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# A Review of Technological Pedagogical Content Knowledge

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**ABSTRACT**

This paper reviews 74 journal papers that investigate ICT integration from the framework of technological pedagogical content knowledge (TPACK). The TPACK framework is an extension of the pedagogical content knowledge (Shulman, 1986). TPACK is the type of integrative and transformative knowledge teachers need for effective use of ICT in classrooms. As a framework for the design of teacher education programs, the TPACK framework addresses the problem arising from overemphasis on technological knowledge in many ICT courses that are conducted in isolation from teachers' subject matter learning and pedagogical training. The present review we have conducted indicates that TPACK is a burgeoning area of research with more application in the North American region. Studies conducted to date employed varied and sophisticated research methods and they have yielded positive results in enhancing teachers' capability to integrate ICT for instructional practice. However, there are still many potential gaps that the TPACK framework could be employed to facilitate deeper change in education. In particular, we suggest more development and research of technological environments base on TPACK; study of students' learning conception with technology; and cross fertilization of TPACK with other theoretical frameworks related to the study of technology integration.

**Keywords**

Technological pedagogical content knowledge (TPACK), ICT, teacher education

## Introduction

While ICT is becoming prevalent in schools, and children are increasingly growing up with ICT, teachers' use of ICT for teaching and learning continue to be a concern for educators (Jimoyiannis, 2010; Polly, Mims, Shepherd, & Inan, 2010). Integrating ICT into classroom teaching and learning continue to be a challenging tasks for many teachers (Shafer, 2008; So & Kim, 2009). Teachers feel inadequately prepared for subject-specific use of ICT and robust theoretical framework is lacking (Brush & Saye, 2009; Kramarski & Michalsky, 2010). To address the challenges, an important theoretical framework that has emerged recently to guide research in teachers' use of ICT is the technological pedagogical content knowledge (TPACK).

The notion of technological pedagogical content knowledge (TPACK) formally emerged in the literature of education journal in 2003 (Lundeberg, Bergland, Klyczek, & Hoffman, 2003). In 2005, several seminal articles appear concurrently (see Angeli & Valanides, 2005; Koehler & Mishra, 2005a; Niess, 2005). Originally given the acronym of TPCK, the acronym has recently been changed to TPACK for the ease of pronunciation (see Thompson & Mishra, 2007–2008). Since 2005, TPACK has been a burgeoning focus of research especially among teacher educators who are working or interested in the field of educational technology. To date, we have identified more than 80 journal articles written with reference to the TPACK framework. However, TPACK still needs to be further understood and developed into an actionable framework that can guide teachers' design of ICT interventions. This warrants a need to review and assess the directions of current TPACK research. This study therefore aims to consolidate the collective emerging trends, findings, and issues generated in TPACK research, and to identify its current gaps. It also proposes a revised TPACK framework to guide possible areas for future research that address the current research gaps.

## Method

### Identifying journal articles

The literatures were identified in May 2011 by first exploring the Web of Science database, follow by Scopus database. The keyword employed was "technological pedagogical content knowledge" and "TPACK OR TPCK." As a result, a total of 40 full articles were located. A further search was conducted using Education Research Complete and ERIC as databases in the EBSCOhost. The search yielded 75 journal articles. Combining the searches and eliminating duplicates, a total of 82 journal articles were collected. We removed 5 book reviews for the *Handbook of Technological Pedagogical Content Knowledge (TPCK) for Educators* (AACTE, 2008) and three position papers with one or two paragraphs advocating that the TPACK framework should guide future work in ICT integration. These position papers were assessed as not adding much to this area of study and were thus not included. The remaining 74 articles were read, analyzed and coded using a spreadsheet program.

## Coding scheme employed

The coding scheme were adapted from the structured/systemic approach to literature review as advocated by Lee, Wu and Tsai (2009; see also Tsai & Wen, 2005). For this review, four main categories were employed to allow the researchers to make sense of the articles. They are listed as follow:

- Basic data: authors, year of publication, journals, localities of study
- Research methods: research approach, method, theme, data collected, method of analyses, research outcomes
- Content analyses: technology, pedagogy, content area and the designed pathway (i.e., how the researchers/teacher educators design their program according to the TPACK framework)
- Discussion: issues discussed, future directions, personal comments

These four areas of coding allow the researchers to systematically study the emerging trends, issues and possible future research directions. The personal comments were memo of the researchers' emerging query and understanding about the literature. All codes were accepted based on consensus among the researchers and each paper was coded twice. As the codes are relatively objective, we do not have many disputes in reaching consensus. In the following sections, we will delimit the 7 dimensions of TPACK before we proceed to present the findings of the review.

## Delimiting TPACK and its constituents

TPACK refers to the synthesized form of knowledge for the purpose of integrating ICT/educational technology into classroom teaching and learning. The core constituents of TPACK are content knowledge (CK), pedagogical knowledge (PK), and the technological knowledge (TK). The interaction of these three basic forms of knowledge gives rise to pedagogical content knowledge (PCK), technological content knowledge (TCK), technological content knowledge (TPK) and the TPACK. As a form of knowledge, TPACK has been described as situated, complex, multifaceted, integrative and/or transformative (Angeli & Valanides, 2009; Harris et al., 2009; Koehler & Mishra, 2009; Manfra & Hammond, 2008). As a framework, it has been employed to unpack ICT-integrated lessons, teachers work with ICT, to design teacher education curriculum, to design classroom use of ICT and to frame literature review pertaining to ICT or educational technology (Polly et al., 2010). In essence, this is a powerful framework which has many potential generative uses in the research and development related to the use of ICT in education. Figure 1 below shows the diagrammatic depiction of the relations among the seven constructs.

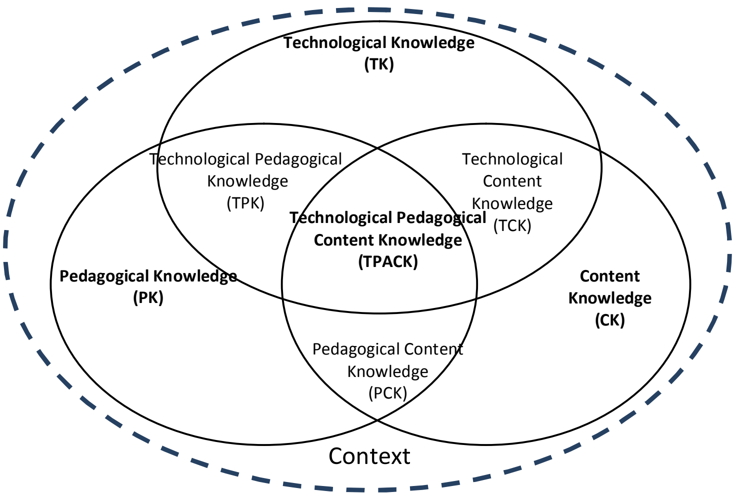



*Figure 1.* TPACK Framework (Koehler & Mishra, 2009; p. 63)

