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Technological pedagogical content knowledge – a review of the literature

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Abstract Technological Pedagogical Content Knowledge (TPACK) has been introduced as a conceptual framework for the knowledge base teachers need to effectively teach with technology. The framework stems from the notion that technology integration in a specific educational context benefits from a careful alignment of content, pedagogy and the potential of technology, and that teachers who want to integrate technology in their teaching practice therefore need to be competent in all three domains. This study is a systematic literature review about TPACK of 55 peer-reviewed journal articles (and one book chapter), published between 2005 and 2011. The purpose of the review was to investigate the theoretical basis and the practical use of TPACK. Findings showed different understandings of TPACK and of technological knowledge. Implications of these different views impacted the way TPACK was measured. Notions about TPACK in subject domains were hardly found in the studies selected for this review. Teacher knowledge (TPACK) and beliefs about pedagogy and technology are intertwined. Both determine whether a teacher decides to teach with technology. Active involvement in (re)design and enactment of technology-enhanced lessons was found as a promising strategy for the development of TPACK in (student-)teachers. Future directions for research are discussed.

Keywords practicing teachers, strategies for technology integration, student teachers, teacher beliefs, technological knowledge, technological pedagogical content knowledge.

Introduction

In 2005, Koehler and Mishra (2005) introduced the term technological pedagogical content knowledge (TPCK) as a conceptual framework to describe the *knowledge base* for teachers to effectively teach with technology. Mishra and Koehler were not the first ones who used the term TPCK. Already in 2001, Pierson (2001) used the term to define a teacher's technology integration. Others used similar terms, such as information and communication technology (ICT)-related PCK (Angeli & Valanides 2005) or technology-enhanced PCK (Niess 2005). TPCK is derived from Shulman's (1986, 1987) well-known work on PCK. PCK is considered a unique feature that qualifies the teacher's profession: teachers are able to integrate domain knowledge with appropriate pedagogical approaches so that learners are able to understand the subject at stake. TPCK has a similar notion; it adds technological knowledge (TK) as an indispensable part of the teacher's profession.

Initially, TPCK had TPCK as acronym. In 2007, it was changed to Technology, Pedagogy, and Content Knowledge (TPACK). TPACK stands for Technology, Pedagogy, and Content Knowledge and was announced as the 'Total PACKage' for effectively teaching with technology (Thompson & Mishra 2007). According to

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the authors, TPACK better reflected the interdependence of the three contributing knowledge domains (i.e. content knowledge, pedagogical knowledge and TK), and it was easier to communicate than TPCK (Mishra, personal communication). In this review, we use both acronyms interchangeably because the change in terminology was not adopted by everyone. Since the introduction in 2005, the notion of TPACK has been rapidly extended across the fields of professional development and technology integration. The increasing number of studies that refers to TPACK calls for a systematic synthesis of both the evolution of TPACK as a concept and its practical applications. The purpose of the review therefore is to investigate the theoretical basis and the practical use of TPACK.

Methods

The search was conducted in four scientific databases (i.e. Education Resources Information Center (ERIC), Web of Science, Scopus and PsychINFO) and was limited to peer-reviewed articles published between 2005 and (September) 2011. In order to get a more comprehensive understanding of the theoretical underpinnings and the practical uses of TPACK, broad search terms were used, including 'TPCK', 'TPACK' and 'Technological Pedagogical Content Knowledge'. The initial search yielded 243 references. To be included in this study, the articles had to make an explicit contribution to (at least one of) the following domains: understanding and/or advancing the theoretical foundations of the TPACK framework; measuring TPACK; and/or developing (student-)teachers' TPACK. All abstracts were screened by two members of the research team. In case of doubts, the article was kept for full-text screening. This resulted in 93 articles. We had no full text access to nine articles. Full-text screening of the remaining 84 articles was carried out by two members of the research team using the same inclusion criteria. In case of doubts, a second opinion was asked from another member of the research team. From the full text screening, 61 articles remained for in-depth analysis. Of these articles, 11 studies addressed theoretical reflections on TPACK and 44 presented (also) empirical findings, mostly from small-scale studies. To ensure that the scientific evidence presented in the empirical studies ($N = 44$) suited the purpose of the review, articles on empirical studies were judged on the following quality criteria (Gough 2007):

- consistency: are research questions/purposes and data sources aligned?; are research questions and data analysis aligned?; are research questions answered by the data?
- data collection: are the instruments for data collection discussed?; are data collection procedures discussed?
- data analysis: are procedures for data analysis discussed?; are instrument reliabilities reported?

Based on these criteria, each article was labelled as having 'good quality' (scored 'yes' on all criteria), 'sufficient quality' (scored 'no/insufficient' on one or two criteria) or 'insufficient quality' (scored 'no/insufficient' on more than two criteria). Six articles had insufficient quality and were therefore excluded from the review. The remaining 55 articles (44 empirical and 11 theoretical) were used in this review. In addition to the articles, one article published in a book by Koehler and Mishra (2008) was included in the review because it provided an update of the authors' theoretical thinking about TPACK. A spreadsheet was used to analyse the articles and extract information about the characteristics of the study (e.g. research questions, type of the study, size of the study, target group, subject domain(s), data sources) and its contributions to understanding the theoretical basis and practical uses of TPACK (e.g. definition of TPACK, strategies to develop teachers' TPACK, instruments used to measure TPACK, etc.). All articles included in the study were analysed by at least two members of the research team and summarized in the spreadsheet. Differences were discussed until consensus was found. By connecting and contrasting the summaries, sub-themes were identified across studies. This resulted in the following elaborations of the main themes. The theoretical basis of TPACK was addressed in the following sub-themes: development of the concept, views on TK, development of TPACK as a concept in specific subject domains and TPACK and teacher beliefs. The practical uses of TPACK were represented by two sub-themes emerging from the analysis: measuring TPACK and strategies for developing (student-)teachers' TPACK. Then, the analysis of the articles (as presented in the spreadsheet) was read again by the first author to identify the specific contribution of the article to sub-theme(s) (Table 1). This resulted in the cross-article analysis, which was discussed until consensus was reached by the research team and presented in this review.

