hughes, 2008; Koehler et al., 2007). The authors of this paper have extensively tested this hypothesis. During the last five years, they conducted a number of empirical investigations regarding the educational uses of computer technology, and based on their findings they concluded that growth in the related constructs does not automatically mean growth in TPCK. These findings suggest that TPCK itself is a body of knowledge different from its constituent components (Angeli & Valanides, 2005; Angeli, 2005; Valanides & Angeli, 2006, 2008a, 2008b). In particular, in-service teachers, who had extensive teaching experience and knowledge of several computer programs, but were not specifically trained how to teach with computers, did not perform significantly better on designing computer-mediated lessons for their students than other teachers who had less teaching experience, good computing skills, but no specific training in the educational uses of computers as well (Valanides & Angeli, 2008b). However, after specific training in how to teach with computers, teachers with stronger pedagogical skills and better knowledge about the content and learners outperformed other teachers with less knowledge in those areas (Valanides & Angeli, 2008c).

Similar results were also found with pre-service teachers. Specifically, studies with undergraduate pre-service teachers showed that without any specific training in the educational uses of computers, sophomores and juniors who had good computing skills did not design better technology-mediated lessons than freshmen who also had good technical skills but no specific training in the educational uses of computers as well. However, after such training, sophomores and juniors outperformed freshmen in designing learning activities with computers (Angeli & Valanides, 2005; Angeli, 2005; Valanides & Angeli, 2006, 2008a). The authors concluded that teacher educators need to explicitly teach how the unique features or affordances of a tool can be used to transform a specific content domain for specific learners, and that teachers need to be explicitly taught about the interactions among technology, content, pedagogy, and learners. These findings suggest that content, pedagogy, learners, and technology are contributing knowledge bases to TPCK, but knowledge and growth in each contributing knowledge base alone, without any specific instruction targeting exclusively TPCK as a unique body of knowledge, does not imply automatic growth in TPCK.

Based on the results of their empirical investigations, the authors suggest that TPCK is a distinct body of knowledge that can be developed and assessed. This body of knowledge goes beyond mere integration or accumulation of the constituent knowledge bases, toward transformation of these contributing knowledge bases into something new. Thus, the authors do not support the integrative view, since growth in the individual contributing knowledge bases without specific instruction targeting exclusively the development of TPCK does not result in any growth in TPCK (Angeli & Valanides, 2005; Angeli, 2005; Valanides & Angeli, 2006, 2008a, 2008b), clearly indicating that TPCK is a unique body of knowledge.

5. From TPCK to ICT–TPCK

ICT–TPCK is conceptualized as a strand of TPCK, and TPCK, as discussed herein, serves as an initial conceptual basis for ICT–TPCK. Thus, ICT–TPCK’s constituent knowledge bases, as shown in Fig. 3, include TPCK’s three contributing knowledge bases, namely, subject matter knowledge, pedagogical knowledge, and technology (restricted to ICT in this case), and two additional elements, namely, knowledge of students and knowledge of the context within which learning takes place. The two additional elements were added taking into consideration research evidence from studies with in-service teachers (Valanides & Angeli, 2008b). This evidence indicated that teachers during teaching with technology drew upon their knowledge relating to their students’ content-related difficulties as well as knowledge of the intricacies of the relevant context, i.e., what worked and what did not in their classrooms, and how they believed they needed to teach for facilitating their students’ learning. Succinctly, in the model depicted in Fig. 3, (a) subject matter knowledge includes an understanding of the facts and structures of a content domain, (b) pedagogical knowledge refers to broad principles and strategies of teaching, classroom management, and organization that are generic across different subject matter domains, (c) knowledge of learners refers to their characteristics and preconceptions that they bring to a learning situation, (d) knowledge of context ranges from the workings of the classroom, to the educational values and goals, as well as their philosophical underpinnings in conjunction with teachers’ epistemic beliefs about teaching and learning, and (e) ICT knowledge is defined as knowing how to operate a computer and knowing how to use a multitude of tools/software as well as troubleshoot in problematic situations. ICT–TPCK is conceptualized as a unique body of knowledge that makes a teacher competent to design technology-enhanced learning. ICT–TPCK can thus be defined as the ways knowledge about tools and their pedagogical affordances, pedagogy, content, learners, and context are synthesized into an

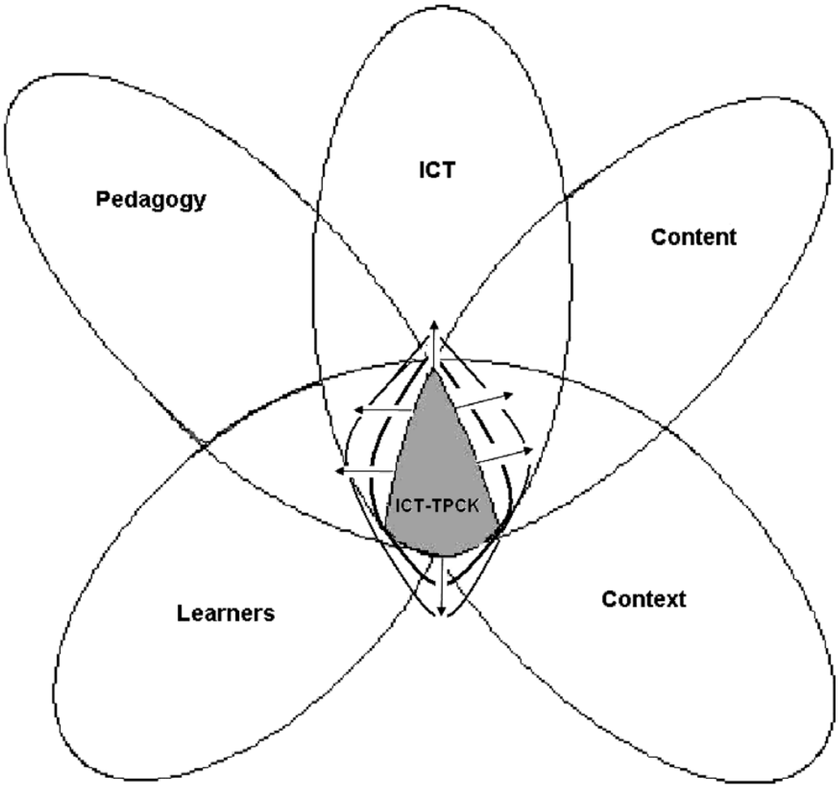

Fig. 3. ICT–TPCK.

