

**TPCK in Pre-service Teacher Education: Preparing Primary Education  
Students to Teach with Technology**

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## **Abstract**

Two epistemological views are assumed, namely the integrative and the transformative views, for exploring the construct of technological pedagogical content knowledge (TPCK). The transformative view is adopted and based on empirical findings it is concluded that TPCK constitutes a unique body of knowledge constructed from the dynamic interaction of constituent knowledge bases, namely knowledge of content, pedagogy, learners, context, and technology. A clarified view of TPCK is discussed and two models for teaching and assessing TPCK are described. Technology Mapping is proposed as a design-based approach for understanding and promoting a constructivist methodology toward the development of TPCK, and an integrating model of assessment, consisting of three forms, namely, expert/teacher assessment, peer assessment, and self-assessment, is proposed for assessing TPCK.

## **1. Introduction**

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 programs (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). 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, they [teachers] still lack the skills and knowledge needed to be able to teach with technology successfully (Rodrigues, 2003).

The failure to adequately prepare teachers to teach with technology can be attributed to various factors. The emphasis of educational technology courses on skills regarding the use of various computer applications, such as word processing, spreadsheets, email, Internet, and graphics, is one major contributing factor. As Becker and Riel (2001), and Selinger (2001) explained, although basic computing skills constitute the cornerstone of technology literacy, skills-based courses are not enough for preparing teachers to teach with technology because they are usually taught in isolation from a pedagogical context. Kenny (2002) stated that the lack of a subject specific focus in many technology 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, and thus teachers cannot effectively think how to link technology with 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 technology integration in teaching and learning is a major weakness in the educational technology literature (Selfe, 1990; Willis & Mehlinger, 1996; Wilson, 2003; Zhao, 2003; Margerum-Rays & Marx, 2003; Niess, 2005; Angeli & Valanides, 2005; Mishra & Koehler, 2006). 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 theoretical frameworks to guide teacher preparation in technology integration, researchers during the last five years initiated systematic research programs for the purpose of developing theory and models to ground research in the area of teacher cognition about technology integration

(Margerum-Rays & Marx, 2003; Niess, 2005; Angeli, 2005; Angeli & Valanides, 2005; Valanides & Angeli, 2008c; Mishra & Koehler, 2006). These researchers advocate that teachers need to develop a new body of knowledge that constitutes an extension of Shulman's (1986, 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 conceptions of how to extend PCK in the domain of teaching with technology exist in the literature under different labeling schemes. For example, Margerum-Rays and Marx (2003) referred to PCK of educational technology, Angeli and Valanides (2005) used the term ICT-related PCK, while Slough and Connell (2006) used the term technological content knowledge, and Mishra and Koehler (2006, 2007) the term technological pedagogical content knowledge (TPCK), which was recently changed to Technological Pedagogical and Content Knowledge (TPACK). 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.

The purpose of this paper is not to offer a polemic view about which scheme is better than the others. On the contrary, the paper seeks to raise theoretical and epistemological issues that are important to consider so that the degree of precision of the frameworks characterizing the extended view of PCK into the domain of teaching with technology can be put under scrutiny for the sake of theoretical robustness and clarification. It is noted that in this paper the term TPCK will be used throughout because it is an all-encompassing term that can be utilized to characterize all existing

conceptions mentioned above. A clarified view of TPCK will then be proposed and a methodology will be discussed about how TPCK can be promoted and assessed.

## **2. PCK as a Conceptual Basis for TPCK**

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, 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 teachers’ understandings of students’ conceptions and content-related learning

difficulties constitute the key elements in Shulman's conception of PCK. Specifically, according to Shulman (1986), transformation of subject matter 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. Thus, PCK implies a transformation of subject-matter knowledge, so that it can be effectively and flexibly used in the communication process between teachers and learners. Shulman (1987) included PCK in the knowledge base of teaching that consists of three content-related categories (content knowledge, PCK, and curriculum 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) curriculum 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.

Other scholars have adopted the key elements of PCK (comprehensible representations of subject matter and understanding of content-related learning difficulties) and extended the concept of PCK by including in it some of the categories of Shulman's knowledge base of teaching. For example, Grossman (1990) perceived PCK as consisting of Shulman's two key elements of PCK, namely subject

matter representations and understanding of content-related difficulties, and knowledge and beliefs about the purposes for teaching particular topics, as well as knowledge of curriculum materials available for teaching. PCK in Grossman's model is at the heart of teacher knowledge and is surrounded by knowledge of subject matter, general pedagogical knowledge and contextual knowledge. Marks (1990) also extended Shulman's (1986) model by including knowledge of media for instruction beyond knowledge of subject matter per se, and considered the development of PCK as a process of integrating the interpretation of subject-matter knowledge and general pedagogical knowledge.