Table 1. Overview of the studies.

Authors	Study design	Development of the concept	Development of the TPACK concept (subject specific)	Views on technological knowledge	TPACK and teacher beliefs	Measuring (student-) teachers' TPACK	Strategies for developing (student-) teachers' TPACK
Abbitt 2011 (USA)	Survey			×	×		
An *et al*. 2011 (USA)	Evaluation study						×
Angeli and Valanides 2009 (Cyprus)	Quasi experimental	×		×		×	×
Archambault and Barnett 2010 (USA)	Instrument design	×				×	
Archambault and Crippen 2009 (USA)	Instrument design					×	
Archambault 2011 (USA)	Survey					×	
Blocher *et al*. 2011 (USA)	Quasi experimental						×
Bower *et al*. (2010) (Australia)	Theoretical study			×			×
Bowers and Stephens 2011 (USA)	Design research	×				×	
Chai *et al*. 2010 (Singapore)	Evaluation study					×	×
Chai *et al*. 2011 (Singapore)	Instrument design			×	×	×	×
Cox and Graham 2009 (USA)	Theoretical study	×		×			
Doering *et al*. 2009 (USA)	Evaluation study	×				×	×
Graham 2011 (USA)	Theoretical study	×					
Guerrero 2010 (USA)	Theoretical study		×				
Hammond and Manfra 2009 (USA)	Theoretical study		×	×			
Hardy 2010 (USA)	Evaluation study						×
Harris and Hofer 2011 (USA)	Case study						×
Harris *et al*. 2010 (USA)	Theoretical study		×				
Harris *et al*. 2009 (USA)	Theoretical study	×	×	×			
Hofer and Swan 2006 (USA)	Case study			×			
Hur 2010 (USA)	Evaluation study						×
Jamieson-Proctor *et al*. 2010 (Australia)	Survey			×			
Jang and Chen 2010 (USA)	Evaluation study						×
Jang 2011 (Taiwan)	Evaluation study						×
Jimoyiannis 2010 (Greece)	Evaluation study		×				×
Khan 2011 (Canada)	Case study		×				
Koehler and Mishra 2005 (USA)	Evaluation study	×		×		×	×
Koehler and Mishra 2008 (USA)	Theoretical study	×		×			×
Koehler and Mishra 2009 (USA)	Theoretical study	×		×			×
Koehler *et al*. 2007 (USA)	Case study	×		×		×	×
Koh and Divaharan 2011 (Singapore)	Evaluation study			×			×
Koh *et al*. 2010 (Singapore)	Survey					×	
Kramarski and Michalsky 2010 (USA)	Experimental design					×	×
Lee and Hollebrands 2008 (USA)	Quasi experimental						×
Lee and Tsai 2010 (Taiwan)	Survey			×		×	
Manfra and Hammond 2006 (USA)	Case study				×		
Mishra and Koehler 2006 (USA)	Theoretical study	×		×			×
Niess 2005 (USA)	Case study	×			×		×
Niess *et al*. 2010 (USA)	Evaluation study						×
Niess 2011 (USA)	Review	×					×
Niess *et al*. 2009 (USA)	Theoretical study		×				×
Özgün-Koca 2009 (USA)	Case study				×		
Özgün-Koca *et al* 2011 (USA)	Case study						×
Özgün-Koca *et al*. 2010 (USA)	Mixed methods			×			×
Özmantar *et al*. 2010 (Turkey)	Evaluation study						×
Polly 2011 (USA)	Case study			×			×
Polly *et al*. 2010a (USA)	Theoretical study			×			×
Polly, *et al*. 2010 (USA)	Evaluation study						×
Schmidt *et al*. 2009 (USA)	Instrument design			×		×	
Shafer 2008 (USA)	Case study			×			×
So and Kim 2009 (Singapore)	Evaluation study			×	×		×
Tee and Lee 2011 (Malaysia)	Design research						×
Trautmann and MaKinster 2010 (USA)	Mixed methods			×			×
Valtonen *et al*. 2006 (Finland)	Evaluation study				×		
Wetzel, *et al*. 2008 (USA)	Action research						×

Findings

Note that in the Appendix, the reference to all 56 studies can be found. In the findings section, we will use *italics* to refer to the studies used in this review.

The development of the concept

Fourteen studies from our database discuss the development of TPACK as a concept. Later, we used the chronology of these publications to analyse how this concept has evolved over time.

Following Pierson (2001), *Niess* (*2005*) used the term TPCK to refer to technology-enhanced PCK. She used the concept to study how a technology integration program impacted student-teachers' use of technology in their classroom practice. *Niess* (*2005*) did not consider TPCK as a new definition of teacher technology integration, as Pierson (2001) did, but described it as 'the integration of the development of knowledge of subject matter with the development of technology and of knowledge of teaching and learning' (p. 510). She argued that 'It is this integration of the different domains that supports teachers in teaching their subject matter with technology' (p. 510). Hence, rather than seeing TPCK as an end (Pierson 2001), *Niess* (*2005*) saw the integration of the three domains as a means for teaching with technology.

