Technological Pedagogical Content Knowledge in the literature: how TPCK is defined and implemented in initial teacher education

Technological Pedagogical Context Knowledge (TPCK) in letteratura: come viene definito e implementato il modello TPCK nei contesti di formazione iniziale dei docenti

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ABSTRACT In recent decades, there has been increasing research interest in teachers' competences regarding the growing role of technologies in educational practices. These competences are grounded on a clear base of technological knowledge, along with the recognized dimensions of a broad pedagogical expertise and deep knowledge of the content. This paper analyses the most significant international literature on the topic, reporting the theoretical discussion about teachers' knowledge as described by the Technological Pedagogical Content Knowledge framework (TPCK – Koehler & Mishra, 2005a) based on Shulman's (1986, 1987) PCK. This framework will be analysed in its definition and main components, as well as in the different interpretations given by researchers in recent years. Finally, some of the main strategies documented in the literature to develop this type of teacher knowledge in pre-service education will be presented.

KEYWORDS Educational technologies; Teachers' knowledge; TPCK; Literature review.

SOMMARIO Negli ultimi anni, il ruolo crescente delle tecnologie nella didattica è stato oggetto di riflessione scientifica in relazione alle competenze degli insegnanti, che comprendono una chiara base di conoscenza tecnologica unita ad una vasta competenza pedagogica e ad una profonda conoscenza dei contenuti. Questo contributo analizza la principale letteratura internazionale sull'argomento, focalizzando

l'attenzione sulla discussione teorica relativa alle competenze dei docenti così come vengono descritte nel framework del Technological Pedagogical Content Knowledge (TPCK – Koehler & Mishra, 2005a), a partire dagli studi di Shulman (1986, 1987) sul PCK. L'analisi riguarderà le definizioni e le componenti principali del framework, così come le diverse interpretazioni fornite dai ricercatori negli ultimi anni. Infine, verranno presentate alcune strategie documentate in letteratura per lo sviluppo di questo tipo di competenze nella formazione iniziale degli insegnanti.

PAROLE CHIAVE Tecnologie per l'educazione; Competenza dei docenti; TPCK; Rassegna della letteratura.

1. INTRODUCTION

In the last decades, several educational policies around the world have explicitly included technology requirements in teachers' qualification processes (Ertmer, 2005; Koehler & Mishra, 2005a; Mouza, Karchmer-Klein, Nandakumar, Yilmaz Olden, & Hu, 2014) and considered technology as an active agent shaping educational practice (Voogt, Fisser, Tondeur, & van Braak, 2016), an essential knowledge and skill base in 21st century society (Tondeur et al., 2012).

On the academic front, theories like the ones of technology mediation and of social agency (Voogt et al., 2016; Voogt & McKenney, 2017) postulate that technology and its users do not have a *neutral* relationship (Voogt & McKenney, 2017), each part being active in shaping comprehension of the world. As may be imagined, this has major consequences in the learning process, where technologies are increasingly perceived as cognitive partners that amplify learners' capacity to understand, communicate and perceive (Angeli & Valanides, 2009, 2015; Ertmer & Ottenbreit-Leftwich, 2010), by helping in the activation of higher order cognitive processes (Kramarski & Michalsky, 2010).

Thus, considering demands arising from educational policies and theories, it would seem that «*effective teaching requires effective technology use*» (Ertmer & Ottenbreit-Leftwich, 2010, p. 256). For technologies to be effectively integrated in teaching practice, though, teachers need to relate technologies' pedagogical affordances with their own pedagogical, content-related approaches (Angeli & Valanides, 2015; Chai, Koh, & Tsai, 2010), in the realization of a specific form of integrated professional knowledge.

This paper provides an overview on the emergence and development of a framework for that knowledge, identified as *Technological Pedagogical Content Knowledge* (TPCK). The study is the result of a wide literature research on the main databases, aimed at selecting significant papers dealing with *TPCK definition* and *TPCK and teacher education*, with the final goal of investigating the main strategies reported in the literature for identifying, enacting and supporting TPCK in teacher education.