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 value of technology. At the heart of this conceptualization is the view that technology is not a delivery vehicle that simply delivers information, but a cognitive partner that amplifies or augments student learning. As shown in Fig. 3, ICT–TPCK is a body of knowledge that grows continuously with systematic engagement in rich teaching experiences. This means that any program or instructional design model that aims at the development of ICT–TPCK must consider teachers' knowledge and classroom experiences, and use them as the starting point for initiating efforts aiming at the development and/or growth of ICT–TPCK.

This last issue is important, because research on instructional design and teacher education clearly indicates that teachers' instructional thinking and decision-making is guided by a unique body of knowledge that is deeply situated in classroom practices (Brown, Collins, & Duguid, 1989; Moallem, 1998; Suchman, 1987). Particularly, in Moallem's (1998) study, teachers' situated knowledge was considered as a highly contextual and practical complex body of knowledge that teachers acquire through years of experience. This knowledge consists of different forms that interact with one another, such as, epistemological beliefs about teaching and learning, contextual knowledge of school expectations and values, practical classroom knowledge – what works and what does not in a classroom – curriculum, content, pedagogy, and learners. These findings have important implications, because they clearly indicate how teachers' situated knowledge can affect their instructional decisions. Consequently, this implies that any preparation for ICT–TPCK development should take into consideration teachers' contextual and highly practical body of knowledge. In other words, ICT–TPCK cannot be considered as a body of knowledge that exists independently of teachers' beliefs and practical experience.

Obviously, any approach intending to develop ICT–TPCK should not only be responsive to teachers' beliefs and knowledge, but it should also be learner-centered. Since PCK is the conceptual basis of TPCK, by corollary, PCK is also the backbone and conceptual basis of ICT–TPCK, despite ICT–TPCK's specialized nature. This means that, by default, teachers' knowledge of representations of subject matter, and their understandings of students' conceptions and content-related difficulties also constitute key elements of ICT–TPCK.

In addition, it is important to raise another issue related to learners' conceptual ecology. The conceptual ecology of a student reflects his or her existing cognitive knowledge base, and any effort pursued for transforming a content domain with technology must first take into consideration learners' current state of conceptual ecology. This means, that ICT–TPCK development efforts need to invest on socio-cognitive constructivist ideas, because the most effective content transformations are those that create cognitive or socio-cognitive conflict and encourage dialogue and negotiation of meaning among students whose initial conceptions are different (Valanides & Angeli, 2008c). The emphasis should not only be on students' cognitive development, but also on their holistic development, taking into account other factors relevant to their personal development. For example, any transformation of the subject matter can potentially have differential effects on individual learners due to learner differences in cognitive style and visual literacy skills (Angeli & Valanides, 2004; Valanides & Angeli, 2006). Thus, ICT–TPCK becomes truly important, because it can support the learning of students with different learning styles, or different ways of processing information, by transforming content with multiple representations using a variety of technological means in ways that learners and technology constitute a joint cognitive system (Angeli & Valanides, 2004; Jonassen, 2000; Kommers, Jonassen, & Mayers, 1992; Salomon, Perkins, & Globerson, 1991).