More or less at the same time, Koehler and Mishra (e.g. *Koehler & Mishra 2005*; *Mishra & Koehler 2006*) started to use TPCK as a conceptual framework. In their studies (*Koehler & Mishra 2005*; *Koehler et al. 2007*) on collaborative design of online courses by teacher education faculty and master students, they had observed that 'the participants developed through the experience a deeper understanding of the complex web of relationships between content, pedagogy and technology and the contexts in which they function' (*Koehler & Mishra 2005*, p. 149). Based on these studies, Mishra and Koehler presented TPCK as a conceptualization of the knowledge base teachers need to effectively teach with technology (cf. *Mishra & Koehler 2006*; *Koehler & Mishra 2008*). In contrast to *Niess* (*2005*), these authors did not present TPCK as an enhancement of PCK but as the development of understanding in three knowledge domains (content, pedagogy and technology) and their intersections [PCK, technological content knowledge, technological pedagogical knowledge (TPK) and TPCK]. However, it appeared difficult to reproduce these seven knowledge domains in exploratory factor analysis (EFA) (e.g. *Archambault & Barnett 2010*), indicating that the TPACK framework as conceptualized by Koehler and Mishra is problematic (*Cox & Graham 2009*; *Graham 2011*; *Niess 2011*). This is further addressed in the section about measuring TPACK.

Furthermore, Koehler and Mishra argued that teaching with technology does not take place in isolation but is situated (cf. *Koehler & Mishra 2008*). Teachers need to develop the flexibility to incorporate knowledge about students, the school, the available infrastructure and the environment in order to effectively teach with technology. Consequently they added context to the seven knowledge domains as an indispensable part of the TPACK framework. The TPACK framework (see Fig 1) as proposed by Koehler and Mishra (2008) has become well-known

Angeli and Valanides (*2009*) questioned the TPACK framework as proposed by Koehler and Mishra. They argued that TPCK as it is positioned in the framework can be considered either as a unique body of knowledge, depicted in the heart of the Venn diagram (i.e. a transformative view on TPCK) or as developing from the three contributing fields (i.e. an integrative view on TPCK). Contrary to Mishra and Koehler (e.g. *Mishra & Koehler 2006*), who suggested that growth in TPCK implies growth in the three knowledge domains, *Angeli and Valanides* (*2009*) claimed that TPCK is a distinct body of knowledge that can be developed and assessed on its own – and hence, advocated a transformative view on TPCK.

Cox and Graham (*2009*) emphasized the relationship between TPACK and PCK, thereby also questioning the TPACK framework as proposed by Koehler and Mishra. *Cox and Graham* (*2009*) provided two arguments to explain this relationship. First, they acknowledged that technology as such has always been part of Shulman's (1987) conception of PCK but argued that many new technologies (referred to as emerging technologies) are not transparent and ubiquitous and TPACK may help to better understand the potential contributions of the emerging technologies for education. They further claimed that as soon as a technology has become transparent and ubiquitous in educational practice, it becomes part of PCK, and therefore, they referred to TPACK as a sliding framework. Second,

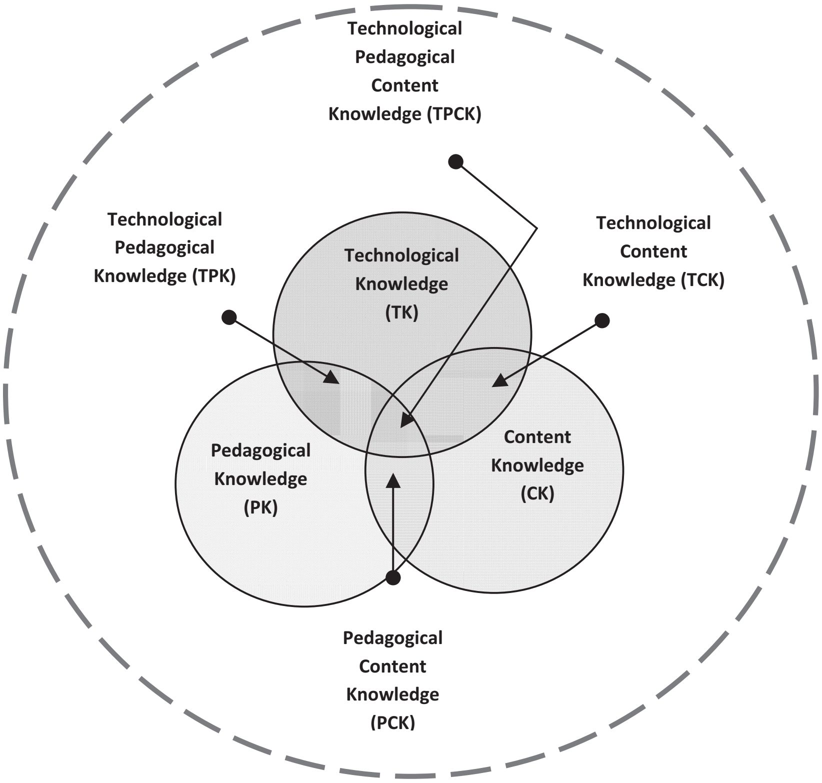

Fig 1 Technological pedagogical content knowledge framework (source Koehler & Mishra 2008).

they stressed the importance of domain knowledge based on the understanding that two key characteristics constitute PCK (Van Driel *et al*. 1998): knowledge of representations of domain knowledge; and understanding of specific learning difficulties and student conceptions related to the teaching of particular topics of the domain. For this reason, *Cox and Graham* (*2009*) defined TPACK as ‘teacher’s knowledge of how to coordinate subject- or topic-specific activities with topic-specific representations using emerging technologies to facilitate student learning’ (p. 64).