## Confusion about TPACK constructs

Due to the overlapping nature of the framework, concerns about the confusion among the constructs have been highlighted by researchers such as Cox and Graham (2009) and researchers interested in measuring teachers' self-reported perception of TPACK (Archambault & Barnett, 2010; Lee & Tsai, 2010). Cox and Graham (2009) emphasize the notion of independence when classifying the forms of knowledge. For example, when discussing knowledge pertaining to TPK such as the principles of the use of online forum for discussion, there should be no reference towards the subject matters (CK). Their suggestion seems very appropriate in helping researchers to delimit the constructs. Based on their suggestion, some loose use of terms in the literature can be detected. For example, Archambault and Barnett (2010) commented that two teachers interpret their item 1d "My ability to decide on the scope of concepts taught within my class" (p.1959) as pertaining to the PCK while they intended it to be representing CK. The item is unclear as content scoping may involve a pedagogical decision, which could be properly classified as PCK. Polly et al. (2010) consider "using technology to address specific academic standards" and the design of "technology-rich units" (p. 866) as work in the area of TCK. As academic standards are usually set for education purpose, they may be designed with implicit pedagogical intentions. In such cases, the materials should properly be classified as TPACK. On the other hand, while software such as Google Earth and SPSS can be undoubtedly classified as TCK since they are designed for general usage without consideration towards pedagogy, digitization of print based materials can hardly be classified under TCK as such digitization can be carried out for all content.

Other areas that may require some clarifications are in the areas of TK and TCK. While it is legitimate to include knowledge of operating overhead projectors and many other traditional forms of technology as technological knowledge (see Schmidt et al., 2009), in the context of TPACK research, it would only serve to cloud the focus. Confining the discussion of TK to skills and knowledge in using technologies associated with computers would be more appropriate and meaningful (see Cox & Graham, 2009).

Synthesizing from the literature we reviewed (Cox & Graham, 2009; Koehler & Mishra, 2009; Mishra & Koehler, 2006), Table 1 below attempts to provide the succinct definition of each construct accompany with some examples.

*Table 1.* Definition and examples of TPACK dimensions

| TPACK Constructs | Definition | Example |
|---|---|---|
| TK | Knowledge about how to use ICT hardware and software and associated peripherals | Knowledge about how to use Web 2.0 tools (e.g., Wiki, Blogs, Facebook) |
| PK | Knowledge about the students' learning, instructional methods, different educational theories, and learning assessment to teach a subject matter without references towards content | Knowledge about how to use problem-based learning (PBL) in teaching |
| CK | Knowledge of the subject matter without consideration about teaching the subject matter | Knowledge about Science or Mathematics subjects |
| PCK | Knowledge of representing content knowledge and adopting pedagogical strategies to make the specific content/topic more understandable for the learners | Knowledge of using analogies to teach electricity (see Shulman, 1986) |
| TPK | Knowledge of the existence and specifications of various technologies to enable teaching approaches without reference towards subject matter | The notion of Webquest, KBC, using ICT as cognitive tools, computer-supported collaborative learning |
| TCK | Knowledge about how to use technology to represent/research and create the content in different ways without consideration about teaching | Knowledge about online dictionary, SPSS, subject specific ICT tools e.g. Geometer's Sketchpad, topic specific simulation |
| TPACK | Knowledge of using various technologies to teach and/represent and/ facilitate knowledge creation of specific subject content | Knowledge about how to use Wiki as an communication tool to enhance collaborative learning in social science |

## Findings of this review

In the following sections, findings of this review are presented in three main sections according to the basic data analyses, research methods analyses, and content analyses. Findings from the analyses of discussion such as identified issues, gaps in research and insights that emerged are incorporated into the findings.

### Findings from the basic data analyses

*General publication trend*

Figure 2 below documents the growth of publication since the first article was published in 2003.

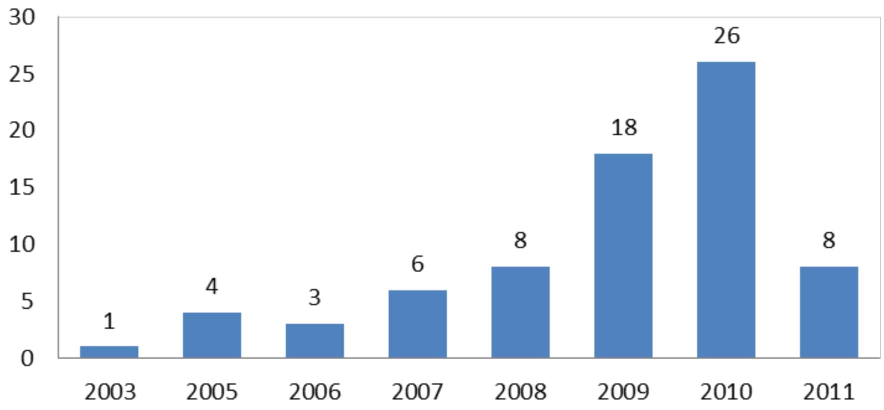



*Figure 2.* Growth of publication since 2003 to May 2011

The trend as reflected clearly indicates a growing interest in applying the framework. While at this point of time we cannot assess if the 2011 figure indicates a drop in publication in this area, we conjecture that the framework will continue to receive attention from educators. The integration of ICT into curriculum inevitably involves the three basic dimensions of TPACK, i.e., the TK, PK, and CK. It is difficult if not impossible to label a lesson as ICT integrated if any of the basic element is missing.

*Site of Studies*

In terms of the sites of study, most of the studies were conducted in the North America (65%, n = 49). The next region is from Europe and Mediterranean, accounting for 16.7% (Turkey, 4; Israel, 3; Cyprus, 2; Finland, Norway, Greece, Spain 1 each). The Asia Pacific region started to contribute to the literature in 2008 accounting for the rest (17.6%) of the contribution (Singapore, 5; Taiwan, 4; Australia, 3; Malaysia, 1). The figures suggest that many more studies can and perhaps should be carried out beyond the US. It is worth noting that theoretical papers have only been written by the US-based researchers. Researchers beyond US could perhaps contribute to theorizing the framework, based on the different cultural contexts and thus the experience in developing teachers for ICT integration. Currently, the TPACK framework is adopted in cross cultural context without questions.

*Types of journals*

To date, 44 journal titles published article employing the TPACK framework. Forty seven of the articles (64%) are published in educational technology journals (e.g., *Australasia Journal of Educational Technology, Computers & Education*). Eight articles (10.8%) are published in cross discipline journals (e.g., *Journal of Technology and Teacher Education, Journal of Science Education and Technology*). Seven articles (9.5%) are classified as published in subject based journals (e.g., *English Education, Journal of Geography*) , 6 in general pedagogy journals (e.g., *Instructional Science*), 4 in teacher education journals (e.g., *Teaching and Teacher Education*), and one in general education magazine (*California Readers*). This distribution indicates that the TPACK framework is more readily accepted by education technologists rather than content specialists. It further implies the need for education technologists to further publicize the frameworks among content specialists.

**Findings from the research method analyses**

Out of the 74 papers, 55 are data driven research while the other 19 papers are non-data driven. The nineteen papers are classified as theoretical paper (9), worked example (9) and an editorial paper. To qualify as data driven papers, the papers need to have an explicitly method section that addresses data collection and data analyses. We report the non-data driven papers below before findings about the data driven papers are reported.