Cochran, DeRuiter, and King (1993) also proposed a modification 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 renamed PCK as Pedagogical Content Knowing (PCKg) to acknowledge the dynamic nature of knowledge 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 synthesized nature of PCK as the result of the concurrent development of these four components. This definition of PCKg places emphasis on the situatedness of teacher training and the central role that teachers' understandings of their students play in teaching. Shulman (1986, 1987) mentioned these two aspects of knowledge, but he did not put emphasis on their necessity as his focus on subject matter transformation veiled their importance.

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 Figure 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.

Moreover, Cochran and her colleagues (1993) argued that the four components of PCKg should not be acquired separately and then put together somehow, but teacher education programs should promote integration by providing appropriate learning experiences to prospective teachers, so that they simultaneously experience all of the components of PCKg and their complex interrelationships. The arrows in the model in Figure 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 teaching experiences, constitutes its dynamic nature that justifies the change from PCK to PCKg.

**---Insert Figure 1 about here---**

Fernandez-Balboa and Stiehl (1995) also emphasized the integration of five knowledge components (subject matter, students, instructional strategies, teaching context, and purposes of teaching), but generally speaking there is no universally accepted conceptualization of PCK. The main differences among scholars refer to the elements included or integrated 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 learning 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. Moreover, because the construct of PCK is directly related with the teaching of particular topics, it is considerably different from subject matter per se. Finally, there is also a universal agreement that PCK is rooted in classroom practice and gradually develops through a process of integrating different sources of knowledge. This implies that prospective or even beginning teachers have incomplete and superficial levels of PCK, and, that their PCK will continually grow with teaching experience.

### **3. Extending PCK to TPCK**

Cochran et al., (1993) as well as Shulman (1986, 1987) did not discuss technology and its relationship to content, pedagogy, and learners. Of course, 25 years ago when Shulman first talked about PCK during his 1985 presidential address to the American Educational Research Association, technology was not as much of an issue as it is today and was mostly considered to be commonplace and transparent.

It is argued that with the steady increase of computers in schools and the numerous implications of computers and other information and communication technologies in teaching and learning, the construct of PCK needs to be extended to account for the phenomenon of teachers learning how to teach with technology. Recently, the 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 (1987) stated

“it is what people do with the machine, not the machine itself that makes a difference” (p. 19).

In principle, this reflects a distinction between technologies as media of conveyance and knowledge dissemination or acquisition, and technologies as tools for knowledge construction or cognitive tools (Jonassen, 2000). It also represents a non-trivial departure from traditional conceptions of technologies. Technologies as cognitive tools are intended to engage and facilitate cognitive processing (Kommers, Jonassen, & Mayes, 1992) and extend the thinking process of their users who construct knowledge “in ways that couple the tool’s intelligence with theirs in mindful engagement with the task” (Salomon, Perkins, & Globerson, 1991, p. 4). Thus, teachers are required to learn new skills and techniques in order to integrate technology in their everyday teaching and use technology to alter their traditional classroom teaching. From this perspective, technological knowledge becomes another important category of the knowledge base of teaching, and any attempt to integrate technology in the teaching-learning environment creates a need for developing TPACK. Conceptualizations of TPACK constitute, therefore, an enhancement or an extension to PCK.

Margerum-Leys and Marx (2003) explored the construct of knowledge of educational technology through the lens of content knowledge, pedagogical knowledge, and PCK. They defined content knowledge of educational technology as knowing how to use several tools as well as knowing about their affordances and general technical skills, such as troubleshooting and file management operations. Pedagogical knowledge was defined as the application of general pedagogical strategies that are not specific to the use of technology, and include strategies for scaffolding students’ thinking, motivating students, and checking for understanding.

They defined PCK of educational technology as knowledge that is derived from, and applicable to, teaching and learning situations involving educational technology. Examples included the time required to teach about and with particular technologies, how to envision potential student problems with particular technologies, configure instruction and learning tasks for a variety of technological capacities, etc.

Mishra and Kohler's (2006) conception of TPCK diverges from Margerum-Lays and Marx's (2003) notion of PCK of educational technology in that it is conceptualized as a situated form of knowledge deeply rooted in the interactions of content, pedagogy, and technology. Specifically, Koehler, Punya, and Yahya (2007), in a recent article in *Computers & Education* [Koehler, M. J., Mishra, P., & Yahya, K. (2007). Tracing the development of teacher knowledge in a design seminar: Integrating content, pedagogy, and technology. *Computers & Education*, 49, 740-762], argued 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 Figure 2, Kohler et al.'s conceptualization of TPCK goes beyond seeing content, pedagogy and technology as constructs in and of themselves. Their approach considers the interactions among these three elements and examines all possible interactions among content, pedagogy and technology, namely, Pedagogical Content Knowledge, Technological Content Knowledge, Technological Pedagogical Knowledge, and Technological Pedagogical Content Knowledge.