While *Cox and Graham* (*2009*) pointed to the dynamic nature of the TPACK framework, as a consequence of rapid changes in technology, *Doering et al*. (*2009*) explained the dynamic nature of the TPACK framework from the bidirectional relationship between knowledge and practice. These authors contended that context influences teacher knowledge and practice, thereby implying that the types of knowledge that a teacher uses in his or her teaching also depends on his or her knowledge of practice. In a similar vein, *Bowers and Stephens* (*2011*) argued that TPACK should be conceived as an orientation more than as a fixed knowledge base. From these perspectives, it is important to relate TPACK as the teachers’ knowledge base for teaching with technology to teacher’s pedagogical and technological beliefs (see also section about beliefs).

In summary: three views on TPCK have developed over time: T(PCK) as extended PCK (*Niess 2005*; *Cox & Graham 2009*); TPCK as a unique and distinct body of knowledge (*Angeli & Valanides 2009*); and TP(A)CK as the interplay between three domains of knowledge and their intersections and in a specific context (*Koehler & Mishra’s publications*). *Graham* (*2011*) discussed the implications of these different views of TPACK for theory development. *Niess* (*2011*) saw similarities with the development of PCK and argued that the different views help to get a more comprehensive understanding of TPACK.

Views on TK

Shulman’s notion of PCK included the appropriate use of technologies when teachers need to think about representations of the concept that is being taught to students (Shulman 1986). Nevertheless, Mishra and Koehler (e.g. *Koehler & Mishra 2008*) argued that because of the immersed role of technology in our society and the rapid changes in technology, there is a need to add technology knowledge (TK) as a third knowledge domain. In 23 publications in our database, TK is defined.[1] Differences in the definitions of TK have to do with what technologies are included in TK and what sort of knowledge is addressed in TK (Anderson & Krathwohl 2001).

In nine publications, TK includes the knowledge of all kinds of technologies. In all except two (*Cox & Graham 2009*; *So & Kim 2009*), Mishra and Koehler are (co-)authors. *Cox and Graham* (*2009*), for instance, defined TK as 'knowledge on how to use emerging technologies' (p. 63). Emerging technologies in their definition are technologies that are not yet transparent and ubiquitous in a specific context (i.e. education). Although emerging technologies will often be digital technologies, this is not necessarily the case.

In the other 14 studies, TK is limited to the knowledge of digital technologies only (sometimes addressed as ICTs). Among these 14 studies, some refer to all kinds of digital technologies, whereas other focus on specific technologies such as Web 2.0 (*Bower et al. 2010*) and the World Wide Web (*Lee & Tsai 2010*).

When looking at the sort of knowledge addressed in TK, we found that in 12 studies, TK is defined as procedural knowledge (Anderson & Krathwohl 2001), and thus refers to the operational skills needed to use technology, sometimes including the ability to troubleshoot problems. For instance, this is the case in *Polly* (*2011*), who defined TK as 'knowledge about and use of specific hard- and software' (p. 40), and in *Angeli and Valanides* (*2009*), who defined TK as 'knowing how to operate a computer and knowing how to use a multitude of tools/software as well as troubleshoot in problematic situation' (p.158). Such a description of TK represents an instrumental – tool-focused – view on technology and suggests that due to the rapid changes of technology, TK should be perceived as a dynamic knowledge domain.

Three other publications explicitly describe TK as the knowledge needed to use digital technologies or teaching and learning. In terms of Anderson and Krathwohl (2001), such knowledge can be regarded as both procedural and conceptual. This is the case in a study of *Bower et al.* (*2010*), who in a study of Web 2.0 tools, explained that TK incorporates knowledge about how affordances of digital technologies relate to teaching and learning requirements. Similarly, *Hofer and Swan* (*2006*) referred to information skills needed to use technology for teaching and learning.

Finally, in seven publications a functional understanding of TK is presented, describing TK as a combination of conceptual, procedural and meta-cognitive knowledge (Anderson & Krathwohl 2001). Such a functional view on TK can be found in *Jamieson-Proctor et al.* (*2011*), who defined TK as 'a measure of competence with current digital technologies that affords individuals the ability to achieve both personal and professional goals with the available technologies' (p. 11). Mishra and Koehler, in their later publications (e.g. *Koehler & Mishra 2009*), adopted the notion of Fluency of Information Technology (FITness) (National Research Council 1999) to define TK. 'FITness requires persons to understand information technology, broadly enough to apply it productively at work and their everyday lives, to recognize when information technology can assist or impede the achievement of a goal, and to continually adapt to changes in information technology' (*Koehler & Mishra 2009*, p. 64). *Graham* (*2011*) did not define TK but points to the fuzziness of the concept technology in TK and argued that technology is not only a device but also a process to solve problems.

The development of TPACK in subject domains

Only a few studies (seven) in our database contributed to the understanding of TPACK for specific subject domains. Interestingly, these studies emphasize the close link between TPCK and PCK.