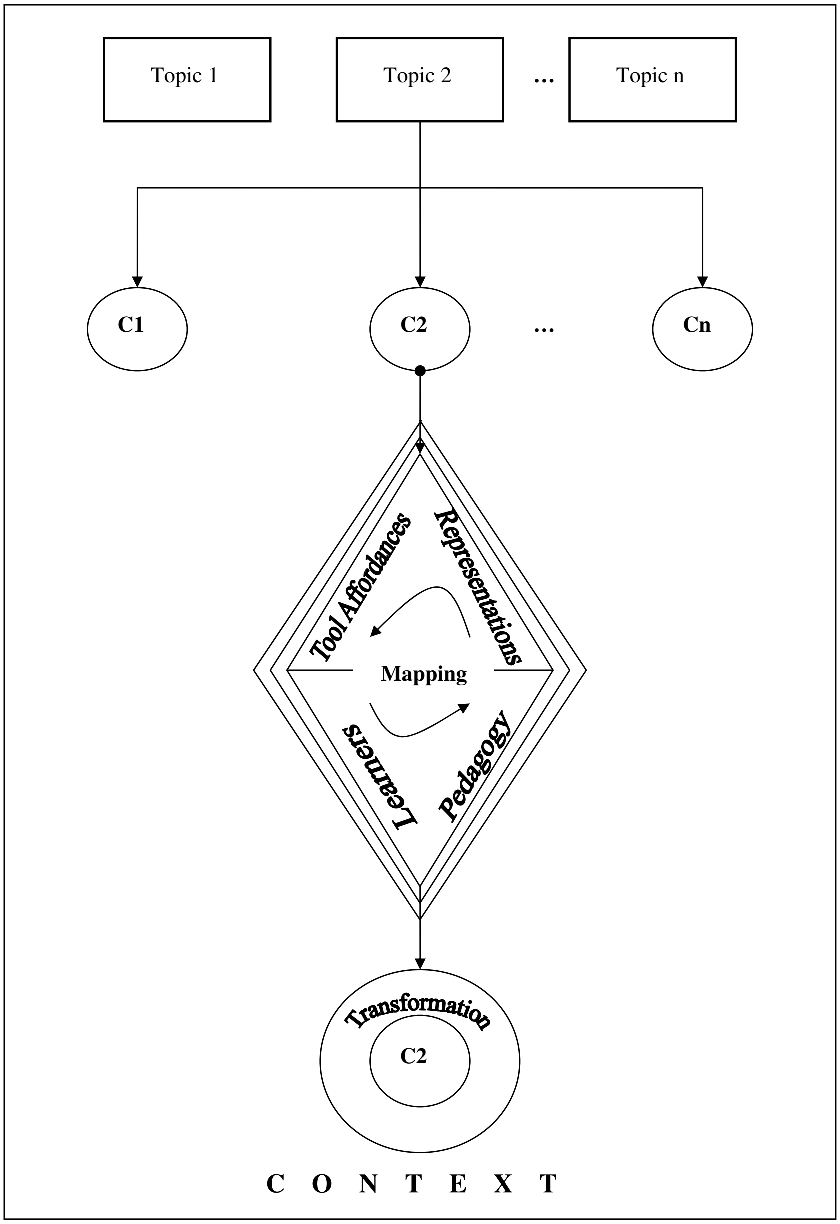

Fig. 4. A situative ID model for the design of technology–mediated learning.

6. Technology mapping: A situative methodology for developing ICT–TPCK

Technology mapping (TM) is an empirically-based approach for understanding and promoting a situative orientation toward the development of ICT–TPCK (Brown et al., 1989; Greeno, 1997; Putnam & Borko, 1997; Putnam & Borko, 2000). TM has been gradually developed by the authors in a number of design-based research studies during the last five years (Angeli, 2005; Angeli & Valanides, 2005; Design-Based Research Collective, 2003; Valanides & Angeli, 2006, 2008a, 2008b), and, as expected, the methodology endured several iterations of modifications. After the last cycle of fine-tuning, TM is presented herein as a methodology for guiding teacher thinking about the ill-defined problem of designing technology-enhanced learning. TM can be used in teacher education departments to teach pre-service teachers how to teach with technology, and thus to develop their ICT–TPCK knowledge; in teacher professional development programs to prepare in-service teachers in the pedagogical uses of technology; by curriculum developers to decide how technology can be infused in the different content domains; and, most importantly, by the teachers themselves to design lessons with technology. TM is predicated on the view that, while there is no one "right" way to deal with design problems, it is possible to guide teachers' thinking with an instructional design (ID) model that is deeply rooted and situated in their real practices. Thus, the ID model shown in Fig. 4 is offered as a participative approach and a tool that teachers can use in order to deal with technology design problems. In essence, TM is an interaction technique that seeks to identify the dynamic transactions among all constituent knowledge bases of ICT–TPCK, while, at the same time, it places emphasis on the situated nature of teachers' thinking and the critical role that teachers' understandings of their context and their students play in their instructional decisions. Like other contemporary models in the field of instructional design, such as, for example, van Merrienboer's 4C/ID model (van Merrinboer, 1997; van Merrinboer & Kirschner, 2007), TM departs from traditional behaviourist and systems-oriented approaches to instructional design, and moves towards a more systemic and authentic design process where context-specific factors, i.e., affordances of technology, content, pedagogical strategies, setting, and learners, are considered in increasing detail throughout the design and development iterative process.

The departure from traditional ID models is deemed necessary, because teachers' instructional design decisions are guided by a body of knowledge that is highly situated within the context of classrooms and teaching (Carter, 1990; Kagan & Tippins, 1992; Leinhardt, 1988; Moallem, 1998). The fundamental difference between designing instruction from the situative perspective and traditional ID is the grounding of the design in teachers' experiences and the context in which researchers seek to understand teachers' thinking. Thus, ID from the situative perspective is not context-free or objective, but a tool for considering context-specific factors, and their complex relationships during the design and enactment of instruction to facilitate learning.

As shown in Fig. 4, context is an overarching factor in the process of designing learning with technology. Any attempt to design technology-enhanced learning is influenced by certain context-sensitive factors, such as, teachers' beliefs about how students learn (epistemological beliefs), teachers' practical experiences about what can and what cannot work in a real classroom, and the school's vision, educational goals, as well as expectations regarding teachers' adopted instructional practices. These context-sensitive factors can influence teachers' thinking about how technology can amplify or augment students' learning at any step of the design process, and can play a crucial role in the way technology is infused in the learning process. For example, if a teacher has deep-rooted beliefs in teacher-centered learning, then technology integration in teaching 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 meaning about something). It was deemed important to include *context* in the model, so that teachers can be aware of their potential biases and or constraints, and, thus, to be continuously reflective about the ways context-related factors may impact their designs of technology-enhanced learning.

Furthermore, a situative ID orientation allows teachers to bring experiences from their classrooms into the design process, and, specifically, experiences that are related to teachers' understandings of their students' alternative conceptions and learning difficulties, as well as teachers' understandings of their own difficulties in making a specific content teachable, and easily learnable for their students. Teachers' difficulties can be attributed to the use of non-optimal content representations and, consequently, to the use of ineffective pedagogical or instructional strategies. For example, elementary school students hold different alternative conceptions about light and color (Valanides & Angeli, 2008c). Specifically, they usually believe that color constitutes an exclusive property of an object and that color remains unchanged, or that when colored light illuminates a colored object, the color of the light mixes with that of the object (Anderson & Karrqvist, 1983; Galili & Lavrik, 1998; Guesne, 1985; Anon, 2008b). These alternative conceptions can be attributed to the fact that light phenomena cannot be experienced directly, since light travels from one point to another invisibly, and learners limit their explanations to poor descriptions of what they can only see and experience. As a result, their conceptual understanding of light phenomena is severely impeded, because of light's high degree of abstractness.