First, we discuss the emergence of this framework in academic research, considering its definition and main components. Different interpretations will be then presented in their differences and commonalities. Finally, we describe some of the main strategies reported in the literature for developing and assessing TPCK in student teachers.

2. EMERGENCE AND DEFINITION OF TPCK AS A FRAMEWORK FOR TEACHERS' KNOWLEDGE

Teacher knowledge is known to be extremely complex and multifaceted (Koehler & Mishra, 2005a), realized in the interaction between (a) professional and personal knowledge (Ben-Peretz, 2011) and (b) theoretical and practical understandings (Verloop, Van Driel, & Mejer, 2001). It is deemed as dynamic and situated in social, usually ill-defined contexts (Angeli & Valanides, 2009; Ben-Peretz, 2011; Harris & Hofer, 2009, 2011; Mishra & Koehler, 2006; Webb & Cox, 2004). Although its definition has changed over time (see

Ben-Peretz, 2011), a shared core has recently been found in the «*interaction of the knowledge of representations of content matter with the understanding of specific learning difficulties and student perceptions related to the teaching of a particular topic*» (Voogt, Fisser, Pareja Roblin, Tondeur, & van Braak, 2012, p. 113). This perspective has been brought by Shulman (1986, 1987), who saw in the teacher a person able to integrate domain knowledge with appropriate pedagogical approaches, so that learners can better understand the subject at stake (Voogt et al., 2012). He summarized teachers' knowledge in the acronym *PCK*, standing for *Pedagogical Content Knowledge* (Shulman, 1986, 1987), which is now commonly acknowledged as the distinctive body of knowledge for teaching (Voogt et al., 2012).

While technologies in education have been rendered transparent (Graham, 2011; Mishra & Koehler, 2006), and thus implicit in teachers' PCK, an explicit base for technology was felt to be needed when considering their growing role in the educational discourse. *Technological Pedagogical Content Knowledge* (TPCK) was thus introduced to identify the knowledge base for teachers to teach effectively with technology (Koehler & Mishra, 2005a; Voogt et al., 2012), considered as a «*powerful mechanism to study and understand teacher cognition about the educational affordances of technology in teaching and learning*» (Angeli, Valanides, & Christodoulou, 2016, p. 13).

TPCK as an extension of PCK was the first interpretation offered in the literature (Voogt et al., 2012), by which TPCK comprises the integration of the three knowledge domains (pedagogical approaches, subject-matter knowledge and technology knowledge) revealing technology's potential in facilitating learning. TPCK's base components are:

1. *Technological Knowledge* (TK), that is knowledge of technologies and the skills required to operate with them (Angeli & Valanides, 2009; Mishra & Koehler, 2006);
2. *Pedagogical Knowledge* (PK), which is related to teaching/learning processes and practices, methods and approaches (De Rossi, 2015; Mishra & Koehler, 2006); and
3. *Content Knowledge* (CK), that is teachers' understanding of a discipline's semantics and syntactic organization (Starkey, 2010) and its forms of content representation.

These bases then overlap in three areas of knowledge:

a. *Technological Pedagogical Knowledge* (TPK), which involves knowledge of technology's affordances and constraints for pedagogical purposes (Terpstra, 2015);
b. *Pedagogical Content Knowledge* (PCK), which, developing on Shulman's *PCK* (1986), focuses on the meaning of teaching a particular content as viewed from the learners' perspective (Ben-Peretz, 2011; Mishra & Koehler, 2006); and
c. *Technological Content Knowledge* (TCK), as the understanding of which technologies are most suitable for a specific learning topic and how this, in turn, could shape and determine technology uses (Mishra & Koehler, 2006).

Finally, the *Technological Pedagogical Content Knowledge* (TPCK) is the specific form of knowledge emergent from the conjunction of the base components, the core of the teaching profession, which requires an understanding of the best pedagogical approaches and representations of concepts using technologies in relation to students' prior knowledge and to possible content-related learning difficulties (Mishra & Koehler, 2006).