Hammond and Manfra (*2009*) developed a model to support *social studies* teachers in planning instruction with technology. In their opinion, teachers first determine how they teach specific content (PCK) and only then consider the use of technology. Their model is based on three pedagogical techniques that social studies teachers often use: giving (knowledge transmission), prompting (coaching students) and making (students demonstrating their knowledge). *Hammond and Manfra* (*2009*) demonstrated that the same technology applications often can be used to enhance all three instructional activities. They see TPACK as a common language for discussing the integration of technology in instruction, which may not be that subject specific after all: 'our model of giving-prompting-making is intended to clarify the relationship between PCK and technology within TPACK' (*Hammond & Manfra 2009*, p. 174).

Niess et al. (2009) endorsed the implementation of TPACK in *mathematics* teacher preparation programmes. They proposed TPACK standards and indicators for mathematics teachers and organized these in four areas: the design/development of technology-rich learning environments; the application of methods/strategies for applying appropriate technologies to maximize student learning; the application of technology to facilitate assessment; and the use of technology to enhance a teacher's productivity and practice. However, and despite the detailed descriptions of the standards by the authors, they are not very specific for mathematics teachers. *Guerrero* (*2010*) also proposed four components of mathematical TPACK, namely conceptions and use (teachers' beliefs about mathematics as a field), technology-based mathematics instruction, technology-based classroom management and depth and breadth of mathematics content. Although these categories also seem rather generic, Guerrero illustrated them with specific uses of technology in mathematics education.

Perhaps the most concrete explanation of TPACK for a specific subject domain has been given by *Jimonyannis* (*2010*), who has developed the Technological Pedagogical Science Knowledge (TPASK) framework for TPACK in *science* education. In his view, 'TPASK represents what science teachers need to know about ICT in science education' (p.1264). The author distinguishes between three knowledge domains: pedagogical science knowledge (a science education operationalization of PCK); technological science knowledge (a science education operationalization of TCK); and TPK [similar to *Mishra and Koehler's* (*2006*) TPK but more oriented towards science education]. *Jimonyannis* (*2010*) saw TPASK as the integration of these three knowledge domains. *Khan* (*2011*) used the generate–evaluate–modify approach to organize science teaching with technology. He demonstrated in detail how pedagogy (teaching methods, teacher guidance) and technology (computer simulations) are jointly used to support students in compiling information, generating relationship, evaluating the relationship and modifying the relationship in learning about a particular topic from chemistry.

Finally, *Harris et al*. (*2009*) and *Harris et al*. (*2010*) developed activity types to help teacher plan instruction with technology for K-6 literacy, mathematics, language arts, social studies and foreign language learning. Activity types are 'a set of classroom activities and interactions that have characteristic roles for participants, rules, patterns of behaviour, and recognizable materials and discursive practices related to them' (*Harris et al*. *2009*, p. 404). Per subject domain, the authors provide a taxonomy of content-based activities, which are related to various technologies that have the affordance to enhance instruction. The authors argue that using activity types can help teachers to develop TPACK.

TPACK and teacher beliefs

In the mind of a teacher, knowledge and beliefs are intertwined, and therefore, both are often conceived as an inherent part of teacher knowledge (Verloop *et al*. 2001). Six studies in our database questioned how a teachers' TPCK is related to their beliefs. Teacher beliefs are discussed from two perspectives: beliefs about technology (*Niess 2005*; *Özgün-Koca 2009*; *Abbitt 2011*) and pedagogical beliefs (*Niess 2005*; *Manfra & Hammond 2006*; *Valtonen et al*. *2006*; *So & Kim 2009*).

Abbit (*2011*) demonstrated that teachers' TK was a stable predictor of teachers' self-efficacy beliefs towards technology. Similarly, *Özgün-Koca* (*2009*) found in her study that beliefs about the functionality of specific technologies affect the way in which teachers integrate technology in their teaching. Further evidence about the influence of teacher beliefs is provided by *Niess*' (*2005*) study, showing that one of the student-teachers participating in an educational technology course felt hindered to apply what she had learned in the program to her teaching practice because of her view of technology. In the same study, *Niess* (*2005*) also described a teacher who did not feel comfortable with the technology herself but whose pedagogical beliefs facilitated the use of the technology because 'she believed that her students were able to see and understand some concepts better with technology' (p. 520).

Manfra and Hammond (*2006*) argued that teachers' decisions during lesson preparation and execution are based on their pedagogical beliefs about content and technology and not guided by the affordances of technology. Moreover, *Valtonen et al*. (*2006*) found that the majority of teachers who designed online courses opted for the design of teacher-centred courses. They concluded that although the affordances of technology may easily support a learner-centred approach, teachers tend to choose familiar teacher-centred pedagogical solutions when they design online courses. In *So and Kim's* (*2009*) study, student-teachers were not able to make connections between their knowledge about ICT and problem-based learning, their pedagogical beliefs and their actions. They concluded that teachers may have the knowledge and skills to use technology (referred to as espoused TPACK) but are not able to use it in practice (referred to as in use TPACK).

Measuring (student-)teachers' TPACK

In many studies in our database (student-)teachers' TPACK is determined through a combination of several instruments in order to triangulate findings (e.g. analysis of student products, classroom observation, interviews, self-assessment surveys). However, only a few studies provide a clear description of the instrument(s) itself, often with a description of the instrument's quality.