Computer tools with appropriate affordances can transform the content into powerful representations that can actually foster or augment students' conceptual understanding about light and color. Therefore, any attempt to design effective instruction for light and color must necessarily consider learners' respective content-related difficulties. Evidently, appropriate use of tool affordances becomes most pertinent and essential in cases such as this, where certain problematic instructional situations can only be handled most effectively by investing on technology and its affordances for powerful transformations of those aspects of content most germane to its learnability, in a specific context and for specific learners.

The ID model depicted in Fig. 4 will be exemplified within the context of preparing in-service and pre-service teachers to design learning with technology. First, teachers are asked 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. In the case of inexperienced pre-service teachers, teacher educators can provide them with a variety of examples from the literature on learners' alternative conceptions and the process of conceptual change. Thus, as shown in Fig. 4, initially, teachers identify various topics within a specific content domain that are challenging to teach and learn. Subsequently, for each topic, teachers associate relevant content (represented as circles in Fig. 4) and tentative objectives based on learners' related alternative conceptions that need to be addressed. The nested design of the diamond in Fig. 4 represents the iterative ID decision process that teachers should be engaged in, in order to decide how they should transform the content to make it teachable to their students. In doing so, teachers need to first decide how tool affordances can be used to transform content into powerful representations (upper part of the diamond), and how to tailor these representations for the specific needs of their students and use them by employing various pedagogical strategies in their respective classrooms (lower part of the diamond).

Mapping tool affordances onto content and pedagogy is at the heart of the TM approach. Mapping refers to the process of establishing connections among the affordances of a tool, content, and pedagogy. Affordances are properties of the relationship between an agent and its physical environment – properties that allow and facilitate specific types of interaction; for example, a floor affords support, and a chair affords sitting. Gibson (1977,1979) defined affordances as all action possibilities latent in the environment, objectively measurable and independent of the individual's ability to recognize them. For instance, a set of steps that rises four feet high does not afford the act of climbing, if the actor is an infant. Thus, according to Gibson's theory of affordances, affordances are action possibilities in the environment with respect to the action capabilities of an actor, and they are independent of the actor's experience, knowledge, culture, or ability to perceive. Contrary to Gibson's theory of affordances, is Norman's (1988) conceptualization which states that:

> *...the term affordance refers to the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used. [...] Affordances provide strong clues to the operations of things. Plates are for pushing. Knobs are for turning. Slots are for inserting things into. Balls are for throwing or bouncing. When affordances are taken advantage of, the user knows what to do just by looking: no picture, label, or instruction needed* (Norman, 1988, p. 9).

Norman's (1990) view diverges from Gibson's conceptualization in that Norman defines an affordance as something of both actual and perceived properties. The affordance of a ball is the round shape, physical material, and bouncability (its actual properties), and the perceived suggestion as to how the ball should be used (its 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).

Table 1
Teachers' perceived connections among software affordances, content representations and pedagogy

Software affordance	Representations	Student-Centered pedagogy
Team I		
1. Pictures	X	X
2. Diagrams	X	
3. Record sound		X
4. Hyperlinks	X	X
5. Creation of personalized symbol library		X
6. Audio support	X	X
7. Animation enabled		X
Team II		
1. Pictures	X	X
2. Diagrams		X
3. Record sound	X	X
4. Hyperlinks	X	X
5. Creation of personalized symbol library	X	X
6. Supergrouper	X	
7. Export materials	X	
8. Cancellations of actions	X	
9. Formatting with color	X	
10. Formatting text	X	
Team III		
1. Pictures	X	X
2. Hyperlinks	X	X
3. Integrated picture and writing views	X	
4. Supergrouper	X	X
5. Audio support	X	
6. Record sound	X	X
7. Creation of personalized symbol library	X	X
8. Visual continuity between picture view and writing view	X	X
9. Formatting text and diagrams	X	
10. Diagrams	X	X

In accordance with Norman's conceptualization of the notion of affordance, TM maintains that in view of the fact that software affordances emerge as a relationship that holds between the software and the teacher who is going to use the software in his or her teaching, teacher educators need to make the connections among software affordances, content, and pedagogy explicit to teachers. This recommendation is supported by the empirical data presented in Table 1.

The authors asked 45 dyads of pre-service teachers, after attending a series of technical workshops for learning how to use a particular software program, to identify the software affordances, and indicate the extent to which each affordance could support content transformations and learner-centered pedagogy. Since there was a considerable overlap in the ideas expressed by the 45 dyads, here only the ideas expressed by three dyads are presented. It is evident from these ideas, as presented in Table 1, that pre-service teachers' conceptions about the affordances of the software varied in terms of not only the actual affordances themselves, but also in terms of teachers' perceived connections of the affordances with content representations and pedagogy. These data support the same view expressed by Norman (1990), that is, software affordance is something of both actual and perceived properties, and that it is not independent of teachers' experience, knowledge, culture, or ability to perceive. In addition, students' conceptions were incomplete and did not constitute well-developed ideas of what teachers and students could do with the software.