*Theoretical papers*

The nine theoretical papers reviewed uniformly argued for relevance of TPACK as a guiding framework for teachers' acquisition of knowledge for ICT integration (Cox & Graham, 2009; Hammond & Manfra, 2009b; Harris, Mishra, & Koehler, 2009; Kereluik, Mishra, & Koehler, 2011; Koehler & Mishra, 2005b; 2009; Pierson & Borthwick, 2010; Robin, 2008; Swenson, Young, McGrail, Rozema & Whitin, 2006). Cox and Graham's (2009) paper deals with precising definitions of the TPACK constructs. The other 8 papers discussed how TPACK framework can be used to guide educators' effort in dealing with the challenges on teaching and learning that are brought forth by rapidly changing technologies. For example, Harris et al. (2009) suggested helping social studies teachers by providing 42 forms of activity type that could integrate ICT to enhance instruction. Kereluik et al. (2011) points out that teaching is complex problem solving while Koehler and Mishra (2005b) highlights TPACK as repurposing technology through teachers' design effort.

In his review of the AACTE (2008) handbook, Hewitt (2008) suggested that there is a lack of critical perspectives among the authors who have contributed. Similar remarks may be also appropriate for these theoretical papers as none of them reflexively challenges the TPACK framework. Perhaps the gaps for further theorizing may be found in the comprehensiveness of the framework or the contextual influences bearing on teachers' TPACK (see later section).

*Worked examples*

Other than the theoretical papers, there are 9 papers classified as worked examples. These papers report schools or the researchers' effort in applying the TPACK framework to structure learning in institutional settings (Brush & Saye, 2009; de Olvieria, 2010, Guerrero, 2010; Kersaint, 2007; Lambert & Sanchez, 2007, Lee & Hollebrands, 2008) or creating resources and examples for ICT integration (Bull, Hammond & Ferster, 2008; Harris et al., 2010; Toth, 2009). The last non-empirical paper is an editorial paper written by Bull et al. (2007). They discussed ICT integration as "wicked problems" and the needs for further research on effective ICT integration to subsequently inform teachers and policy makers. In sum, the publication of these papers indicates that educators perceive strong needs for the sharing of resources, examples, best practices and further studies for ICT integration. In the following section, we dwell more into depth on the data driven research.

*Data driven research*

Based mainly on the explicit classification of the research methods reported by the authors, the 55 data driven papers can be classified into 3 types of research approaches (31 qualitative, 13 quantitative, and 11 mixed approach papers) and 7 categories of research methods. The research methods and the number of studies include artifact evaluation (2), software development (1), case study (10), intervention study (32), document analysis (1), survey study (4), and instrument validation (5). Table 2 below provides a summary of these studies.

*Table 2.* Summary of empirical research papers

| References | Research method | Research approach | Theme of research |
|---|---|---|---|
| Oster-Levinz & Klieger, 2010; Valtonen, Kukkonen, & Wulff, 2006 | Artifact evaluation | Qualitative | Online courses website evaluation |
| Wu, Chen, Wang, & Su (2008) | Software development | Mixed | Development of game-based environment for computer engineering course |
| Doering & Veletsianos, 2008; Hammond & Manfra, 2009a; Manfra & Hammond, 2008; Schul, 2010a; Schul, 2010b | Case study | Qualitative | Students' perception and practice of learning with technology |
| Almas & Krumsvik, 2008; An & Shin, 2010; Hofer & Swan, 2008 | | | Teachers' perception and practice of teaching with ICT integration in classrooms |
| Wilson & Wright, 2010 | | | Teachers' development (5 years) of TPACK from preservice to inservice stage |
| Khan, 2011 | | Mixed | University teachers and students' perception of the pedagogical use of simulation for learning chemistry |
| Allan, Erickson, Brookhouse, & Johnson, 2010; Angeli & Valanides, 2009; Doering, Veletsianos, Scharber, & Miller, 2009; Hardy, 2010a, 2010b; Koehler & Mishra, 2005; Mishra & Koehler, 2006; Özmantar, Akkoç, Bingölbali, Demir, & Ergene, 2010; Tee & Lee, 2011 | Intervention studies | Mixed | Reports of courses designed to the improved teachers (pre-service, inservice, university faculty) TPACK. |
| Akkoç, 2011 ; Archambault, Wetzel, Foulger, & Williams, 2010; Bowers & Stephens, 2011; Groth, Spickler, Bergner & Bardzell, 2009; Haris & Hofer, 2011; Holmes, 2009; Jang, 2010; Jang & Chen, 2010; Koh & Divaharan, 2011; Lundeberg et al., (2003); Nicholas & Ng, 2010; Niess, 2005; Richardson, 2009; Shafer, 2008; So & Kim, 2009; Jimoyiannis, 2010 | | Qualitative | |
| Angeli & Valanides, 2005; Chai, Koh & Tsai, 2011a; Chai, Koh & Tsai, 2010; Graham et al., 2009; Koehler, Mishra & Yahya, 2007; Kramarski & Michalsky, 2010; Kramarski & Michalsky, 2009 | | Quantitative | |
| Lee & Tsai, 2010; Archambault, & Barnett, 2010; Koh, Chai & Tsai, 2010; Sahin, 2011; Schmidt et al., 2009 | Instrument validation | Quantitative | Creation of survey to measure the various TPACK dimensions |
| Greenhow, Dexter & Hughes, 2008 | Survey studies | Mixed | Survey of teachers' view and use of ICT with reference to TPACK constructs |
| Banas, 2010; Ozgun-Koca, 2009 | | Qualitative | |
| Jamieson-Proctor, Finger, & Albion, 2010 | | Quantitative | |
| Polly et al., 2010 | Document analysis | Qualitative | Review of PT3 project reports and journal papers |

*Artifacts evaluation*

Valtonen, Kukkonen, and Wulff (2006) evaluated 13 high school teachers created online courses for virtual high school employing the TPACK framework, with focus towards Jonassen, Peck and Wilson (1999) meaningful learning framework. The online activities were classified according to the five aspects of the meaningful learning framework (active authentic, intentional, constructive and cooperative), for example completing drill-and-practice as a form of active learning (which is disputable from our perspective). The evaluation essentially mapped out the various forms of TPK of the online activities. Frequency of subject matter (CK) that employs online activities were then computed to reflect the forms of TPACK that teachers adopted. Their analysis indicates that the courses foregrounded active learning over the rest of the dimensions, and the courses are teacher centric in nature with drill-and-practice and self-assess assignment as the predominant online activities. Oster-Levinz and Klieger (2010) also reported that they have created an instrument based on the TPACK framework for the evaluation of online tasks and it was used to evaluate 53 online tasks. The quality of the PK and PCK reflected in the designed online task was assessed with three point scales (high, medium, low). For example, choosing appropriate representations of the curricular is an indicator for assessing the PCK.

Efforts in developing of rubrics for assessing the quality of instruction according to the various TPACK constructs may be a meaningful area of study. It offers a comprehensive ways of evaluating designed ICT integrated lessons, thereby helping educators to identify weaknesses and strengthen course design.