From the first introduction of the construct, multiple versions of this acronym emerged with different specifications. For example, Cox (2008) observed around a hundred significantly different definitions of TPCK constructs. She performed a conceptual analysis of these that, as the author affirmed, while not setting a clear line between and among the knowledge bases, contributed by helping to clarify the lexis with which to discuss them (see Cox & Graham, 2009).

The most significant framework modification was the change from TPCK to TPACK, standing for the *Total PACK-age* for teaching effectively with technology (Thompson, 2008). Still based on the three knowledge

bases of TK, PK, and CK, it is easier to pronounce. This spelling modification is particularly important when considering the transformative (Angeli & Valanides, 2005) or integrative (Mishra & Koehler, 2006) perspective, as we will discuss shortly. Otherwise, the terms are to be considered as synonyms, as not every author has adopted the new phonetics (Voogt et al., 2012), and thus the acronym TPCK will be used here, as according to source. The new acronym was adopted, for example, by authors conceiving TPACK as the integration of the three knowledge domains and their intersections, in a situated, integrative perspective, like Mishra and Koehler (2006).

As we will discuss later, several researchers found it difficult to distinguish the boundaries and relations between and among the knowledge bases both in assessing and in developing TPCK, and this has been one of the reasons why Angeli and Valanides (2005, 2009) proposed a different, transformative perspective, considering TPCK a unique body of knowledge that can be developed and assessed on its own (Angeli et al., 2016).

While the transformative possibility would help in understanding why TPCK boundaries are so difficult to trace in educational practices, the issue is still under discussion. A clear definition of TPCK's boundaries and their interaction seems to be a challenge that, if overcome, could help establish the validity and level of generalizability of the TPCK framework and related research (Angeli & Valanides, 2015; Angeli et al., 2016; Graham, 2011), so further research is needed on this topic.

2.1 *Different interpretations of TPCK*

As mentioned, from the original identification of TPCK as a framework for teacher knowledge, diverse interpretations and specifications of the construct later emerged. In their attempts to clarify the TPCK framework, most researchers have tended to focus primarily on one or two of the model's components (Technology, Pedagogy and Content Knowledge) rather than devoting equal attention to all three (Table 1). In the following sections, we will discuss the relations among these components, as reported in the literature.

Reference (alphabetical)	TP(A)CK framework specification			Overall perspective on the framework	
	Focus on Technologies	Focus on Pedagogy	Focus on Content	Integrative (TPACK)	Transformative (TPCK)
Angeli & Valanides (2005)					X
Angeli & Valanides (2009)	X				X
Benton-Borghi (2015)		X			
Chai, Koh, & Tsai (2013)		X			
Doering, Scharber, Miller, & Veletsianos (2009)			X	X	
Figg & Jaipal (2012)	X	X		X	
Guerrero (2010)			X		
Harris & Hofer (2011)		X	X	X	
Jimoyannis (2010)					
Kramarski & Michalski (2015)		X			
Lee & Tsai (2010)	X				
Mishra & Koheler (2006)				X	
Wang (2008, 2009)	X				
Yeh, Hsu, Wu, Hwang, & Li (2014)	X	X			X

Table 1. Principal interpretations of the TPCK framework as reviewed in the literature.

On the technological front, Angeli and Valanides (2009) operated from a transformative perspective and proposed the *ICT-TPCK,* circumscribing TK only to ICT. These authors deem ICT-TPCK to support different learning styles by transforming content with multiple representation, using a variety of technological means in ways that learners and technology constitute a joint cognitive system (Angeli & Valanides, 2009). Furthermore, the *TPCK-W* proposed by Lee and Tsai (2010) considers mainly the specificities of the Web 2.0 and teachers' perceptions of technology's uses, while Wang (2008, 2009) suggests a *PST-TPCK* focused on technological affordances. Overall, the theoretical interpretations of TPCK, declined on its technological component, focus on the explicit consideration of technology's specific affordances, trying to help focalizing the framework and defining the boundaries of its components, but with the risk of a rigidity that might ignore the everchanging technology's features (Messina & De Rossi, 2015).