An example of how the connections among software affordances, content, and pedagogy can be made explicit to teachers is presented in Table 2. The entries in Table 2 are not meant to be exhaustive but illustrative of how the connections can be made. According to Angeli and Valanides (2005), Angeli (2005), Valanides and Angeli (2006, 2008b), it is very important that teacher educators explain in detail who – the teacher or the learner or both – will be using these powerful representations in the classroom, for what purposes, and why. The outcome of this complex instructional decision process will be a series of powerful pedagogical transformations, as depicted in the double-round circle in Fig. 4. It is worthy to mention, at this point, that as teachers gradually become more experienced in assessing the added value of computers in teaching and learning, they will feel more competent and confident to integrate them in their classroom practices in more sophisticated ways. As teachers become more expert in designing learning with technology, technology integration efforts will move away from teacher-directed practices to more learner-centered approaches (Valanides & Angeli, 2008a).

7. Assessing ICT–TPCK

The assessment of ICT–TPCK necessarily requires new ways of thinking about how to assess learning-in-progress as teachers advance from novice to expert thinking about designing instruction with technology. Alternative forms of assessment must extensively depart from older conceptions of assessment that focus on grades. As Black and William (1998) argued, conventional methods of assessment with a focus on grades, and not on learning, are not appropriate to be used for the assessment of complex learning outcomes. Contemporary views for assessing complex learning outcomes advocate for authentic, progress-based and continuous assessment, such that learners' performance is assessed repetitively over a period of time. Moallem (2007) stated:

> *The concept of assessment for learning emphasizes integrating assessment and instruction, and requires a dynamic, continuous, and performance-based assessment system that emphasizes progress in learning, and in becoming increasingly sophisticated learners and knowers* (p. 351).

Table 2
Mapping software affordances onto content representations and their pedagogical uses

Software affordance	Content representations	Pedagogical uses
Pictures/symbols in libraries	Visualization of concepts	• Students use pictures and symbols to observe, express themselves, explain, and make their thinking/understanding visible • Teachers can use pictures to explain something, to create cognitive conflict, to present discrepant events, to initiate discussion about a topic
Pictures are paired with their corresponding words	Textual and pictorial representations	• Students' early reading skills begin to emerge and young students "can write" their own stories
Visual association between a pictorial view and writing view	Images get dynamically transformed into their equivalent written expressions and vice versa	• Learners explore the connections between images, words and their meaning by switching from the pictorial view to the writing view and vice versa
Record and hear sound	Auditory representations	• Students and teachers can record their ideas • Students can hear any text read aloud, strengthening word recognition and comprehension
Hyperlinks	Multimodal representations: • auditory • textual • visual • interactive	• Students can "travel" to the Internet to read about something, to hear about something, to view a video, to explore different points of view, to run a model or simulation, or even to visit a virtual museum

In face to face environments, instructors run into challenges when they are asked to apply an authentic and progress-based assessment system, simply because it is difficult within a limited time to assess the progress of many learners, and provide timely and constructive feedback to them. Additionally, in face to face environments, it becomes complicated to manage and consider multiple sources of assessment information that are necessary in order to assess learning progressively. For these reasons, it will be valuable to consider alternative ways for authentic assessment using the affordances of electronic learning environments that support both synchronous and asynchronous communication among teachers and students, beyond the walls and the time constraints of the traditional classroom. It is therefore feasible to implement some components of authentic assessment in online learning environments, so that learners' progress can be most effectively recorded and assessed, and, most importantly, for enabling learning and assessment to blend in ways that one constructively informs the other during the act of teaching.

Fig. 5 shows the conceptualization of design- and progress-based assessment of teachers' competencies to teach with technology. As shown in Fig. 5, design tasks constitute the backbone of the assessment model. The model involves assessment of teachers' performance on different design tasks that are integrated throughout the entire learning process. For each design task, as shown in Fig. 5, three forms of assessment take place, namely, expert assessment, peer assessment, and self-assessment.

Peer assessment is included in the model, because, as argued by different educational reformers and in accordance with the situative perspective, for teachers to be successful in constructing new roles, they need opportunities to participate "in a professional community that discusses new teacher materials and strategies, and supports the risk taking and struggle entailed in transforming practice" (McLaughlin & Talbert, 1993, p. 15). Similarly, self-assessment is important to be included in the model, because, as teachers bring their own unique perspective in the design process, they must be allowed to defend their designs, and explain how they were affected by the intricacies of their respective contexts. Peer assessment can take place in an asynchronous computer-mediated communication environment for continuous feedback. The expert and peers evaluate learners' performance on the design task at hand, using the same list of criteria as proposed by the expert or co-constructed by the expert and the learners. Once the peer assessment is completed, the expert asks learners to reflect on their individual performance and conduct a self-assessment, taking into consideration the comments from their peers. After learners complete their self-assessment, the expert finalizes his or her own assessment and discloses his or her own opinion to each learner individually. The expert also discusses in class the strengths and weaknesses of the group's overall performance on the design task. A new cycle of assessment takes place with each new design task. The quality of learners' performance on each design task is assessed using a list of criteria. Table 3 provides a detailed description of criteria and specific examples for each criterion.

As shown in Table 3, five indicators are proposed: (a) 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. These topics may include abstract concepts (i.e., cells, molecules) that need to be visualized, phenomena from the physical and social

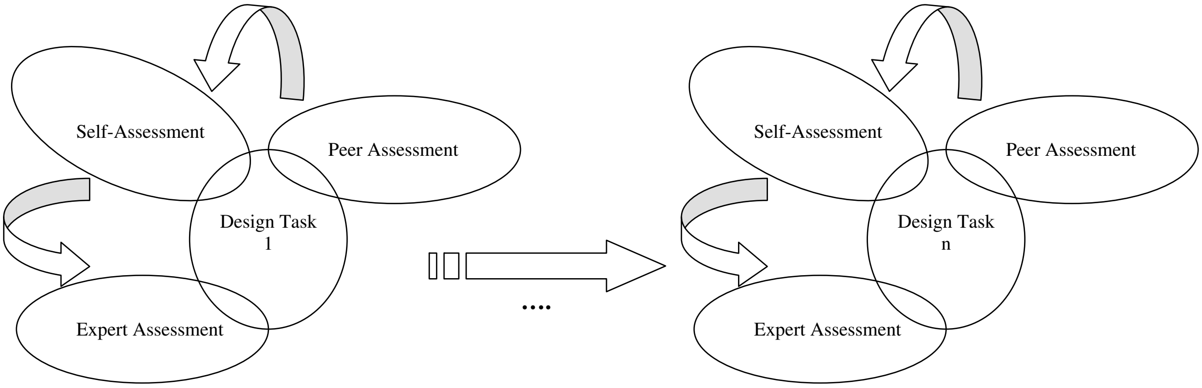

Fig. 5. A model for ICT–TPCK assessment.