*Software development*

The TPACK framework can be a powerful framework for software development but it has thus far been only reported once. Wu, Chen, Wang, and Su (2008) developed a role-playing game-based learning environment for undergraduate computer majors and map out the features of the environment in relation to the TPACK framework. They also identified the difficulties that they faced in the all seven TPACK constructs and identified possible solutions to address the problems. For example, based on literature review, they selected role playing as the appropriate pedagogy (PK) for learning of software engineering curriculum. They then identified the difficulties that they faced as articulating the details of professional skills involved for all the characters involved in the game, and they proposed to seek experts in the real world for help in this aspects. The designed environment was pilot tested with a group of 34 students and students' feedback affirmed the usefulness of the designed gaming environment.

Wu et al.'s (2008) work provides an example of how the TPACK framework can be employed for the development of content-based technological environment that addresses identified pedagogical challenges. Design, development and evaluation of learning environments is an important area if technology is going to contribute more to education and the TPACK framework should be further exploited in this important area. Well-designed educational environment based on the TPACK framework could reduce the effort teachers need to integrate ICT. Emerging technologies that have been advocated as pedagogically powerful include mobile technologies, multi-touch collaborative software, multi-users virtual environment etc. The TPACK framework could be employed to steer and enhance these learning environments.

*Case studies of students and teachers' practices and perception*

As shown in Table 2, there are 9 case studies reported to date. The themes of research cover mainly teachers' and students' perception and practice of teaching and learning given some forms of technological tools (e.g., movie makers) or environment (e.g., simulation or 1-1 laptop). These case studies were conducted in real world setting, thus providing the readers a sense of how TPACK are enacted and the perceptions of the teachers and learners. The five studies reporting students' perception contribute to educators' understanding of the effects of TPACK on students (Hammond & Manfra, 2009a; Khan, 2011; Manfra & Hammond, 2008; Schul, 2010a, 2010b). Hammond and Manfra interviewed students after they have completed their digital documentary making for history. They reported that students' prior conception of technology and their preferences influences their experiences. For example, some students viewed PrimaryAccess (the software for creating digital documentary) as not so useable and inflexible and some students disliked recording their own voices. In addition, the digital documentaries produced mimic authoritative sources of information such as the textbook and teachers' presentation, implicitly reflecting the students' conception of learning history as reproducing accurate information. The study points to the importance of understanding students' perspectives.

When teachers are able to design TPACK integrated lesson, students learning could be enhanced. Khan (2011) reported that the students view simulation software (TCK) as effective in helping them to understand Chemistry after they went through 11 cycles of generate-evaluate-modify (a form of PCK instructed by the teacher) relationships between variables. Doering and Veletsianos (2008) also reported that students who learn Geography using geospatial technology and real time authentic data provided by scientist station in the Artic develop a better "sense of place." On the other hand, Schul (2010a; 2010b) utilize both the Cultural Historical Activity Theory (CHAT) and the TPACK framework to study how TPACK activities evolve over time and shape the students' learning practices. He asserts that the two studies show that students are developing empathy for history and are acting like historian. The approach of utilizing CHAT and TPACK can be expanded to study how teachers' TPACK shape the classroom activities and impact on other activity systems within the schools; and how such reciprocal interactions play out socio-historically over time.

Interestingly, except for Khan's (2011) study that was focused on undergraduate chemistry students, students' learning was investigated mainly by researchers in the field of social studies (history, geography). More investigations about students' learning in general and for specific content areas such as mathematics and language art are needed. Asian students' perception of learning with technology could be another area worth exploring. In addition, current investigations of students' learning are qualitative in nature. Quantitative research especially in terms of students' learning processes and achievements should be conducted.

With regards to the teachers' perception and practices about the use of ICT for teaching, Almas and Krumsvik's (2008) findings indicate that while the two teachers they observed and interviewed see ICT as integral to their work especially for administration, their teaching practices did not change much. ICT was used to support teacher lectures and students' homework. The teachers' TPACK is emerging but national examinations are still their key concerns. Manfra and Hammond (2008) studied how teachers' pedagogical aims influence their practices and students' learning practices as reflected in their final products. They reported that one of the teachers adopted traditional stance and the students' learning practice are closely aligned to reproductive learning. For the other teachers who are more constructivist oriented, the students exhibited more sense making and creativity in their work.

In other words, there is a need to distinguish TPACK that is teacher-centric or student-centric. These studies (Almas & Krumsvik, 2008; Khan, 2011; Manfra & Hammond, 2008) reveal that teachers' pedagogical beliefs, facilitation and technological skills are important factors that influence the enacted TPACK in classroom, which subsequently shape students' practice and perception. The teachers' pedagogical beliefs and skills can be classified as intra-mental factors while examination requirements, time constraints and technological environments can be seen as institutional and physical factors (see also An & Shin, 2010). The TPACK models may need to be expanded (see last section) in order to explain the types of ICT integration practices enacted in the classrooms. In addition, more studies on how teachers' belief shape their TPACK and classroom practices are needed to clarify the relationships between beliefs, knowledge and skills, and contextual affordances and constraints. Ethnographical research, which has not been employed to date, could provide important insights needed to unpack the complexities involved.

*Intervention studies*

There are 32 intervention studies that examine course effectiveness and these studies employ the TPACK framework to structure professional development programs for pre-service (17 studies), in-service (10 studies) and/or higher education teachers (5 studies). Among these studies, seven were classified by the respective authors as case studies. In addition, five were categorized as design-based research by the authors (Angeli & Valanides, 2005; Bowers & Stephens, 2011; Mishra & Koehler, 2006; Tee & Lee, 2011; Shafer, 2008). However, as the purpose of these studies was oriented toward course effectiveness; we believe it is clearer for them to be categorized as intervention studies. It is worth noting at this point that the in-service and higher education studies normally involved small number of participants (around 20) and therefore they employed mainly qualitative (12) or mixed methods (3). It seems desirable to have large scale quantitative study among in-service teachers. In addition, while preschool and other more specialized education teachers may also be using ICT, we did not find any study conducted for these teachers.

The design-based research involves iterative design of the learning environment which is informed by the implementation and analyses from authentic classroom context. It is intervention by nature but it does not treat the effects as summative (Angelia & Valanides, 2005). On the whole, they are rigorous and they provided strong evidences of the effectiveness of the TPACK framework. For example, Mishra and Koehler (2006) reported six case studies that allow them to iteratively design and study how graduate students (mostly inservice teachers) and faculties, who were involved in collaborative design of online courses or other technology-based learning environment, were able to deepen their understanding of technology, pedagogy and content and also the overlapping areas (i.e. TCK, TPK, PCK and TPACK). Their study affirmed the fruitfulness of the TPACK framework. Angeli and Valanides (2005) reported three cycles of intervention employing different pedagogical approaches (case-based learning and an instructional design model based on ICT-related PCK); to enhance teachers TPACK. The pre-service teachers were assessed based on their ability to identify a) topics to be taught with ICT; b) representation to transform content; c) teaching strategies and d) to infuse ICT activities in classroom teaching. The results showed that the ICT-related PCK model was superior.