The *TPACK – Practical* proposed by Yeh, Hsu, Wu, Hwang and Li (2014) acknowledges the importance of teaching experience in predicting teachers' TPACK proficiency (Angeli et al., 2016; Jang & Tsai, 2012), focusing the model on both content knowledge and ICT understanding. Moreover, the *TPCK – in – Practice* suggested by Figg and Jaipal (2012) defines TPCK as the knowledge that emerges from the infusion of TK into PCK (Jaipal-Jamani & Figg, 2015), involving the understanding of a repertoire of technology-enhanced activity-types for a specific content. This interest in teaching practice could help to close the gap between theoretical definitions and concrete teaching evidence, but presents the issue of analysing and generalizing the latter in a clarification of the former.

Moreover, on the side of the Pedagogical basis of TPCK, we find the *Technological Learning Content Knowledge* (*TLCK)* interpretation offered by Chai, Koh and Tsai (2013), which primarily considers learning conceptions and processes connected to the uses of technology for learning a specific content (Messina, 2015). Moreover, the *Universal Design for Learning – TPCK* (*UDL – TPCK)* proposed by Benton-Borghi in 2015 concentrated on pedagogical strategies enabled by technologies. Technologies' multimodal affordances would meet the needs of the *UDL* reinforcing equity and inclusion (Benton-Borghi, 2015). These two are examples of more learner-centred interpretations of TPCK, opening interesting avenues of research that may have extensive implications for the design of teacher education course.

Finally, various interpretations of TPCK have been applied to the different disciplines. Examples include Doering, Scharber, Miller and Veletsianos's G-TPACK (2009) applied to technologies for geographic learning, Guerrero's (2010) *TPACK for mathematics* (see Voogt et al., 2012), and even Jimoyannis' *TPASK* (*Technological Pedagogical Science Knowledge*; 2010). This line of content-related specification of TPCK could also help in bridging TPCK's theoretical definition with practical demands, but some authors observe an unequal distribution of studies on mainly scientific-related disciplines, seeming to «*reinforce the opinion that the use of technology is more akin to the mathematics and science subjects*» (Chai, Koh & Tsai, 2013, p. 44).

3. DEVELOPING TEACHERS' KNOWLEDGE WITH TPCK

3.1 *TPCK implementation*

Having discussed TPCK definition and interpretations, in this section we will present different strategies reported in the literature to support the development of this type of teacher knowledge (Table 2).

Niess (2005) suggests that TPCK development involves attitudinal change, acquisition of technological skills, and creation of pedagogical ideas for technology integration (Voogt et al., 2012). Considering Niess' study, Mouza, Karchmer-Klein, Nandakumar, Yilmaz Olden and Hu, (2014) identified five levels of TPCK