Eleven studies in our database presented 10 different self-assessment surveys in which (student-)teachers report their perceptions on or confidence in TPACK (see Table 2). Nine of the 10 self-assessment surveys (except *Doering et al. 2009*) used five to seven-point Likert scales but with different answering categories. Reliability and validity data are available for seven of the 10 instruments. In most of the 11 studies, the seven knowledge domains of the TPACK framework (or a subset) (*Koehler & Mishra 2008*) were represented as subscales. Some studies focused on a specific technology (*Lee & Tsai 2010*) or pedagogy (*Chai et al. 2011*), resulting in slightly different scales. In two studies, the knowledge domains of the TPACK framework could not be reproduced through EFA (*Archambault & Barnett 2010*; *Koh et al. 2010*), suggesting that the boundaries between the knowledge domains are fuzzy (*Graham 2011*). This becomes clear when the individual items of the instruments are inspected. For instance, *Archambault and Barnett* (*2010*) classified the item 'My ability to plan the sequence of concepts taught within my class' as an item in the domain of content knowledge. The operationalization of *Schmidt et al.* (*2009*) of this domain is very different (e.g. 'I can use a mathematical way of thinking'). This problem in the self-assessment surveys could be a result of the ambiguity about the theoretical notions of TPACK as described earlier.

Next to self-assessment surveys, a few studies (four) in our database measured TPCK based on demonstrated performance or through observation. *Angeli and Valanides* (*2009*) used a design-task (an ICT-enhanced lesson). To determine student-teachers' ICT-TPCK, the design task is scored on five criteria (identification of suitable topics, appropriate representations to transform content, identification of teaching strategies difficult to implement by traditional means, selection of appropriate tools and their pedagogical uses and identification of appropriate integration strategies); each criteria is rated on a five-point scale (score 5: total poor – score 25: outstanding). The tasks are scored by two independent raters (inter-rater agreement Pearson's $r = 0.89$). *Kramarski and Michalsky* (*2010*) used a design and a comprehension task to measure TPCK. The design task is rated on four criteria (i.e. identifying learning objectives, selecting content, planning didactical material, designing the learning environment) using a five-point scale (score 0: no answer – 4: full answer). Inter-rater reliability (Cohen's kappa) was >0.85 per criteria. The comprehension task was composed of two open questions, which are scored on five criteria (i.e. understanding, application, analysis, synthesis, evaluation) on a four-point scale (0: no answer, 1: low–3: high). The inter-rater reliability (Cohen's kappa) per criteria was >0.92. *Bowers and Stephens* (*2011*) developed a rubric to determine mathematics teachers' TPACK, in which five components are distinguished: CK, TK, TCK, TPK and TPCK. Two raters (inter-rater agreement 83%) scored student projects on the five components of the rubric, but the scoring rules are not clearly described in the study. *Mishra et al.* (*2007*) measured TPACK development through the analysis of conversations in teams of faculty and student-teachers who had to design online courses. They reported the frequency of discussion segments per each of the seven knowledge domains and are able to show how the discussion in the teams changed over time. The same data were coded twice and the agreement between the two coding intervals was 90%.

The discourse about TPACK as a concept is also reflected in the way a (student-)teacher's TPACK is determined. To measure TPACK, most of the self-assessment surveys decomposed TPACK in (a subset of) the seven knowledge domains. However, in most of the studies that use performance-based assessment measures, TPACK is considered a unique body of knowledge.

Table 2. Overview of self-assessment survey instruments.

Authors	What is measured	Number of items	Scales	Reliability	Validity
Archambault and Crippen 2009; Archambault and Barnett 2010[1]	Perceptions of own TPACK	24	Three scales: (TK, PCK, Technological Curricular Knowledge); five-point Likert scale, poor–excellent	Cronbach's alpha ranged from 0.70–0.89 on seven TPACK constructs	Content validity expert appraisal; think aloud testing; construct analysis (EFA)
Archambault 2011	Perceptions of preparedness to teach with technology	24	Seven scales: (TK, PK, CK, TPK, TCK, PCK, TPCK); five-point Likert scale, not at all prepared–5 very well prepared	Cronbach's alpha ranged from 0.84–0.93 on seven TPACK constructs	Content validity Expert appraisal; think aloud testing)
Chai et al. 2010	Perceptions of own TPACK	18	4 scales: TK, PK, CK, TPCK; seven-point Likert scale, strongly disagree–strongly agree; adapted from Schmidt *et al*.	Cronbach's alpha ranged from 0.85–0.94 on 4 TPACK constructs	Construct validity (EFA)
Chai et al. 2011	Perceptions of own TPACK	46	Seven scales: TK (Web-based competencies), CK, TPK, TCK, PCK, TPCK, pedagogical knowledge for meaningful learning (PKML); seven-point Likert scale, strongly disagree–strongly agree; adapted from Schmidt *et al*.	Cronbach's alpha ranged from 0.86–0.95 on seven constructs	Construct validity (EFA/ CFA)
Doering *et al*. 2009	Perceptions of changes in own TPACK	4	TK, PK, CK (single items) Likert scale items (1 novice–5 expert) +1 open-ended question; TPACK: teachers depict themselves on a graphical representation of TPACK (Venn diagram – similar to Fig 1)	No	No
Koehler and Mishra 2005	Perceptions of own thinking about TPACK	5	Individual TPCK; seven-point Likert scale, strongly agree–strongly disagree	No	No
Koehler and Mishra 2005	Perceptions of one's group thinking about TPACK	9	Group TPCK; seven-point Likert scale, strongly agree–strongly disagree	No	No
Koh et al. 2010	Perceptions of own TPACK	27	Five scales: TK, CK, knowledge of pedagogy (KP); knowledge of teaching with technology (KTT), knowledge from critical reflection (KCR) (after factor analysis); seven-point Likert scale, strongly disagree–strongly agree; adapted from Schmidt *et al*.	Cronbach's alpha ranged from 0.83–0.96 on five constructs	Content validity (expert's appraisal); construct validity (EFA)
Lee and Tsai 2010	Perceptions of confidence in TPACK-Web	30	Five scales: Web general, Web communicative, Web pedagogical knowledge; Web content knowledge, Web pedagogical content knowledge; six-point Likert scale, strongly unconfident–strongly confident	Cronbach's alpha ranged from 0.92–0.96 on five constructs	Content validity (expert appraisal); construct validity (EFA)
Schmidt et al. 2009	Perceptions of own TPACK	47	Seven scales: TK, PK, CK, TPK, TCK, PCK, TPCK; five-point Likert scale, strongly disagree–strongly agree	Cronbach's alpha ranged from 0.75–0.92 on seven TPACK constructs	Content analysis; construct analysis (EFA, but over subscale)