**---Insert Figure 2 about here---**

While Kohler et al. (2007) do emphasize that content, pedagogy, and technology need to be treated in an integrated manner, and not as separate knowledge bases, by engaging students in rich design activities where they can act as designers of learning enhanced with technology, the conviction of the authors of this paper is that TPCK- in its current conceptualization - lacks 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 it has important implications for its assessment. For example, it is not clear from Kohler 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). This lack of knowledge categorization or discrimination is a serious lack of precision in the current conceptions of TPCK and more discussion is needed to clarify the nature of the construct.

#### **4. Clarifying TPCK: Epistemological Considerations**

The first consideration is whether TPCK constitutes a distinct body of knowledge. This issue is crucial to consider because if TPCK is a distinct body of knowledge, then the next question that becomes relevant is whether it can be taught and whether it can be assessed. 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 signifies growth in TPCK. The authors of this paper have tested this hypothesis extensively during the last five years and found that

growth in the related constructs does not automatically mean growth in TPCK (Angeli & Valanides, 2004, 2005; Angeli, 2005; Valanides & Angeli, 2008a, 2008b, 2008c). For example, based on the results of several studies, in-service teachers who had no TPCK training but had extensive teaching experience did not perform significantly better on technology design tasks than teachers who also had no TPCK training but had less teaching experience (Angeli & Valanides, 2004; Angeli, 2005, Angeli & Valanides, 2005; Valanides & Angeli, 2008a, 2008b, 2008c, 2006). However, after TPCK training, teachers who had stronger pedagogical skills and better content knowledge outperformed those with weaker knowledge in both pedagogy and content (Authors, 2005, 2008). Similar results were found with pre-service teachers. Specifically, studies with undergraduate pre-primary students showed that without any TPCK training sophomores and juniors did not design better technology-enhanced lessons than freshmen, but after TPCK training, sophomores and juniors outperformed freshmen in designing learning activities with technology (Angeli & Valanides, 2004; Angeli, 2005, Angeli & Valanides, 2005; Valanides & Angeli, 2008a, 2008b, 2008c, 2006). The authors concluded that teacher educators need to explicitly teach how the unique features of a tool can be used to transform a specific content domain for specific learners, and that students need to be explicitly taught about the interactions among technology, content, pedagogy, and learners. Knowledge and growth in each constituent knowledge base, such as content, pedagogy, learners, and technology, per se, without any specific instruction targeting exclusively TPCK as a unique body of knowledge, does not imply automatic growth in TPCK.

Therefore, based on the results of several empirical investigations, the authors of this paper conclude that TPCK is a distinct body of knowledge that can be taught, and thus, assessed. This body of knowledge is an extension of Shulman's PCK

and goes beyond mere integration or accumulation of the constituent knowledge bases, toward transformation of these knowledge bases to something new. As shown in Figure 3, TPCK's constituent knowledge bases include subject-matter knowledge, pedagogical knowledge, knowledge of learners' difficulties, knowledge of the context within which learning takes place, and technology knowledge. Succinctly, (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) technology 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. 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 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. In spite of this, TPCK is not a reified or an objectified body of knowledge, but, as shown in Figure 3, it is a body of knowledge that grows continuously with systematic engagement in rich design experiences. This

means that any program or instructional design model that aims at the development of TPCK must consider teachers' knowledge and classroom experience and use them as the starting point for initiating efforts aiming at the development and/or growth of TPCK.

**---Insert Figure 3 about here---**

This last issue is important, because research on instructional design and teacher education has shown that teachers use a unique body of knowledge, that is socially situated, as a starting reference point in order to guide their instructional thinking and decision making (Moallem, 1998; Brown, Collins, & Duguid, 1989; Suchman, 1987). Particularly, in Moallem's (1998) study, socially situated knowledge was considered as a highly contextual and practical complex body of knowledge that teachers acquired 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) curriculum, content, pedagogy, and learners. The implications of these findings are important because they reveal how teachers' situated knowledge can affect their instructional decisions and consequently this means that any preparation for TPCK development must take into consideration teachers' contextual and highly practical body of knowledge. In other words, TPCK cannot be considered as a reified body of knowledge that exists independently of teachers' beliefs and practical experience.