Reference (alphabetical)	Study design	Strategies to develop TP(A)CK				Strategies to assess TP(A)CK		
		Focus on Technologies	Focus on Instructional Design	Focus on Discipline Content	Organization of integrated educational courses	Self-assessment (surveys, questionnaires)	Interviews	Performance observation / assessment
Angeli & Valanides (2013)	Design-based research	X	X					X
Archambault & Barnett (2010)	Design-based research					X		
Britten & Cassady (2005)	Survey							X
Chai, Koh, & Tsai (2010)	Theoretical							X
Chien, Chang, Yeh, & Chang (2012)	Design-based research		X					
Hammond & Manfra (2009)	Theoretical							
Harris & Hofer (2011)	Case study		X					
Harris, Grandgenett & Hofer (2010)	Rubric		X					
Hofer & Grandgenett (2012)	Rubric		X		X			X
Hsu, Liang, Chai, & Tsai (2013)	Survey					X		
Jaipal & Figg (2010)	Theoretical						X	
Jang & Tsai (2012)	Design-based research					X		
Khan (2011)	Case study			X				
Koehler & Mishra (2005a, 2005b)	Case study		X					X
Koh (2013)	Rubric					X		X
Koh & Chai (2014)	Design-based research		X			X		
Koh & Divaharan (2011)	Case study	X	X					
Krauskopf, Zahn, & Hesse (2012)	Survey					X		
Lee & Tsai (2010)	Survey					X		
Mishra, Peruski & Koehler (2007)	Case study		X				X	X
Mouza, Nabdakumar, Yilmaz Ozden, & Karchmer-Klein (2015)	Longitudinal study				X			
Niess (2005)	Case study			X	X			
Ozgün-Koca (2009)	Case study						X	
Papanastasiou & Angeli (2008)	Design-based research					X		
Schmidt et al. (2009)	Survey					X		
Tondeur, Roblin, van Braak, Voogt, & Prestridge (2016) Tondeur et al. (2012)	Theoretical				X			
Williams, Foulger & Wetzel (2010)	Design-based research						X	
Yilmaz-Ozden, Mouza & Harlow Shinas (2016)	Survey					X		

Table 2.. Strategies reported in the literature to develop and assess TPCK.

development: (a) recognizing, (b) accepting, (c) adapting, (d) exploring, and (e) advancing. Moreover, Krauskopf, Zahn and Hesse (2015) propose two levels of cognitive transformation characterizing TPCK development: (1) transformation of knowledge in the basic sub-domains (TK, PK, CK) into knowledge of the intersecting sub-domains (PCK, TCK, TPK); and (2) meta-conceptual awareness of the demands of the teaching task.

While there is quite some literature on TPCK's developmental stages, it is still under discussion how to trigger teachers' advancement from one to another. Archambault and Barnett (2010) remind how difficult it is to define practical applications for a framework that is yet to be fully defined, while Mouza and Karchmer-Klein (2013) suggest using TPCK as a "conceptual lens" for studying the development of teacher knowledge about technology, more than a professional development model, although «*it is most helpful when not described in isolation from techniques for developing it*» (Harris, Mishra & Koehler, 2009, p. 402). Considering also that the quality and quantity of pre-service technology integration experiences are found to be crucial to foster teachers' TPCK (Agyei & Voogt, 2011; Tondeur et al., 2012), pre-service education proves to be a crucial moment to observe and support TPCK development. For example, among other reviews , Mouza et al. (2014) observed how educational technology courses, method courses and field experiences collectively have the merit of exposing pre-service teachers to a variety of TPCK models, fostering their TPCK's development through the Niess' stages (Angeli & Valanides, 2015; Koh & Divaharan, 2011; Mouza et al., 2014).

3.2 *Strategies to develop TPCK: focus on design*

The first strategic line to develop TPCK among pre-service teachers is active engagement in design cycles (Table 2) For example, Koehler and Mishra (2005b) pointed out the importance to offer opportunities for dialogue and interactions in which TPCK's components are developed concurrently (Kramarski & Michalsky, 2010), while Baran and Uygun (2016) suggested that the design process, especially if supported by reflection, offers meaningful opportunities to show almost explicitly how technology, pedagogy, content, and contextual factors mutually reinforce/constrain each other.

Moreover, Harris and Hofer (2009), deeming technology-enhanced instructional design to be content-focused, context-sensitive, and activity-based, proposed a taxonomy of activity types matched with technology choices based on the forms of knowledge implied (*LAT)*, which is intended as a methodological shorthand to build and describe learning plans. The authors engaged pre-service teachers in LAT-related design tasks and, through interviews and analysis of designed products, observed that participants grew more conscious of the multiple options available for technology-enhanced learning activities and therefore are more likely to incorporate technologies into their instructional design.

Furthermore, Chien, Chang, Yeh and Chang (2012) proposed four steps for assisting science teacher educators in linking technology and instructional design, transforming pre-service teachers into active designers of technology-enhanced learning environments. Through analysis of design tasks, they found significant growth in pre-service teachers' technology competence levels and in critical examination of pedagogical affordances.