[1]These studies report about the same self-assessment instrument.
CFA, confirmatory factor analysis; EFA, exploratory factor analysis.

Strategies for (student-)teachers' development of TPACK

Thirty-six studies in our database address strategies to support (student-)teachers in their TPACK development. Active involvement in technology-enhanced lesson or course design was found as major strategy, followed by modeling how to teach in a technology-rich environment.

Eight contributions are of conceptual nature. In these studies, the situated nature of teachers' thinking and the important role of context in teacher decision making is mentioned as an important starting point for developing strategies to develop TPACK in teachers (*Koehler & Mishra 2008*, *2009*; *Angeli & Valanides 2009*). Based on conceptions of PCK, *Niess* (*2011*), based on Grossman (1990), argued that TPACK development needs to be based on four central components: an overarching concept about the purposes for incorporating technology in teaching a particular subject; knowledge of students' understanding, thinking and learning with technology in that subject; knowledge of curriculum; and curriculum materials in a particular subject that integrates technology in learning and teaching, and knowledge of instructional strategies and representations for teaching and learning that particular topic with technology. Other authors contend that strategies are needed to help (student-)teachers to map affordances of technology to representations of content, learners and pedagogy (e.g. *Bower et al. 2010*; *Polly et al. 2010a*). To actively involve teachers in their TPACK development, Koehler and Mishra (*Mishra & Koehler 2006*) introduced 'Learning technology by design'. 'Learning technology by design' starts with authentic curriculum problems for which technology-based solutions are collaboratively designed. *Niess et al.* (*2009*) realized that the development of TPACK will go through different phases [following Rogers' (1995) model of the diffusion of innovations]. They conceptualized five sequential stages to develop TPACK: recognizing, accepting, adapting, exploring and advancing. *Özgün-Koca et al.* (*2011*) used this model to follow a teacher's development in TPACK.

Sixteen studies in our database focused on developing TPACK in student-teachers. One study reported the evaluation of projects from the Preparing Tomorrow's Teachers for Technology (PT3) programme (*Polly et al. 2010*). This study identified three successful strategies: mentoring by experts of teacher education faculty who plan to integrate technology in their teaching; promoting TPACK of both pre- and in-service teachers through linking student-teachers with practicing teachers and supporting both of them, and joint redesign of curriculum materials into technology-enhanced curriculum materials in teams.

Nine studies described how student-teachers' TPACK was developed in a general educational technology course (e.g. *Wetzel et al. 2008*; *Chai et al. 2010*; *An et al. 2011*). From these nine studies, six developed TPACK in math, science or both subjects (e.g. *Hardy 2010*; *Özmantar et al. 2010*). In most courses, several strategies are used to develop TPACK. Frequently used strategies include: modeling (nine studies, e.g. *Lee & Hollebrands 2008*), technology-enhanced lesson design (10 studies, e.g. *Wetzel et al. 2008*) and enactment of technology-enhanced lessons, either through micro-teaching or during field experiences (five studies, e.g. *Jang & Chen 2010*). Two studies (*Koehler & Mishra 2005*, *Koehler et al. 2007*) applied 'Learning technology by design' to develop TPACK in teacher education faculty and master students, who collaboratively transformed a face-to-face course into an online course.

In-service teachers' TPACK development was the focus of 10 studies. Except for one (*Tee & Lee 2011*), all the other studies are domain-specific. In all 10 studies, in-service teachers were asked to implement technology-enhanced lessons or units in their own classroom and to reflect on the experience (e.g. *Trautman & Makinster 2010*). In most cases, in-service teachers enacted the lesson(s) they had designed themselves (eight studies, e.g. *Jang 2010*). In five studies, technology integration was modelled, most often through exemplary curriculum materials (e.g. *Doering et al. 2009*). School follow-up support was part of the professional development arrangement in one study (*Polly 2011*). One study (*Blocher et al. 2011*) paid attention to the development of TPACK leadership by having teachers write mini-grants for follow-up activities.