Table 3
Criteria for assessing ICT–TPCK

Criterion	Examples
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	• Abstract concepts (i.e., cells in biology) that need to be visualized • Phenomena from the physical and social sciences which consist of certain events and need to be animated (i.e., water cycle, immigration) • Complex systems (i.e., ecosystems, organizations) in which certain factors function systemically and need to be simulated or modeled • Topics that require multimodal representations (i.e., textual, iconic, and 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	• Interactive representations • Dynamic transformation of data • Dynamic processing of data • Multiple simultaneous representations of data • Multimodal representations of data
3. Identification of teaching strategies, which are difficult or impossible to be implemented by traditional means	• Exploration and discovery in virtual worlds • Virtual visits (i.e., virtual museums) • Testing of hypotheses and or application of ideas into contexts not possible to be experienced in real life • Complex decision-making • Creation of cognitive conflict • Long distance communication and collaboration with experts • Long distance communication and collaboration with peers • Personalized learning • Adaptive learning
4. Selection of appropriate ICT tools	• Appropriate pedagogical uses of affordances to transform content and pedagogy as defined in 2 and 3 above
5. Identification of appropriate 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: ○ express a point of view, ○ explore, ○ observe, ○ discover, ○ inquire, ○ collaborate with others, ○ resolve cognitive conflict, and ○ problem solve

sciences that need to be animated (i.e., water cycle, immigration), 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; (b) 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. They include interactive representations, dynamic transformation of data, dynamic processing of data, multiple simultaneous representations of data, and multimodal representations of data; (c) Identification of teaching strategies, which are difficult or impossible to be implemented with traditional means. For example, exploration and discovery in virtual worlds, virtual visits (i.e., virtual museums), testing of hypotheses and or application of ideas into contexts not possible to be experienced in real life, complex decision-making, long distance communication and collaboration with experts, long distance communication and collaboration with peers, personalized learning, adaptive learning, and context-sensitive feedback; (d) Selection of appropriate ICT tools and effective pedagogical uses of tool affordances; and (e) Identification of appropriate strategies for the infusion of technology in the classroom, which includes any strategy that puts the learner at the center of the learning process to express a point of view, observe, explore, inquire, and in general, problem solve.

8. Empirical appraisal of the models

8.1. Participants

An empirical investigation was conducted during the course of three consecutive semesters, namely, spring of 2007, fall of 2007, and spring of 2008, to examine the impact of TM depicted in Fig. 4, and the assessment model depicted in Fig. 5 on student learning. In total, 215 first- and second-year pre-service primary education teachers participated in the study. All students were enrolled in an Instructional Technology course, which is offered every semester and is mandatory for all pre-service teachers. The aim of the course is to teach pre-service teachers how to teach with ICT, and thus to develop their ICT–TPCK competency. The student enrollment in the course was 80, 50, and 85 for spring of 2007, fall of 2007, and spring of 2008, respectively. The course instructor was the same for all participants. All students had only basic computing skills, but were considered as novices in the design of ICT-enhanced learning.

8.2. Research procedures

The course consisted of 13 one-hour weekly lectures and 13 75-min weekly laboratories. Participants were requested to attend all meetings, both lectures and laboratories. During the one-hour weekly lectures, the instructor of the course taught explicitly and methodically the ID process, depicted in Fig. 4, using rich examples from a variety of content domains relating to the elementary school curriculum. Each step of the process was exemplified with specific examples of how the pedagogical affordances of specific ICT tools could transform the content into powerful pedagogical representations tailored to the learners' abilities, interests, and previous knowledge and/or alternative conceptions. During lab time, students were engaged in rich practice examples in order to be able to apply their knowledge in real teaching/learning contexts. Also, during lab time, students learned how to use a variety of software and discussed the pedagogical affordances of the tools in order to design ICT-enhanced instructional lessons. The primary focus of the lectures and laboratories was to make visible and explicit to the students the interconnections among tool affordances, learners, content, and teaching strategies.

During the fifth week of the course, students were given their first design task. They were asked to follow the ID process depicted in Fig. 4 and design ICT-enhanced learning activities for a topic of their choice. Students completed their first design task by the seventh week. During the 10th week, students were given a second design task and were asked to complete it within two weeks time. During the last week of the semester, students reflected as a group on their design experiences and shared with their fellow students and the instructor the challenges they faced in designing their ICT-enhanced lessons.