Furthermore, any intended approach for developing TPCK must not only be responsive to teachers' beliefs and knowledge, but it must also be learner-centered. Conceptually, as discussed above, PCK is the backbone of TPCK. This means that teachers' knowledge of representations of subject matter, and teachers'

understandings of students' conceptions and content-related learning difficulties constitute the key elements of PCK. By default, the same holds for TPCK. In addition to this, it is important to raise another issue that is 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 TPCK development efforts need to invest on socio-cognitive constructivist ideas because the most effective content transformations are those that create cognitive conflict and encourage dialogue and negotiation of meaning among students whose initial conceptions were different. It is also argued, that the emphasis should not only be on students' cognitive development but also on their holistic development taking into consideration other factors related to their personal development that goes beyond cold cognition. For example, any transformation of the subject matter can have, potentially, differential effects on individual learners due to learner differences in cognitive style and visual literacy skills (Angeli & Valanides, 2004; Valanides & Angeli, 2006). Thus, TPCK becomes 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 become a joint cognitive system.

Concisely, for the purpose of reiterating the main points discussed here, TPCK is a distinct or unique body of knowledge that is constructed from the dynamic interaction of its constituent knowledge bases namely knowledge of content, pedagogy, learners, context, and technology. We call this conceptualization of TPCK the transformative view, because it calls for the transformation of the five knowledge

bases into a unique form of knowledge. This new body of knowledge consists of the interactions among all constituent knowledge bases and is teachable. The authors reject the integrative view of TPCK which states that TPCK is not a distinct form of knowledge but a body of knowledge that is made of from other forms of teacher knowledge that are brought together independently during the act of teaching, because growth in the individual knowledge bases does not imply automatic growth in TPCK (Angeli & Valanides, 2004, 2005; Angeli, 2005; Valanides & Angeli, 2008a, 2008b, 2008c, 2006).

## **5. Technology Mapping: A Methodology for Developing TPCK**

Technology Mapping (TM) is an empirically-based approach to understanding and promoting a constructivist orientation toward the development of TPCK. As shown in Figure 4, the development of TPCK is approached analytically with a systematic model which aims at the design of technology-enhanced learning. TM has been gradually developed in a number of design-based research studies during the last five years (Angeli & Valanides, 2004, 2005; Angeli, 2005; Valanides & Angeli, 2008a, 2008b, 2008c, 2006), and as expected, the methodology endured several iterations of modifications. After the last cycle of fine-tuning, TM is presented herein as a model or methodology for guiding teacher thinking about the wicked problem of designing technology-enhanced learning. TM can be used in teacher education departments to teach pre-service teachers how to teach with technology; in teacher professional development programs to prepare in-service teachers in the pedagogical uses of technology; and most importantly, by the teachers themselves to design lessons with technology. TM is predicated on the view that while there is not 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 in teachers’ real

practices. Thus, the ID model shown in Figure 4 is offered as a participative approach and a tool for teachers to use in order to deal with technology design problems. In essence, TM is an interaction technique that seeks the dynamic transactions among all constituent knowledge bases of TPACK while at the same time it places emphasis on the situated nature of teachers' thinking and the critical role that teachers' understandings of their students play in their instructional decisions.

As shown in Figure 4, 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 work 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 the integration of technology in teaching will most likely be teacher-directed (i.e., the teacher uses the technology to present 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 these context-sensitive factors 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 these factors may impact their designs of technology-enhanced learning.

Furthermore, as shown in Figure 4, a constructivist orientation toward the development of TPACK encompasses an understanding of students' misconceptions and learning difficulties, as well as an understanding of teachers' difficulties in

making the specific content teachable. Teachers' difficulties can be attributed to the use of non-optimal content transformations and consequently to the use of ineffective pedagogical or instructional strategies. For example, elementary school students hold different misconceptions and alternative conceptions about light and color (Valanides & Angeli, 2008b). Specifically, they believe that color constitutes an exclusive property of an object and thus it remains unchanged, and that when colored light illuminates a colored object the color of the light mixes with that of the object. These misconceptions can be attributed to the fact that light phenomena cannot be experienced directly since light travels from one point to another invisibly, and thus 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 augment students' conceptual understanding about light and color. Therefore, TPCK cannot be developed in isolation of learners' content-related difficulties, because TPCK competencies become most pertinent and essential in those cases where certain problematic instructional situations can only be handled most effectively with the involvement of technology.

After selecting an appropriate topic to be taught with the help of technology, teachers need to be explicitly taught how tool affordances can be used to transform content into powerful pedagogical forms. Mapping tool affordances onto content and pedagogy is at the heart of the TM approach. Mapping refers to the process of establishing a connection between 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, but always in relation to the actor and therefore dependent on their capabilities. For instance, a set of steps which rises four feet high does not afford the act of climbing if the actor is a crawling 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:

"...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 he [Norman] defines an affordance as something of both actual and perceived properties. The affordance of a ball is both, 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).