Discussion

The purpose of this review was to investigate the theoretical basis and the practical use of TPACK. From our work with TPACK with practicing teachers, we know that TPACK is an intuitive and easy-to-communicate concept. However, as this literature review showed, from a theoretical perspective, TPACK is a very complex concept and causes scholarly debate (cf. Graham 2011). Three different understandings of the concept emerged from the review. T(PCK) as extended PCK, TPCK as a unique and distinct body of knowledge and TP(A)CK as the interplay between three domains of knowledge and their intersections. While the first two conceptualizations view TPCK as a knowledge domain on its own, TP(A)CK represents an integrative view and emphasizes the relationship between the three knowledge domains and their intersections. All studies in our data set agree that TPCK stems from Shulman's (1986) PCK. And as there is no universal agreement what PCK entails (Van Driel *et al*. 1998), there is also no agreement on what TPACK is (Cox & Graham 2009; Graham, 2011; Niess 2011). However, two key characteristics of PCK are clear: PCK is about (1) knowledge if representations of domain knowledge, and (2) understanding of specific learning difficulties and student perceptions related to the teaching of *particular* topics of the domain. Based on these characteristics of PCK, we support the view that TPACK should be understood as a distinct body of knowledge. From this perspective, it is surprising that only a few studies in our review discussed the meaning of TPACK for a specific subject domain. The added value of TPACK is how technology can support students in learning conceptual and procedural knowledge of a particular subject domain (cf. Cox & Graham 2009; Niess 2011). In this view, TPACK is not the same as technology integration [see Graham's (2011) critique on the use of the concept] but a knowledge base (of which the content needs to be discussed).

Our review shows that pedagogical beliefs affect how teachers integrate technology as is also found in other studies (see, e.g. a recent study of Ottenbreit-Leftwich *et al*. 2010). Because teacher knowledge and beliefs are closely connected, Webb and Cox (2004) argued that it is not enough to only define teacher knowledge but also to study teachers' pedagogical reasoning in order to fully understand teachers' decision making about technology use. Based on this review, we would argue that it is also necessary to understand how a teacher's technological reasoning affects his (or her) decision making while using technology.

We see TK as conditional to TPACK, together with pedagogical knowledge and domain knowledge. However, this review revealed many different views on TK. Beyond the various views about the scope of technology (all technologies versus digital technologies), there is a more fundamental debate between an instrumental and a functional perspective on TK. Technology has immersed in our society and changes not only teaching and learning but also the curriculum (Voogt *et al*. 2011a). A functional view on TK seems more robust to changes in technology tools and applications. In our view, only a functional understanding of TK (Anderson 2008) justifies TK as a separate knowledge domain.

The discourse about TPACK may be seen by practitioners as a purely academic debate. However, this debate has an impact in the practical use of TPACK, particularly in how a (student-)teacher's TPACK development is determined. In our study, we found a variety of measures and measurement methods for determining TPACK, with self-assessment surveys as the most researched instrument so far. Self-assessment instruments can be useful as they tend to measure a teacher's self-efficacy, which usually is a good predictor of actual teacher behaviour (e.g. Tschannen-Moran & Hoy 2001). However, most self-assessment surveys in our data set varied significantly in the way they have operationalized the different constructs. In addition, they address domain-specific (technological and pedagogical) knowledge in rather general terms, thereby making it difficult to measure a teachers' TPACK in a specific subject domain. We believe that ultimately, (student-) teachers need to demonstrate what they can actually do with technology in their subject for enhancing teaching and learning. Such instruments, however, are not very well developed, at least not for research purposes.

To facilitate (student-)teachers' development of TPACK, a major strategy applied in several studies in our data set is composed of actively involving (student-) teachers in technology-enhanced lesson or course design. From research on teacher learning (e.g. Borko 2004; Voogt *et al*. 2011b) we know that collaborative (re)design and enactment of (technology-enhanced) curriculum materials is a promising strategy for developing teacher learning, in this case TPACK. Our review found that student-teachers do get experience in the design of technology-enhanced lessons but lack experiences in enacting technology-based lessons. For this reason, we support the recommendation from Polly *et al*. (2010) to link student-teachers with practicing teachers and to support both of them.

We recommend the following directions for future research on the development of the TPACK framework.

First, if TPACK is conceptualized as the knowledge base a teacher needs to effectively teach with technology, we need to better understand what that knowledge base is for specific subject domains. We suggest that based on a conception of PCK (e.g. Grossman 1990; Niess 2011), this knowledge base should be developed for specific domains and that consensus among scholars and practitioners should be sought through Delphi-type studies. One point to start in a specific subject domain is to review literature on what is already known about the use of technology in helping students learn difficult concepts. In the domain of science education, Snir *et al*. (2003) and Tao (2004) provide useful examples. Second, as teacher knowledge and beliefs are closely related, we also need further research focused on the complex relationship between TPACK (teacher knowledge), teacher practical knowledge and teacher beliefs. Van Driel *et al*. (1998) used the term craft knowledge in their study about PCK. Craft knowledge refers to 'teachers' accumulated wisdom with respect to their teaching practice' (p. 674). It includes knowledge about pedagogy, students, subject matter and the curriculum gained in formal schooling and practice and beliefs teachers hold about these issues. Such an approach will also emphasize the dynamic nature of TPACK. Furthermore, we think that craft knowledge could be a useful concept for professional development strategies aiming to develop TPACK in (student-)teachers. Third, if we better understand what TPACK means for specific subject domains, we will also be able to better assess a teacher's TPACK. In addition to more specific self-assessment surveys, there is a need for valid and reliable instruments, where a teacher can demonstrate TPACK.

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Note

[1]Studies using Mishra's and Koehler's definition of TK are not discussed in this section.

Supporting information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. The studies selected for the review.

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