Koehler and Mishra (2005a, 2005b) developed the *Learning Technology By Design* approach, meant to encourage teachers to develop technological solutions to authentic pedagogical problems (Mouza et al., 2014). They interviewed the participants engaged in collaborative design, observing significant development in their TPACK, within an integrative perspective.

Also, Koh and Chai (2014) found pre-service teachers' engagement in design processes to have a positive influence on TPK and TCK perceptions, fostering their TPACK overall. They used self-reported TPACK measures which suggested that participants involved in ICT-based lesson design deepened the connections among TPK, TCK and TPACK.

Self-reported measures like the one just mentioned once again raise the issue of the gap between perceived and actual enactment of TPCK. A further limitation of the reviewed studies is their strong contextualization, as several of them are case studies investigated with qualitative instruments (Baran & Uygun, 2016). This calls for further validation and replication of research procedures to better understand the most useful approaches for developing teachers' effective technology-enhanced design and supporting their TPCK development (Baran & Uygun, 2016; Mouza et al., 2014).

3.3 *Strategies to develop TPCK: focus on the content*

Other studies focused on TPCK development within a specific disciplinary area (Table 2). One example is Niess' work (2005), which investigated TPCK development in pre-service mathematics teachers, proposing TPCK standards and subject-related indicators in four areas: (a) design/development of technology-related environments; (b) application of technology-related strategies to maximize student learning; (c) application of technology in assessment; and (d) use of technology to enhance teachers' productivity and practices (Voogt et al., 2012). Khan (2011) also dealt with science teachers and demonstrated how pedagogy and technology are jointly used to support students in learning chemistry, using a generate-evaluate-modify approach in their case study.

Although TPCK's disciplinary declinations and investigations are mainly set in the area of sciences (Chai et al., 2013), Hammond and Manfra (2009) operated with social-studies teachers to foster their planning of instruction with technology. Starting from the specific content to teach (PCK), and only later considering technology uses, they used TPCK as a common language for discussing technology integration in instruction. These researches posed an interesting question on TPCK definition, in terms of specificity: while Hammon and Manfra (2009) saw TPCK as not particularly subject specific, but rather a broad strategy to extend PCK to comprise technologies, Jimoyannis (2010), Guerrero (2010) and others detailed TPCK specifically for single disciplines. As mentioned earlier, TPCK's theoretical definition as a whole and its components are still under discussion, and the extent of discipline specifics in relation to a more comprehensive definition of teacher knowledge is an interesting line of research to pursue.

3.4 *Strategies to develop TPCK: focus on technology*

Other studies focused on the technological side of TPCK development, having a common strategy in providing pre-service teachers with technology courses (Mouza et al., 2014). These have been found to foster teachers' self-efficacy in technological skills, but do not seem decisive in developing their TPCK altogether (Mouza et al., 2014). In a more systematic consideration of technology, pedagogy and content, Angeli and Valanides (2009, 2013) proposed the *Technology Mapping (TM)* approach to TPCK development. This is based on mapping tool affordances to align student teachers' PCK with their knowledge about ICT, and engaged pre-service teachers in authentic design tasks, evaluating their products. Furthermore, Koh and Divaharan (2011) and Niess (2015), starting from the assumption that teachers first need to be comfortable with ICT as users before being ready to use it as teachers, proposed a *TPACK developing instructional model* that encompasses confidence building, subject-focused pedagogical modelling, and hands-on application. While the mentioned approaches offer interesting findings, they were focused on specific technological tools (Excel and Interactive Whiteboards, respectively), highlighting the need of further examples with different tools to gain validation.

3.5 *Strategies to develop TPCK: organization of educational courses*

Other strategies to foster TPCK development can be found in the specific organization of educational courses for pre-service teachers. Mouza (2016) reviewed the specific strategies proposed and pointed out three main pathways: (a) stand-alone educational technology courses; (b) instructional strategies embedded within an educa-

tional technology course or content-specific method course; and (c) instructional strategies implemented in the entire curriculum of teacher education, like the ones carried out by Niess (2005), Hofer and Grandgenett (2012), or Mouza, Nabdakumar, Yilmaz Ozden and Karchmer-Klein (2015).