In accordance with Norman's conceptualization of the notion of affordance, TM maintains that in view of the fact that software affordance emerges 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 between software affordances, content, and pedagogy explicit to teachers. This recommendation is supported by the empirical data presented in Table 1. Forty-five dyads of pre-service teachers were asked, 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 pedagogy (Authors, in press). Since there was a considerable overlap among the tables the 45 dyads prepared, here we present only the tables prepared by three dyads. It is evident from the data presented in Table 1 that teachers' conceptions of the program's affordances varied in terms of not only the actual affordances themselves, but also in terms of teachers' perceived connections of the affordances with content transformations and pedagogy. These data support the view that 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.

**---Insert Table 1 about here---**

An elaborated account of how the connections between software affordances and 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 detailed the connections can be made. According to Angeli and Valanides (2004, 2005), Angeli (2005), and Valanides and Angeli (2008a, 2008b, 2008c, 2006), 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 and for what purposes. 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 technology 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 (Angeli & Valanides, 2008a).

**---Insert Table 2 about here---**

## **6. Assessing TPCK**

The assessment of TPCK as a complex learning outcome necessarily requires new ways of thinking about how to assess learning-in-progress as learners advance from novice to expert thinking about technology integration. Alternative forms of assessment must depart significantly from older conceptions of assessment with a focus on grades. As Black and William (1998) argue, 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) states: "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).

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. Additionally, in face to face environments it becomes complicated to manage and consider multiple sources of assessment information that are necessary in order to allow students to approach their learning progressively. For these reasons, it will be valuable to consider alternative ways for assessing student-centered authentic assessment using the affordances of electronic management learning environments that support synchronous and asynchronous communication among teachers and students beyond the walls and time constraints of the traditional classroom. It is therefore feasible to implement some components of authentic assessment in online learning environments so that students' 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 learning.

Figure 5 shows the conceptualization of design- and progress-based assessment of TPCK. The proposed model can be used to assess TPCK in face to face classrooms, however, due to the fact that it requires multiple sources of information it might be a challenge to assess systematically students' progress over time without using electronic means, such as for example asynchronous online discussion forums. As shown in Figure 5, design tasks are the focus of TPCK assessment, since the design of instruction is at the heart of TPCK knowledge and teacher knowledge in general. TPCK assessment involves assessment of students' performance on different design integrated in instruction throughout the entire learning process. For each design task, as shown in Figure 5, three forms of assessment coexist, namely, expert/teacher assessment, peer assessment, and self-assessment. Peer assessment can take place in an asynchronous computer-mediated communication environment for

continuous feedback. Expert- and peer-assessment occur in parallel. The expert/teacher and peers evaluate students' performance on the design task at hand using the same list of criteria as proposed by the expert/teacher. While the expert knows how peers evaluate each other, students do not know anything about the expert's opinion. Once the expert- and peer-assessments are completed, but without disclosure of the expert's opinion, the expert/teacher asks students to reflect on their individual performance and conduct a self-assessment taking into consideration the comments from their peers. After students complete their self-assessment, the expert/teacher discloses his or her own opinion to each student individually and discusses in class the strengths and weaknesses of the group's overall performance on the design task. A new cycle of assessment takes place for each new design task.

As mentioned above, the quality of students' performance on each design task is assessed using a list of criteria. Table 3 provides a detailed description of the criteria and specific examples for each criterion. As shown in Table 3, four indicators are used: (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 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, 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 by 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; and (d) 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.

## **7. Concluding Remarks**

The purpose of this article was to first raise several epistemological issues regarding the construct of TPCK for the purpose of clarifying it, and thereafter to discuss and propose models for its development and assessment. The transformative and integration views were used for exploring the construct of TPCK. The integrative view was rejected and the transformative view was adopted concluding that TPCK is a unique body of knowledge that is constructed from the interaction of its individual knowledge bases such as content, pedagogy, learners, context, and technology. It was emphasized that 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 the added value of technology.

Two models were then described for teaching and assessing TPCK. TM was proposed as an approach for understanding and promoting a constructivist methodology toward the development of TPCK, and three forms of assessment, namely, expert/teacher assessment, peer assessment, and self-assessment were proposed for assessing TPCK. At the heart of the three assessment forms is the assessment of students' performance on design tasks, and the repetitive nature of assessment for each new design task as learners progressively develop more sophisticated ways of thinking about how technology can support their teaching practices.

In conclusion, the development of TPCK is not an easy task and intensive systematic efforts need to be planned and implemented in order to extend teachers' knowledge base. We do hope that researchers 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 even improve the proposed framework for the development and assessment of TPCK will be of utmost importance to the research community.