8.3. Assessment procedures

For this study, the two design tasks constituted the units of analyses. Rich assessment procedures were followed especially for the first design task. Specifically, during the eighth week of the semester, after students completed and submitted for evaluation their first design task, they were engaged in peer assessment using the asynchronous communication feature of Blackboard 6. Specifically, after receiving students' permission, the course instructor posted in Blackboard 6 all ICT-enhanced lessons submitted by the students for evaluation. Then, in teams of five that were randomly formed, students evaluated five of these lessons. These lessons were randomly assigned by the instructor after excluding the ones prepared by the members of each team. Students in each team were requested to post their own assessment for each lesson, and then for each lesson to exchange at least three messages with the other students in their team for the purpose of discussing the qualities of each ICT-enhanced lesson. The instructor's assessment was not known at that time and students were asked to evaluate their fellow students' work using the criteria shown in Table 3. The participants were engaged in asynchronous communication for two weeks and during the tenth week of the course, when peer assessment was completed, they were asked to write a reflection paper about their individual performance on the first design task and conduct a self-assessment using the criteria in Table 3 taking into consideration the comments from their peers. When self-assessment was completed, the course instructor discussed in class students' overall performance on the first design task and announced student grades. These assessment procedures were followed for the first design task only. For the second design task, due to time limitations, student performance was assessed only by the course instructor using again the criteria in Table 3. At the end of the course, students also completed course evaluations. On the course evaluations, students were asked to reflect on their own trajectory of learning from the beginning to the end, and discuss any challenges they faced during the course. Specifically, they were asked to evaluate the impact of the lectures, labs, and asynchronous communication on their learning throughout the semester.

Each criterion in Table 3 was assessed with a numerical scale from 1 to 5. A score of 1 indicated failure in satisfying the criterion and a score of 5 indicated success in satisfying the criterion. Thus, total scores for the overall ICT–TPCK performance ranged from 5 to 25. A total score of 5 indicated poor ICT–TPCK performance and a score of 25 indicated outstanding ICT–TPCK performance. Two experts in instructional technology, with the help of content experts, evaluated all lesson activities using the criteria in Table 3 as well as students' self- and peer assessments. A Pearson r between the two ratings was found to be .89. Discrepancies between the two raters were resolved with the help of the researchers.

Two different independent raters also performed a qualitative analysis (Patton, 2002) of students' course evaluations that were completed at the end of each semester. The interrater agreement was found to be .93.

8.4. Results

8.4.1. Student performance on the design tasks

Table 4 shows descriptive statistics (means and standard deviations) for each criterion that was used to assess students' ICT–TPCK performance on the two design tasks and students' total ICT–TPCK competency scores. Repeated measures within-subject effects for the two design tasks were tested and found to be statistically significant, $F(1, 214) = 1980.43$, $p = 0.00$, $F(1, 214) = 4879.33$, $p = .00$, $F(1, 214) = 990.15$, $p = .00$, $F(1, 214) = 420.76$, $p = .00$, $F(1, 214) = 2634.80$, $p = .00$, and $F(1, 214) = 13774.99$, $p = .00$ for each criterion, respectively, as these are listed from 1 to 5 in Table 4, and for the total ICT–TPCK scores. The results clearly indicate that student performance on the second design task was significantly better than student performance on the first design task and that their total ICT–TPCK competency significantly improved during the course of the semester.

8.4.2. Student course evaluations

The qualitative analysis of students' evaluations was particularly useful in explaining these quantitative findings. Interestingly, the qualitative analysis uncovered a four step knowledge construction process which reveals the trajectory of novices' learning when they are con-

Table 4
Descriptive statistics of students' ICT–TPCK performance on two design tasks

Criterion	Design task 1			Design task 2		
	Mean	SD	N	Mean	SD	N
1. Identification of suitable topics to be taught with technology	3.08	.76	215	3.97	.72	215
2. Identification of appropriate representations to transform content	2.40	.88	215	3.50	.88	215
3. Identification of teaching strategies difficult to be implemented by traditional means	2.43	.96	215	3.06	.93	215
4. Selection of appropriate tools and appropriate pedagogical uses of their affordances	2.35	.99	215	3.06	.93	215
5. Identification of appropriate integration strategies	2.33	.98	215	3.38	.89	215
Total ICT–TPCK competency	12.59	3.87	215	16.97	3.73	215

fronted with ill-defined and unknown tasks, such as design tasks. The four steps are: (1) Gather initial information; (2) Engage in real-world authentic tasks; (3) Share, discuss and reflect with others to eliminate uncertainty; and (4) Discuss with an expert.

8.4.2.1. Gather initial information. At the beginning students commented on wanting to learn more and more about instructional design, because they had no prior knowledge relating to the design of learning activities. A student (S23) wrote: "At the beginning, I felt I needed to listen to my course instructor and learn about instructional design. My initial knowledge about the design of ICT-enhanced learning activities was zero, and I wanted to just hear about it and read about it". Another student (S117) explained: "At the beginning of the semester, when the instructor explained the requirements for the course, I felt immensely uncomfortable. I mean, I had no knowledge whatsoever about instructional design, and I felt that the course would require a tremendous amount of time in order to get a good grade. Gradually, through the instructor's lectures and practice during labs, things started to become clearer. When you know nothing about a topic, you really need to listen to what the experts have to say". It is evident from students' overall comments that they appreciated the instructor's lectures about the ID process depicted in Fig. 4 and the practice that followed during lab time.

8.4.2.2. Engage in real-world authentic tasks. Once students acknowledged the importance of lectures and practice in constructing initial knowledge schemata about instructional design, they were quick to comment on the importance of applying new knowledge in authentic real-world tasks. Thus, a student (S203) expressed his appreciation for the combination of theory and practice as follows: "The combination of theory during lectures and practice during lab time was effective for me. From the one hand, I needed the theory, but from the other hand I also needed to see the application of this knowledge in real-world classroom examples. I found the fact that we were engaged in rich practice experiences gratifying". Other students (S215, S173, S141, S109, S95, S73, S67, S61, S56, and S34) stated explicitly that they also appreciated the systematic efforts of the instructor in explicitly explaining the mapping of tool affordances onto teaching strategies and content transformations for each practice example discussed in class. This tactic "was most important in helping us construct an interconnected body of knowledge and not isolated bits of information" (S141).