Through the review of several qualitative studies, Tondeur et al. (2012) and Tondeur, Roblin, van Braak, Voogt and Prestridge (2016) defined an SQD–model to analyse and assess educational programs for pre-service teachers in supporting TPCK development. They identified different strategies on the micro-level (e.g., using teacher educators as role models, learning technology by design, scaffolding), and conditions necessary at the institutional level (namely, technology planning and leadership, cooperation within and between institutions, staff training). Although their model has not yet been validated, it seems an interesting strategy for investigating the quality of higher education programs for developing pre-service teachers' TPCK.

3.6. *Different paths to investigate and assess TPCK*

3.6.1. *Self-assessment*

In the following sections, we will describe the main instruments to assess and investigate TPCK enactment in pre-service education, as revealed by the reviewed literature. Findings will be organized in the following macro-categories: self-assessment (surveys, questionnaires, self-reports); performance observation; performance assessment; interviews and discourse analysis (see Table 2).

Self-assessment, in particular, is one of the most commonly reported research strategies. One example is Schmidt et al.'s (2009) validated model, with its seven-factor analysis divided in different subject areas, which was found to be useful in detecting teachers' TPCK level and dimensions from an integrative perspective (Abbitt, 2011). Adaptations of this survey can be found in Chai et al.'s (2010) study, whose findings indicate that construct validity for the seven TPACK factors, taken as a whole, proves problematic. Moreover, the *Survey of Teaching Knowledge with Curriculum-Based Technology* proposed by Yilmaz-Ozden, Mouza and Harlow Shinas (2016) was found to be a valid and reliable reorganization of Schmidt et al.'s (2009) survey, while its implementation suggested that it would be useful to consider TPCK from a transformative perspective. Archambault and Barnett (2010) proposed a survey with 24 items to assess the seven TPACK factors, coming to the conclusion, though, that these theorized bases could not be reflected in practice. The same conclusion was reached by the implementation of Lee and Tsai's (2010) survey based on six factors for web-based learning. Several of these instruments, starting with Schmidt et al.'s one (2009), present evidence that teachers may not be consciously considering as separate the knowledge areas that in theory are distinct – TK, PK, CK, TPK, TCK - even if overlapping (Chai et al. 2010; Chai, Koh, & Tsai, 2016; Cox & Graham, 2009; Mouza, 2016). Once again, the gap between theoretical definition and practical measurements calls for further reflection on TPCK as a framework.

Other surveys dealt with specific interpretations of the TPCK framework, such as the one proposed by Hsu, Liang, Chai and Tsai (2013) on game-based TPACK, or the one by Krauskopf, Zahn and Hesse (2012) on TPACK for the use of educational videos. Moreover, Jang and Tsai (2012) developed a questionnaire based on the *IWB-TPACK*, with the aim to identify CK and TK as distinctive factors, while creating a "*PCK* (*context*)" factor from the joining up of PK, PCK and the context factor.

Finally, Papanastasiou and Angeli (2008) created a survey to examine which factors might impede teachers' efforts to teach with technology. The survey, whose reliability was found sufficiently high, considered six main factors: teachers' (a) knowledge of technology tools, (b) frequency of personal technology use, (c) frequency of instructional-related technology use, (d) attitudes toward technology, (e) self-confidence in instructional technology use, and (f) school climate.

3.6.2. *Performance observation and assessment*

The second strategy to investigate TPCK development is through performance observation and assessment (Table 2), one of its earliest examples being Mishra and Koehler's (2005b). They studied and assessed, through the analysis of authentic design-based activities, the evolution of participants' learning and perceptions about: (a) the learning environment; (b) knowledge of technology; (c) course content; and (d) TPACK growth (Mishra & Koehler, 2006). In a later study, Mishra, Peruski and Koehler (2007) analysed design teams' conversations by monitoring the frequency of the seven knowledge domains.