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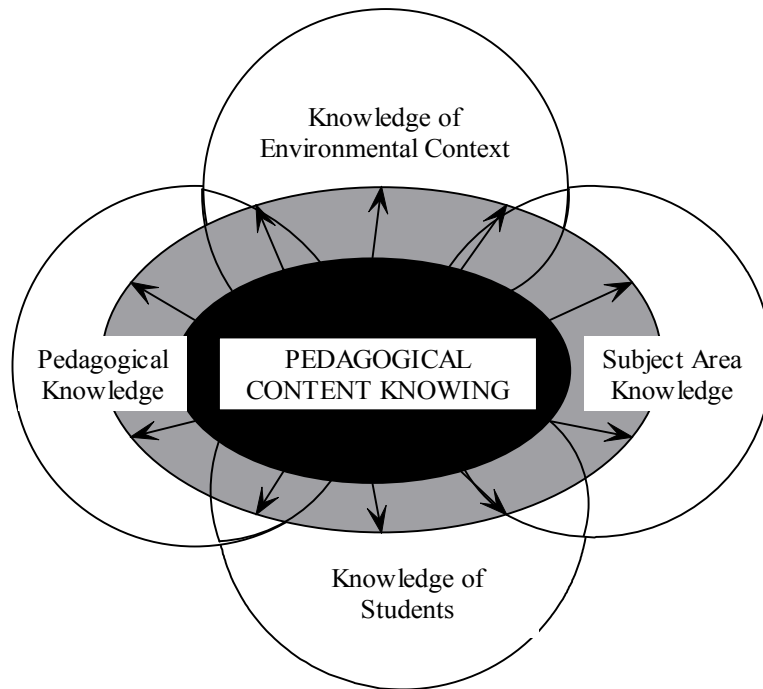
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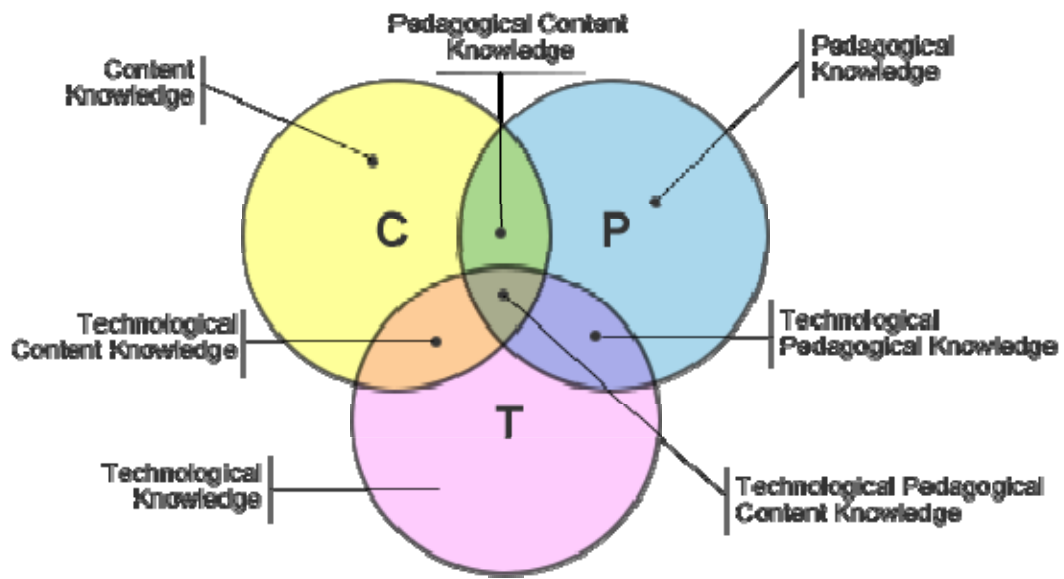
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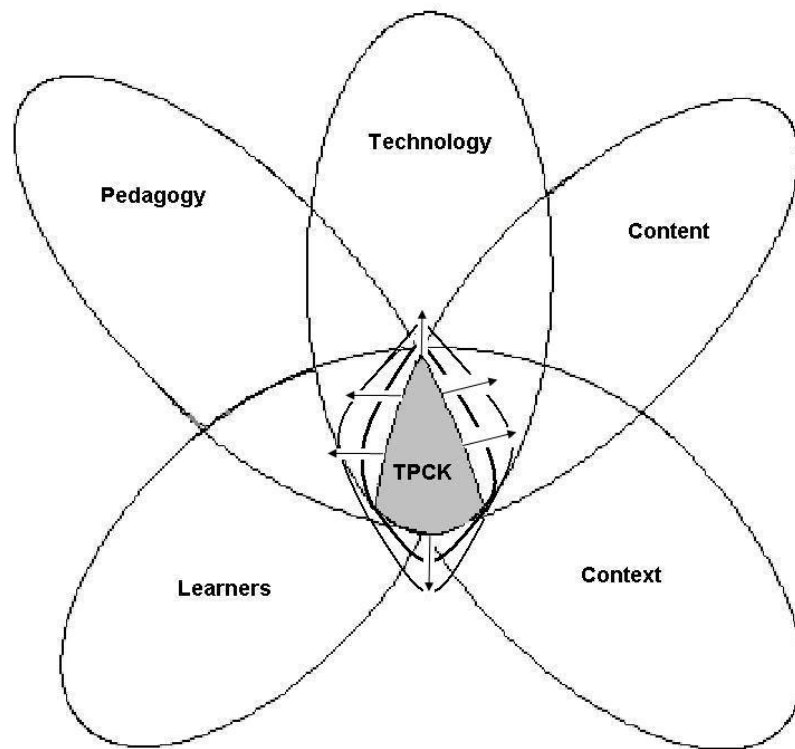
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**Figure 1. A Model of Pedagogical Content Knowing (PCKg) adopted from Cochran et al., (1993).**