Except for Lundeberg et al. (2003) who employed action research to help pre-service science teachers to learn about the use of simulation; and Doering et al. (2009) who trained 20 teachers through workshop on how to use the GeoThentic environment, all intervention studies required the teachers to plan or design lessons for ICT integration as an important part of the course. This approach has been generally referred to as learning by design (see Koehler & Mishra, 2005b; 2009). Lundeberg's study was conducted before the learning by design approach was publicized. The GeoThentic environment, on the other hand, is a well-designed 3D environment that could be used directly without much additional design effort from the teachers. Regardless of the approach for the intervention studies, 28 out of these 32 studies reported positive outcomes and while 4 reported mixed outcomes. Among the studies that reported positive outcomes, some also reported achieving good effect sizes (Chai et al., 2010; Chai et al., 2011a; Kramarski & Michalsky, 2010; Tee & Lee, 2011). Together, these studies which involve different research approaches provide firm foundation for the effectiveness of engaging teachers in learning by design, undergirded by the TPACK framework.

More recent intervention studies have identified additional factors and issues associated with facilitating teachers' development of TPACK. Kramarski and Michalsky (2009, 2010) highlighted the metacognitive demands of design work, specifically in terms of self-regulation. They therefore created question prompts supporting the various aspects of self-regulation. The studies conducted indicate that it is important to provide metacognitive support to pre-service teachers when they are tasked to design ICT lessons. Tee and Lee (2011), on the other hand, employed the SECI (Socialization, Externalization, Combination, Internalization) model to structure a master course to develop teachers' TPACK. The SECI model is based on the knowledge spiral framework (Nonaka & Takeuchi, 1995), which is a model of knowledge creation. In other words, Tee and Lee (2011) see TPACK development as a form of knowledge creation within the teachers' professional community. The SECI model points to the importance of community and the social dimensions of knowledge creation. Similar recognition and utilization of community's resources is also an implicit feature of a number of intervention studies (e.g. Chai et al., 2011a; Mishra & Koehler, 2006; Koehler et al., 2007). It seems that research in TPACK can be further expanded from the perspective of knowledge creation. Paavola, Lipponen, and Hakkarainen (2004) highlighted three models of knowledge creation, of which CHAT (see Schul, 2010a, b) and knowledge spiral have been employed in relation to TPACK research. Perhaps the knowledge building model could also be applied to enhance teachers' TPACK by helping teachers to build theories about ICT integration.

The four intervention studies which reported mixed results (Groth et al., 2009; Nicholas & Ng, 2010; Niess, 2005; So & Kim, 2009) point to other factors that need to be considered to facilitate deeper and wider integration of ICT in classrooms. For example, two out of five teachers from Niess (2005) study expressed doubts in the usefulness of technology in facilitating students' learning even though the yearlong program provided multiple opportunities and formal lessons on the use of ICT. So and Kim (2009) detected gaps between knowledge, beliefs and action related to ICT among Singaporean pre-service teachers. While the pre-service teachers demonstrate good understanding of problem-based pedagogy and have adequate ICT skills, they perceived difficulties in designing authentic and engaging problems and appropriate scaffolds for their subject matter. They also tend to think that using problem-based learning with ICT are too time consuming. With such perception, the teachers may not be willing to design and implement ICT-based problem-based pedagogy. Their study again reinforces our earlier suggestion about the importance of teachers' beliefs, competencies and context. In sum, enhancing teachers' TPACK is a necessary but insufficient condition for widespread pedagogical use of ICT. The intrapersonal factors such as teachers' beliefs and their creative capacity in designing appropriate problems or scenarios need to be addressed. Institutional problems that surface in these studies include insufficient curriculum time, time for planning and examination constraints (Groth et al., 2009; Haris & Hofer, 2011; Nicholas & Ng, 2010). While the TPACK framework seems to provide some solutions, perhaps additional effort should be devoted in helping the teachers to deal with contextual constraints and addressing their beliefs.

Beside both intra-and-extra personal contextual that may need attention, the epistemic nature of learning by design also require further consideration. Engaging teachers in learning by design helps to move teachers away from traditional epistemology which is primarily concern with true/false values of knowledge claims. Learning by design promotes designerly ways of thinking (Cross, 2007), solving wicked problems through the criteria of satisficing. We argue that it is very important for teachers to be experienced in this form of thinking. Designing a new way of learning with technology is essentially a form of contextualized knowledge creation. It may open up teachers' perspective on what teaching and learning should be and what knowledge creation is about; beyond the view that creating knowledge refers exclusively to establishing truth claims. Equip with both traditional and design epistemology, teachers would be able to better engage students to learn with technology. How teachers' experience of "learning by design" changes their epistemological and/or pedagogical beliefs and practices in classroom could be the focus of future research. In addition, while current studies indicate engaging teachers in learning by design is fruitful, it may not be sufficient in providing evidence about the level of design expertise that teachers' acquire. What level of design expertise should teachers attain if they are to be able to continuously renew teaching practices as new pedagogical affordances emerge with new technologies? The intervention studies reviewed in this paper typically involve a single course in engaging teachers to learn by design. Such single pass approach may be insufficient. Weaving multiple courses to reinforce and strengthen teachers' design competencies is likely to be more fruitful.

### *Document analysis*

There is only one document analysis that employed the TPACK framework. Polly et al. (2010) analyze 26 "Preparing Tomorrow teachers to teach with technology (PT3)" reports together with 10 journal articles published based on PT3. Their general conclusion support the foregoing section in that they also found that most intervention produced positive outcomes, especially for TK and pre-service teachers' willingness to use ICT. As illustrated by their work, the TPACK framework can be a common conceptual framework for many more review studies. For example, one can employ the TPACK framework to study how medical educators employ ICT for teaching and learning of pathology. In addition, we suggest that TPACK could also be used to analyze policy documents to examine whether there is a shift towards the use of overlapping constructs such as TPK, TCK and TPACK to formulate policies or standards, which could reflect a deeper understanding among policy makers.

### *Survey studies*

To date, there are 4 survey studies that claim to employ the TPACK framework. Jamieson-Proctor et al. (2010) surveyed 345 Australian pre-service teachers with 2 scales (Learning with ICT, 20 items; Technological Knowledge 25 items). The findings indicate that while access to computers and Internet were very high, about 33% of the teachers indicate that they are not confident in using ICT in classroom. The survey also indicates low competence in web page development and multimedia authoring among pre-service teachers. Banas (2010) coded 225 reflective essays written by in-service teachers on their attitude towards technology. Only 13% of the teachers were facilitating students learning *with* technology. The majority of teachers were getting students to learn *from* technology. The necessity of enhancing teachers' TPACK knowledge for more adventurous learning seems obvious. Ozgun-Koca (2009) obtained open-ended survey responses and conducted group interview with 27 Turkish pre-service teachers with regards to the role of graphing calculator. While about 88% of the teachers indicated that using the graphing calculator save time, most teachers did not elaborate much on doing more interpretive work or building deeper conceptual understanding with the saved time. In addition, only one third of the pre-service teachers indicated using the graphing calculator as discovery tool. Greenhow et al. (2008) compare the differences between in-service and pre-service teachers' thinking about ICT integration problem elicited through online multimedia problem solving scenarios. As expected, in-service and pre-service teachers are different with regards to the process and the content of their instructional decision. The pre-service teachers are more superficial and uncritical as compared to their counterparts. However, both groups lack consideration about the relative advantage/disadvantages between different options of ICT tools.