One of the most widely used instruments to assess performance is indeed the rubric. Britten and Cassady's (2005) *Technology Integration Assessment Instrument* (TIAI), aimed at assessing technology integration in lesson plans, was found to have adequate reliability (Herring, Koehler, & Mishra, 2016) and was later adapted by Harris, Grandgenett and Hofer (2010) to create the *TPACK-based Technology Integration Assessment Rubric (TIAR)*. This instrument was used in a longitudinal study of pre-service teachers, involving assessment of their lesson plans in terms of TPK, TCK, and TPACK (Hofer & Grandgenett, 2012; Mouza, 2016). They also adapted this rubric to develop the *Technology Integration Observation Instrument*, which was found to be valid and reliable in assessing TPCK enactment in pre-service contexts (Harris, Grandgenett, & Hofer, 2010).

The evaluation of design products was also at the centre of the rating scale developed by Angeli and Valanides (2005) to assess pre-service teachers' technology enhanced learning design for ICT-TPCK, which considered (a) selection of appropriate topics; (b) identification of technological representations of the content; (c) identification of teaching strategies; (d) design of computer-based learning activities; (e) identification of integrated activities (Angeli & Valanides, 2009).

Koh (2013) proposed a rubric highlighting how the meaningful learning of a subject matter needs adequate support from ICT in each and every dimension, in consideration also of Harris and Hofer's (2009, 2011) forms of knowledge. In another work, Chai, Koh and Tsai (2010) reframed this rubric to be helpful in scaffolding teachers' transition toward constructivist-oriented ICT integration.

Finally, Mishra, Peruski and Koehler (2007) used interviews to observe the ways faculty members integrate new technologies in content-related pedagogical practices. As a result, they found evidence of complex and conscious reasoning among the faculty members about the relationships among the contents, pedagogy and technology domains. Along the same lines, Williams, Foulger and Wetzel (2010) and Jaipal and Figg (2010) tried to map TPACK domains through interviews among faculty and pre-service teachers. Another example can be found in Ozgün-Koca's (2009) work with pre-service mathematics teachers, interviewed about their beliefs on visual and transformational technological tools for teaching their subject.

The reviewed examples of performance observation and assessment use interesting instruments to examine the meaningful use of technology in teaching practice (Archambault, 2016), but maintain heavy contextual bounds that hinder data generalization and call for additional research on the use of the TPCK framework in different learning settings and content areas (Archambault, 2016; Koh, 2013).

4. CONCLUSIVE REMARKS

This paper reviewed several articles on the introduction and development of the TPCK framework for teachers' knowledge as a response to the changing role of technology in educational practices during the last decades. TPCK's definition and main components have been described, along with the later interpretations and the main strategies for its development and assessment in teacher education, as reviewed in the literature. Although this review tried to embrace different perspectives as retrieved in accredited studies,

academic discussion and research on the topic is particularly active, so further review would be encouraged, especially in the strategies of TPCK operationalization in pre-service education, a topic this paper could not address in detail.

TPCK has proved an interesting lens for researchers to investigate teachers' meaningful use of technology in their practice (Archambault, 2016; Harris et al., 2010), offering both teacher educators and policy makers the possibility to analyze and reflect upon technology-integrated planning (Archambault, 2016; Mouza & Karchmer-Klein, 2013). As mentioned earlier, though, the theoretical boundaries of TPCK's framework are still to be specified and verified, with consequences for its definition and measurements. Moreover, there is a need to understand better how to foster its development in pre-service teacher education (Cox & Graham, 2009) as the documented methods and approaches are varied, making it difficult to compare the outcomes (Mouza, 2016). Data generalization is a major challenge for research on TPCK, which is usually heavily contextually bound (Archambault, 2016), and calls for more validated qualitative and quantitative instruments in the different content areas to map TPCK development trajectories clearly (Chai et al., 2016).

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