**Figure 2. Technological Pedagogical Content Knowledge adopted from Kohler et al., (2007).**



**Figure 3. Technological Pedagogical Content Knowledge.**

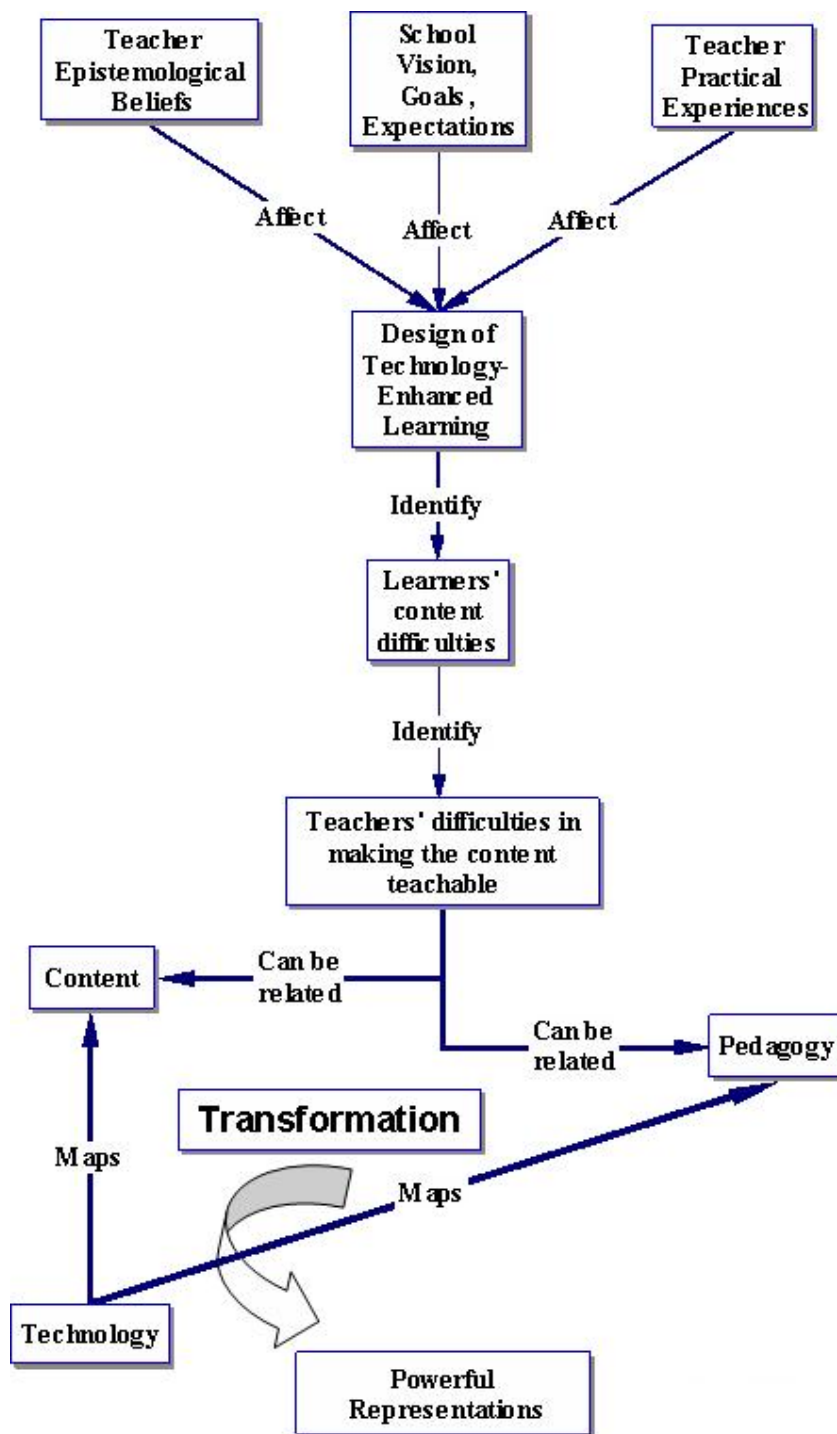


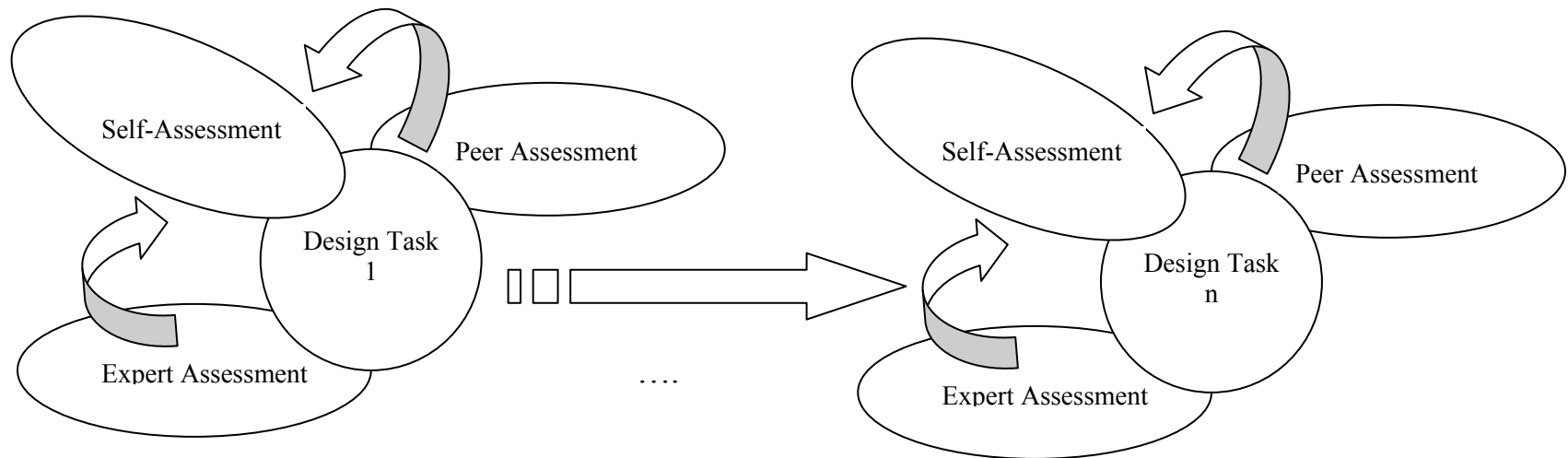
Figure 4. A design process for technology-enhanced learning.

**Table 1. Teachers' perceived connections between software affordances, content and pedagogy**

<b>Software affordance</b>	<b>Content transformation</b>	<b>Student-centered learning</b>
<b>Team I</b>		
1. Pictorial representations	X	X
2. Diagrammatic representations	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
<b>Team II</b>		
1. Pictorial representations	X	X
2. Diagrammatic representations		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	
<b>Team III</b>		
1. Pictorial representations	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. Diagrammatic representations	X	X

**Table 2. Mapping software affordances onto content and pedagogy**

<b>Software affordance</b>	<b>Content transformations</b>	<b>Pedagogical uses</b>
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.	Multiple representations of concepts (textual and pictorial representations at the same time)	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	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.



**Figure 5. A model for TPACK assessment.**

**Table 3. Criteria for assessing TPACK**

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.	<ul style="list-style-type: none"> <li>• Abstract concepts (i.e., cells in biology) that need to be visualized.