In sum, these studies point to the need of helping pre- and in-service teachers to build deeper understanding about TPACK, especially for constructivist-oriented student centered learning where technologies are employed to scaffold sense making. We would argue that more surveys that compare pre- and in-service teachers TPACK could be helpful in identifying the gaps in their TPACK and teacher educators can then plan how to support the continuous development of TPACK. In addition, survey studies of other educators beyond K-12 in higher education setting should be carried out to understand their notion of TPACK. This is especially so for the faculties in higher education as they are likely to be the most important people to help form the pre-service teachers' TPACK.

*Instrument validation*

Five studies have been written on the creation and validation of self-report surveys. The first reported 7-factors survey was created by Schmidt et al. (2009), assessing primary school teachers' TPACK in different subject areas. Schmidt et al. analyzed the 7 factors individually, perhaps because of the small sample size (N = 124). Sahin (2011) also created a 7 factors survey and analyzed the factors individually (N = 348). Both surveys reported good reliability coefficients. However, they cannot be considered as fully validated.

Lee and Tsai (2010) and Archambault and Barnett (2010) have both created surveys to measure teachers TPACK related constructs with reference to web-based environment. Archambault and Barnett created a 7 factors 24 items survey and obtained responses from 596 K-12 American teachers involved in online teaching. Factor analyses yielded a 3 factors instead of 7. The non-technology constructs (CK, PK and PCK) loaded as one factor, while 3 technology-related constructs (TPK, TCK, and TPCK) formed the other factor. Items from TK form the last factor.

Lee and Tsai (2010) created a 6 factors 30-items survey to study Taiwanese teachers' self-efficacy of web-based TPACK (N = 558). The 6 factors are web-general, web-communicative, web-pedagogical knowledge, web-content knowledge, web-pedagogical-content knowledge, and attitudes towards web-based instruction. They obtained five factors after factor analysis, with web-pedagogical-content knowledge and web-pedagogical knowledge and combined into one factor.

Similarly, Koh et al.'s (2010) attempt to factor analyzed the adapted Schmidt et al.'s (2009) survey among Singaporean preservice teachers (N = 1185) also faced problems. Exploratory factor analysis generated five factors labeled as TK, CK, Knowledge of teaching with technology (KTT), Knowledge of Pedagogy (KP), and knowledge from critical reflection (KCR). KTT comprises items from TCK, TPK and TPACK. KP comprises of items from PK and PCK. The three studies to date indicate that items belonging to technology-related factors tended to group together while non-technology related pedagogical items formed another group. They also indicate that teachers are not quite able to distinguish the 7 factors of TPACK.

It is obvious further work in designing valid instrument is necessary. This work would allow educators to understand and compare teachers' TPACK employing demographic variables such as teaching experience, content areas, gender etc. To this end, Chai, Koh and Tsai (2011b) have been able to design a survey and identify all seven factors through exploratory and confirmatory factor analyses for Singaporean pre-service teachers. The questionnaire they created were contextualized towards constructivist pedagogy (PK), and constructivist used of ICT. Further adaption of this survey or the creation of new surveys that are contextualized towards specific subject matter, pedagogy and technology is an important area for future research in TPACK. For example, survey can be created for problem-based learning (PK) supported by simulation (TK) for Earth Science (CK). Such specific instrument can allow the researchers to have more confidence in measuring the contextualized TPACK constructs and it may be easier to identify the 7 factors. They also provide more specific information for course design and evaluation.

**Findings from content analysis**

This study also analyzed the articles based on the three foundational dimensions of TPACK framework: The content, technology and pedagogy. As some papers do not make clear reference to technology, pedagogy and subject matter, which make it impossible to see how TPACK or ICT integration is formed, papers that do not address any one of the three TPACK aspects are excluded in this part of analysis. In addition, the subject matter for pre/in-service teachers who are in courses that prepare them to use ICT are lumped under instructional technologies. Instructional technologies or educational technology is an established discipline and therefore should be treated as one. Based on these criteria, 54 studies were analyzed and the outcomes are provided below. Table 3 provides a summary of the content analysis.

*Table 3.* Content analyses of content, pedagogy and technology

| Reference | Pedagogical Approach | Subject domain (number of studies) | Technology |
|---|---|---|---|
| Nicholas & Ng, 2010 | Constructivist | Engineering (2) | Picaxe microchips programming |
| Wu, Chen, Wang, & Su (2008) | | | Game-based software engineering education system |
| Doering & Veletsianos, 2008 | | Geography (2) | Geospatial software |
| Doering, Veletsianos, Scharber, & Miller, 2009 | | | Geothentic online system |
| Niess, 2005 | | Instructional Technology (17) | Multiple ICT tools |
| Kramarski & Michalsky, 2010 | | | Hypermedia |
| Kramarski & Michalsky, 2009 | | | Web-based learning environment |
| Koh & Divaharan, 2011; | | | IWB (IWB) |
| Kereluik, Mishra & Koehler, 2011; Mishra & Koehler, 2006; Chai et al., 2010, 2011a; So & Kim, 2009; Tee & Lee, 2011; Angeli & Valanides, 2005, 2009; Koehler et al., 2007; de Oliveria, 2010 | | | Multiple ICT tools (e.g. Moodle, Office package, Wikipedia, Dreamweaver etc) |
| Archambault, Wetzel, Foulger, & Williams, 2010 | | | web 2.0; social networking tools |
| Koehler & Mishra, 2005a, 2005b | | | Web-based learning environment, I-video |
| Lambert & Sanchez, 2007 | | Interdisciplinary (3): Language art and social studies | Multiple ICT tools, e-mail and video conferencing |
| Hofer & Swan, 2008 | | Interdisciplinary: History and language art | Digital documentary making (i.e. digital movie maker I-movie/ photostory) |
| Robin, 2008 | | Interdisciplinary: History, language, 21st century skills | Digital story telling |
| Hardy, 2010a; 2010b | | Mathematics (12) | Tablet PC, Blackboard, PowerPoint presentation, Geo sketchpad, graphing, spreadsheet |
| Lee & Hollebrands, 2008 | | | Video case of using students using ICT tools for learning Mathematics |
| Richardson, 2009 | | | Virtual manipulative, graphing calculator, simulation software, GeoGebra. |
| Groth, Spickler, Bergner & Bardzell | | | graphing calculator |
| Holmes, 2009 | | | IWB |
| Bowers & Stephens, 2011; Shafer, 2008 | | | Geometer Sketchpad (GSP) |

| | | | |
|---|---|---|---|
| Kersiant, 2007 | | | Graphing calculator; applets |
| Guerrero, 2010 | | | GSP, Cabri Geometry etc |
| Özmantar, Akkoç, Bingölbali, Demir, & Ergene, 2010 | | | Graphic calculus |
| Akkoç, 2011 | | | Cabri Geometry and Geogebra |
| Jang & Chen, 2010 | | Science (8) | Multimedia authoring, presentation, social networking, collaboration, mapping, blog |
| Jimoyiannis, 2010 | | | Simulation, modelling tools, spreadsheet, Web resources, Web 2, LMS, Webquest |
| Graham et al., 2009 | | | Digital microscope, Google earth, GPS |
| Lundeberg, Bergland, Klyczek, & Hoffman (2003) | | | Simulation (Case It!), Web-based posters, conferencing tools |
| Khan, 2011; Toth, 2009 | | | Simulation, virtual laboratory |
| Jang, 2010 | | | IWB |
| Allan et al., 2010 | | | EcoScienceWorks, Simulation and programmable simulation |
| Haris & Hofer, 2011 | | Social studies (9) | Multiple ICT tools |
| Schul, 2010a; 2010b | | Social studies: history | Digital documentary making (photostory 3/ Imovie), online archives |
| Manfra & Hammond, 2008 | | | Digital documentary making: PrimaryAccess |
| Brush & Saye, 2009 | | | Multiple ICT tools, video case; Google earth overlay; blog, e-portfolio |
| Hammond & Manfra, 2009a | | | PrimaryAccess and/or PowerPoint presentation |
| Bull et al., 2008 | | | Web 2.0 tool: PrimaryAccess, digitize historical artifacts, online movie with PrimaryAccess |
| Hammond & Manfra, 2009a; Harris et al., 2009 | Mixed (Constructivist and traditional) | Social studies | Multiple ICT tools |
| Harris et al., 2010 | | Multiple subjects (1) | |