8.4.2.3. Share, discuss, and reflect with others to eliminate uncertainty. While students found the rich practice examples useful and necessary for becoming more knowledgeable about instructional design, the assignment of the first design task was still perceived as daunting, as it was clearly articulated by a student who wrote: "When I first read the requirements for the first design task, I felt so uncertain about it. I learned so many things about designing instruction with computers and still, I was not sure of the instructional decisions that I needed to make. The asynchronous communication in Blackboard was a pleasant activity. Discussing and sharing concerns and uncertainties with others was very important for me" (S115). Many other students (e.g., S25, S27, S33, S39, S48, S52, S66, S78, S126, S146, S159, and S167) also wrote that the Blackboard activity was not only useful in giving them a forum to discuss and exchange points of view with others, but also cautiously made them aware of the fact that in order to evaluate others, they first had to reflect on their own performance and evaluate themselves. This self-realization confronted them with their own incorrect conceptions about their own instructional designs, and, through the social exchanges in Blackboard, they were able to reconstruct their understandings.

8.4.2.4. Discuss with an expert. Lastly, students commented on the feedback they received from their course instructor and the discussion they had with her during the debriefing sessions. The excerpt from one of them clarifies the way of their thinking: "It is always useful to receive feedback from an expert, when you are not one. My course instructor helped me clarify a few things I was uncertain about, and helped me develop better pedagogical reasoning about my instructional design decisions" (S89). Many other students (e.g., S11, S23, S26, S35, S40, S68, S71, S89, S93, S104, S121, S132, S135, S147, S150, S161, S177, S189, S194, S205, S214, and S215) also explained that becoming an expert instructional designer requires a tremendous amount of knowledge, skills, and experiences, and cannot be easily and quickly achieved. They also stated that the instructor's pedagogical explanations about why and how they needed to improve their designs were especially constructive.

8.5. Discussion

The quantitative findings of the empirical investigation clearly show that students' performance on the second design task was significantly better than their performance on the first design task. Also, the findings indicate that students' ICT–TPCK competency developed and significantly improved during the course of a semester. It is interesting to note that students' mean performance on the first design task after the first four weeks of training, which mostly included lectures and practice, was found to be 12.59 ($SD = 3.87$), whereas after engagement in asynchronous communication for peer assessment, and after self-reflection and receiving feedback from the course instructor, students' performance was calculated to be 16.97 ($SD = 3.73$), an increase that was found to be statistically significant. These results show that the teaching of the ID process depicted in Fig. 4 in combination with the implementation of the assessment model shown in Fig. 5 had a positive impact on the development of students' ICT–TPCK knowledge.

In addition, based on learners' qualitative comments, it is evident that ongoing- and progress-oriented assessment procedures can be most beneficial in assessing complex learning outcomes, such as ICT–TPCK competency. In particular, the qualitative analysis showed that students' learning trajectory was contingent not only upon the instructor's lectures, but also upon the additional assessment procedures – i.e., peer assessment, self-assessment, and expert assessment – that were carried out. Most importantly, these findings show that when it comes to restructuring old teaching practices, teachers must be trained in powerful learning environments where teaching is situated in real and authentic tasks, and in ways where teachers themselves constitute a part of a larger learning and professional community for the purpose of exchanging perspectives, resolving dilemmas, and confronting uncertainty in transforming classroom practice.

Lastly, in this study no data were analyzed concerning the social exchanges among the students during asynchronous communication in Blackboard. However, recent developments emphasize the importance of examining the learner in interaction with others (Valanides & Angeli, 2008c), and while this type of analysis was not the focus of the present empirical investigation, it should be performed in future studies concerning the development of ICT–TPCK knowledge.

9. Concluding remarks

The present paper initially raised and discussed several epistemological issues regarding the construct of TPCK for the purpose of clarifying it, and, thereafter, introduced ICT–TPCK as a strand of TPCK and proposed models for its development and assessment. The transformative and integration views were used for exploring the construct of TPCK. Based on evidence from their own empirical investigations, the authors adopted the transformative view, concluding that TPCK is a unique body of knowledge that is constructed from the interaction of its individual contributing knowledge bases, and that the mere development of one or more of its knowledge bases does not guarantee and does not imply concurrent development of ICT–TPCK. It was emphasized that ICT–TPCK is what makes a teacher competent to design technology-enhanced learning, 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 that are difficult to be understood by learners or difficult to be presented by teachers can be transformed and taught more effectively with technology in ways that signify its added value.

One model for developing and another one for assessing ICT–TPCK were then described. TM was proposed as an approach for understanding and promoting a situative methodology toward the development of ICT–TPCK, and three forms of assessment, namely, expert assessment, peer assessment, and self-assessment, were proposed for assessing teachers' competencies to teach with technology. At the heart of the assessment model is the assessment of teachers' performance on design tasks, and the repetitive nature of assessment for each new design task, as teachers progressively develop more sophisticated ways of thinking about how technology can transform their teaching practices. Finally, an empirical investigation of the impact of the models on pre-service primary school teachers' learning within the context of two design tasks in an Instructional Technology course showed that student performance on the second design task was significantly better than student performance on the first task, and that total ICT–TPCK competency was significantly advanced at the end of the course.

In conclusion, despite the optimistic results of the empirical investigation, the development of ICT–TPCK is not an easy task. Consequently, intensive, coordinated and dedicated systematic efforts need to be planned and implemented in pre-service and in-service education programs in order to develop teachers' ICT–TPCK. We do hope that researchers, instructional designers, and practitioners will find the conceptual framework discussed herein useful and applicable in their respective contexts. Any future research efforts that will be undertaken to validate, modify, or improve the framework proposed for the conceptualization, development, and assessment of ICT–TPCK will be important for both research and practice.

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