</li> <li>• Phenomena from the physical and social sciences which consist of certain events and need to be animated (i.e., water cycle, immigration).</li> <li>• Complex systems (i.e., ecosystems, organizations) in which certain factors function systemically and need to be simulated or modeled.</li> <li>• Topics that require multimodal representations (i.e., textual, iconic, auditory) such as phonics and language learning.</li> </ul>
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.	<ul style="list-style-type: none"> <li>• Interactive representations.</li> <li>• Dynamic transformation of data.</li> <li>• Dynamic processing of data.</li> <li>• Multiple simultaneous representations of data.</li> <li>• Multimodal representations of data.</li> </ul>
3. Identification of teaching strategies, which are difficult or impossible to be implemented by traditional means.	<ul style="list-style-type: none"> <li>• Exploration and discovery in virtual worlds.</li> <li>• Virtual visits (i.e., virtual museums).</li> <li>• Testing of hypotheses and or application of ideas into contexts not possible to be experienced in real life.</li> <li>• Complex decision-making.</li> <li>• Long distance communication and collaboration with experts.</li> <li>• Long distance communication and collaboration with peers.</li> <li>• Personalized learning.</li> <li>• Adaptive learning.</li> </ul>
4. Identification of appropriate strategies for the infusion of technology in the classroom.	<ul style="list-style-type: none"> <li>• Any strategy that puts the learner at the center of the learning process.</li> </ul>