*The pedagogy employed or advocated*

The first common theme that emerges from the analysis is that out of the 54 papers, 51 can be described as advocating or practicing generally constructivist-oriented pedagogy. Project-based or inquiry-based learning were common among qualitative case studies that investigate students' perception reported earlier. Earlier section has also reported that most intervention studies adopted the learning by design approach, which is also essentially constructivist in nature. The three papers that presented both constructivist and traditional strategies are theoretical papers or worked examples (Hammond & Manfra, 2009b; Harris et al., 2009; Harris et al., 2010). Given the common pedagogical approach, the TPK involved would also be constructivist oriented. The common TPK is characterized by emphasis on bringing in authentic problems through technological representation (simulated environment, raw data, video-cases, etc.); engaging students in active sense making with the aid of technology as cognitive tools in collaborative groups. The emphasis of constructivist-oriented learning with technology is not surprising as constructivism forms a strong theoretical foundation for the use of technology (see for example Jonassen et al., 1999).

*The content knowledge*

Table 3 depicts the distribution of subject matter that the 54 papers were focused on. Not surprisingly, the biggest share of the studies is devoted to instructional technology (31%). TPACK was originated by teacher educators and instructional technology is the main course to help teachers in the use of ICT for classroom teaching. Science, mathematics and engineering, which can be considered as hard disciplines, together account for 41% of the distribution. Soft disciplines such as geography and social studies (6 of which are about history) combined with interdisciplinary studies occupied about 28% of the distribution. The distribution seems to reinforce the opinion that the use of technology is more akin to the mathematics and science subjects. Surprisingly, no study is targeted exclusively towards language learning and also literature. Interdisciplinary project-based learning that crosses the hard/soft discipline also seems rare. In addition, the TPACK framework has also not been employed in many more specialized subject matters such as economy, visual arts, music, accounting etc. More studies in these content areas are desirable.

*The technology involved in TPACK research*

The technologies reported in TPACK research can be generally classified into two categories: subject general technology corresponding to the TK dimension; and subject-specific technology corresponding more toward TCK. There are 34 studies that employed subject general technologies which can be used for many content areas such as web-based environments, learning management system, office tools, hypermedia authoring and interactive whiteboard (IWB). The 17 studies classified under instructional technology typically involved more than one form of these general technologies except for Koh and Divaharan (2011) that focused on IWB. One study that involved multiple subject matters (Harris et al., 2010) and three interdisciplinary studies (Hofer & Swan, 2008; Lambert & Sanchez, 2007; Robin, 2008) also employ general technologies. Social studies (9) constitute the next content area that employs general technologies. Five studies in this group focus on digital documentary making involving tools like photo-story, i-movie etc. especially for the study of history. Other subject-based TPACK studies that employ general technology include mathematics (2); and science (2). While technologies created for general purpose could be adapted for teaching and learning, these forms of technologies are demanding on teachers' design capacity to repurpose the tools.

For subject-specific technologies (i.e., TCK), a total of 20 studies were reported covering four areas. There are 10 studies that employ TCK in mathematics (Akkoç, 2011; Bowers & Stephens, 2011; Groth et al, 2009; Guerrero, 2010; Hardy, 2010a, 2010b; Kersaint, 2007; Özmantar et al., 2010; Richardson, 2009; Shafer, 2008). The mathematics-based technologies include Geometer Sketch Pad, graphing calculators, Cabri Geometry, GeoGebra and applets for simulation. For science subjects, there are 6 studies that employed simulations (Allan et al., 2010; Jimoyiannis, 2010; Khan, 2011; Lundeberg et al., 2003, Toth, 2009) and specialized technology such as digital microscope (Graham et al., 2009). Four other uses of TCK were reported for engineering course (Nicholas & Ng, 2010; Wu et al., 2008) and Geography (Doering & Veletsianos, 2008; Doering et al., 2009). Bowers and Stephens (2011) have rightly pointed out that TCK was less researched for TPACK framework. The analyses also show that TCK is more employed for hard disciplines. Given that technology are very important for the advanced study of almost all subjects, teachers in K-12 settings should be using more specialized form of technology in the near future. It may also be that when TCK is involved in teaching, the research is published in specialized journals and the researchers may be subject matter experts who are not familiar with the TPACK framework. Reviewing the use of TCK in specialized field of study from the TPACK framework could be an important step forward for the inclusion of these technologies into K-12 education.

*The possible pathways to foster TPACK*

Within this study, we attempted to analyze the sequence in which educators draw upon the aspects of TPACK to foster teachers or students' ability to teach or learn with ICT. Twenty nine out of the 55 data driven papers provide sufficiently clear information for us to map out the sequences that the authors employed. Among the 29 papers, 17 described engaging the teachers or learners starting from the overlapping aspects of TPACK such as PCK (7 papers), TPACK (5), TCK (4) and TPK (1 paper). The other paper started describing the intervention with CK (5), PK (4) and TK (3). After the starting point, diverse approaches are taken. For example, Harris et al. (2010) advocate that teachers begin with identifying activity types suitable for the learning of specific topics, which can be classified as PCK, and look for relevant technology to support the activity types. Jang (2010) describes beginning his intervention by discussing TPACK theories first, followed by identifying topics that traditional teaching were not effective (i.e., PCK) and understanding how IWB could help (TPK). Many PT3 projects (Polly et al., 2010) started with enhancing technological knowledge or providing technical skills training, follow up with discussion on how the technologies can be used in teaching and learning (TPK), transforming content into some digital forms of representation (TCK) and finally designing some projects for specific subject matter (TPACK). Two studies from Singapore (Chai et al., 2010; Chai et al., 2011a) started building pre-service teachers TPACK from pedagogical knowledge about the meaningful learning framework (see Jonassen et al., 2008); followed by how technology (TK/TCK) could enhance meaningful learning (TPK). The teachers then applied the knowledge to design a TPACK lesson for a specific topic (CK). Lastly, the two studies from Angeli and Valanides (2005; 2009) began by identifying topics (CK) for technology integration and proceed into the technology mapping processes where all constituents of the TPACK knowledge based are considered in a situated manner to transform the curriculum into TPACK units.

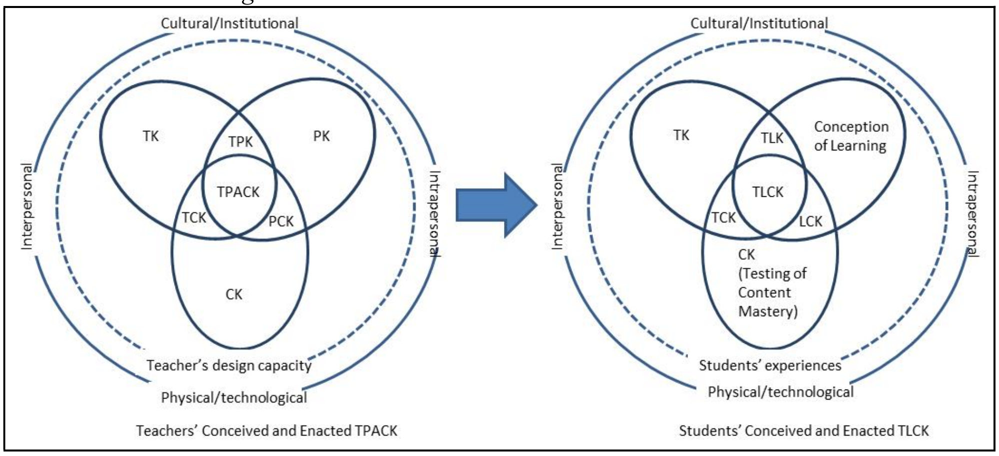
In short, there are diverse ways to employ the various aspects of TPACK to design ICT integrated lessons. Our analysis indicates that the sequence of drawing upon the TPACK aspects to finally build TPACK lessons are dependent on contextual factors such as the availability of technological solutions, the learners familiarity with the software and the instructors' pedagogical reasoning. As most studies yield positive results, it seems that sequence does not matter. However, interested researchers could perhaps conduct research to compare if different sequence of instruction drawing on different aspects of TPACK would result in different learning trajectories.

In addition, it seems to make sense to begin from one of the overlapping constructs such as PCK, which is the most common starting point, and proceed to other constructs. For example, Akkoç (2011) and Wu et al. (2008) both started by understanding students' difficulties in learning the subject matter (PCK) and seek technological representations (TCK) that could help to address students' problem. Doering and Veletsianos (2008) identified geospatial technology (TCK) and adopt appropriate constructivist-oriented pedagogy (PK) to enhance students' learning. Many simulation packages have the advantage of representing TCK and this make ICT integration less problematic. We would argue that the design of educational technologies that encompass all aspects of TPACK, i.e., TPACK ready, is essential in encouraging teachers to use ICT. While on the one hand it is essential to enhance teachers' competency to design TPACK lessons, it is unreasonable to expect teachers to spend much time on designing ICT integrated lesson.

## Concluding remarks

The TPACK framework is a generative framework with many more possible future applications. In this paper, we have reviewed a sizable and representative set of studies and pointed out many possible directions for future research. Based on our review, we would propose a revised representation of the TPACK framework to guide future research as depicted in Figure 3 below.

*Figure 3.* The revised TPACK with TLCK framework



The first revision we have made to the original conception is to make explicit the contextual factors that would influence the TPACK integrated lessons designed by educators. TPACK are highly situated form of designed knowledge and many researchers employing the TPACK framework are acutely aware of the importance of context in shaping the manifestation of TPACK in classrooms (e.g., Doering et al., 2009; Pierson & Borthwick, 2010). The contextual factors are elaborated below.

Based on the literature reviewed, we identified four interdependent contextual factors that are to a certain extent distinctive. The intrapersonal dimension of context refers to the epistemological and pedagogical beliefs that teachers hold. These beliefs have been identified as influencing teachers' instructional decision (e.g., Tsai, 2007). In the context of creating TPACK lessons, teachers have to assume the epistemic agency and appropriate "design literacy", which characterized by flexibility and creativity (Kereluik et al., 2011). Most of the time, however, teachers are more acquainted with being the authority in the classrooms who deals with verified knowledge. The epistemic roles involved are at odd with each other. For the interpersonal dimension, Koehler et al. (2007) study indicates its importance especially in terms of collaborative design. Given that design work is best carried out in group, the interpersonal dimension should be carefully considered. Cultural/Institutional factors such as the prevalent view of seeing schools as places for cultural reproduction and the emphasis on paper-and-pencil tests and examinations can be daunting barriers that exert strong influence on if and how teachers use technology (Almas & Krumsvik, 2008; Groth et al., 2009). Lastly, the physical/technological provision in schools obviously influences teachers' decisions. Polly et al. (2010) highlighted that insufficient provision may cause beginning teachers to regress towards not using technology. If the provision for the use of technology is not ubiquitous and teachers have to make special arrangement to use technology such as bring students to computer laboratories, the additional effort is likely to deter teachers' willingness when there exist simpler solution.

From students' perspective, how students' conceptions of learning are related to the way they use technology to learn specific CK could provide a check on the effects of teachers' TPACK implementation. Conceptions of learning refer to how students perceive or interpret their learning experiences toward specific CK (e.g., science, mathematics) or in certain contexts such as technology-enhanced learning environments (Marton, Dall'Alba, & Beaty 1993; Tsai et al., 2011). These conceptions are found to guide students' approaches to learning and are associated with learning outcomes (Bliuc et al., 2010, 2011; Yang & Tsai, 2010). We believe the TPACK research can be further enhanced by investigating more refined constructs, such as the extension of the ideas about conceptions of learning. We suggest to investigate how students' notion of learning of particular content (LCK corresponding to PCK), learning with technology (TLK corresponding to TPK), and technological content knowledge could help to inform teachers about what can or should be done in the classrooms. For example, students may have good understandings or conceptualizations about how some game-based learning could enhance and impede their learning (TLK). Teachers can draw on such notion and facilitate students learning with technology. In addition, if students' LCK formed through prolonged exposure to certain pedagogical practices, for example learning for tests, they may resist new pedagogy such as that involving knowledge co-construction (see for example Hammond & Manfra, 2009a). Similar to framework of TPACK, the ideas of TLCK (Technological Learning Content Knowledge) are proposed in this review. For successful implementation of ICT in teaching practice, in addition to teachers' thorough understandings toward TPACK, it also requires students' awareness of TLCK-related constructs (such as more sophisticated conceptions of learning, TLK, LCK and TLCK), as illustrated in Figure 3. Understanding students' perceptions in these areas would help teachers and designers to design better lessons and programs. More importantly, students' academic achievement given the TPACK integrated lessons has not been reported by any of the study we reviewed. This is a clear gap that needs attention. In addition, survey studies about students' perception of learning with technology could also provide important information to help ministry and schools in planning education programs.

Finally, we would like to point out the possibility of cross fertilizing some older framework for the study of ICT integration with the TPACK framework. Established framework such as the technology acceptance model, concern-based adoption model and the three models of knowledge creation(i.e. SECI, expansive learning and knowledge-building) as reviewed by Paavola et al., (2004) could be brought to bear on TPACK. For instance, researchers can possibly envision the acceptance of certain emerging technology by analyzing its TPACK properties and the possible stages of concern that would follow when the technology is implemented. The SECI, expansive learning and knowledge-building approach can also be synthesized to inform teachers on how new TPACK integrated lessons can be designed. More studies that meaningfully merges complimentary framework could be a promising way forward.

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