Cognitive Processes Underlying TPCK: Mental Models, Cognitive Transformation, and Meta-conceptual Awareness

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Introduction

Emerging technologies can be utilized as cognitive tools for learning (Koehler et al. 2011; Putnam & Borko, 1997; Zahn, Krauskopf, Hesse, & Pea, 2012; Zahn, Pea, Hesse, & Rosen, 2010). For example, they can be used to enable learners to access information in constructive ways, by writing Wikipedia articles or by annotating digital videos with specific video tools (e.g., Zahn et al., 2012). However, educational uses of emerging technologies are manifold and not predetermined in advance. This reinforces the demand on the teacher to repurpose technology for classroom instruction (Koehler et al., 2011). Repurposing includes two parts. First, teachers have to understand the different affordances and constraints of emerging digital technologies (Angeli & Valanides, 2009; Gamage, Tretiakov, & Crump, 2011; Koehler & Mishra, 2008; Suthers, 2006) for teaching and learning. Second, the teacher needs to be aware of what the underlying learning processes are that she is aiming at (cf. Oser & Baeriswyl, 2001). Based on this, the teacher needs to carefully plan the integration of technology in teaching and learning by selecting appropriate tools and creating appropriate learning activities (Bromme, 1992; Harris, Mishra, &

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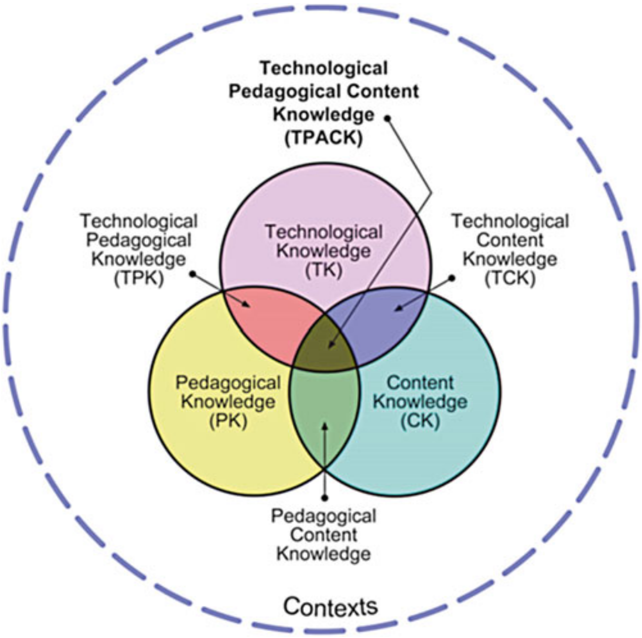

Fig. 1 Graphic representation of the TPCK framework [sic!], http://TPACK.org/

Koehler, 2009; Webb, 2011; Webb & Cox, 2004). To sum up, the challenge for the individual teacher to leverage the potential of any technology begins with understanding and adequately representing its (socio-)cognitive functions in the light of their prior professional knowledge.

The Technological Pedagogical Content Knowledge (TPCK) framework has provided a common ground for discussing this issue, based on its central claim that technology can only add value to learning environments, when considered *simultaneously* with pedagogy and the subject matter (Angeli & Valanides, 2009; Harris et al., 2009; Mishra & Koehler, 2006; Niess, 2005). TPCK research has largely focused on the practice of teacher training and professional development, as well as on measures to evaluate respective training programs. Less effort has been put into developing TPCK *as a theory* (cf. Graham, 2011) and specifying the assumed cognitive processes underlying the development of TPCK.

The pervasive representation of the framework in a Venn diagram (see Fig. 1) does not add to the clarification of these issues. In the research literature, this problem has been discussed as the competing *integrative* view of TPCK, as spontaneously emerging knowledge when the teacher possesses knowledge in the sub-domains TK, PK, and CK versus the *transformative* view, defining TPCK as a unique body of knowledge that is qualitatively different from all other proposed sub-domains (Angeli & Valanides, 2009; Graham, 2011). However, the cognitive processes that characterize this transformation have not been conceptualized in detail.

In this chapter, we elaborate on the transformative view of TPCK research by proposing two levels of cognitive transformation characterizing the development of

Table 1 The constructs proposed by the TPCK framework and hierarchical structure, as proposed in this chapter

Hierarchical structure proposed in this chapter	TPCK constructs
Basic sub-domains	Technological knowledge (TK)
	Pedagogical knowledge (PK)
	Content knowledge (CK)
Intersecting sub-domains, *first level of transformation*	Technological pedagogical knowledge (TPK)
	Pedagogical content knowledge (PCK)
	Technological content knowledge (TCK)
Meta-conceptual awareness, *second level of transformation*	Technological pedagogical content knowledge (TPCK or TPACK)

TPCK (cf. Table 1). On the first level, the transformation of knowledge of the basic sub-domains (TK, PK, CK) into knowledge of the intersecting sub-domains (PCK, TPK, TCK) is defined as the construction of mental models (Brewer, 1987; Johnson-Laird, 1980, 1983). On the second level, considerations from the conceptual change literature are followed (Clark, D'Angelo, & Schleigh, 2011; diSessa, Gillespie, & Esterly, 2004; Ioannides & Vosniadou, 2002; Vosniadou, 1994), and TPCK is conceptualized as meta-conceptual awareness of the demands of the teaching task. In conclusion, implications for research, teacher training, and professional development are described.

First Level of Transformation: Teacher Knowledge as Mental Model Representations

Our first claim is that the cognitive transformation of knowledge in the basic subdomains (TK, PK, CK) into knowledge in the intersecting sub-domains (PCK, TPK, TCK) is defined as the construction of mental models. This claim is substantiated and specified in the following paragraphs.

Mental Models Mapped on the TPCK Framework

The Venn diagram shown in Fig. 1 depicts the most common representation of the TPCK framework. As Graham (2011) puts it, this visualization adds to the theoretical fuzziness and suggests that growth in either of the basic sub-domains (Graham, 2011, speaks of core categories) would automatically result in growth in all the subdomains depicted as overlaps of the basic sub-domains. Such an assumption does not adequately represent the current empirical results (e.g., Angeli & Valanides, 2005, 2009) and contradicts the initial reasons to introduce the TPCK framework. Even though Mishra and Koehler (2006) have described TPCK in a *transformative* way from the start (Graham, 2011; Mishra & Koehler, 2006), that is, conceptualizing TPCK as a distinct body of knowledge not arising automatically from its adjacent sub-domains, the literature has not directly addressed the assumed relations among the seven (TK, PK, CK, TPK, TCK, PCK, and TPCK) proposed constructs. The precise definitions of the TPCK constructs introduced by Cox and Graham (2009) provide a clearer understanding of each sub-domain and their unique features (see Table 1); however, it remains an open theoretical question as to how the knowledge in different sub-domains is cognitively represented, and how they relate to each other. In sum, TPCK has only been formulated as a structural model, and the formulation of a process model, such as the more generic one by Baumert and Kunter (2011), has not been the focus of prior research.

This is furthermore an open empirical question. Studies applying TPCK surveys and quantitative analytic methods (Archambault & Barnett, 2010; Chai, Koh, & Tsai, 2010; Koh, Chai, & Tsai, 2010; Lee & Tsai, 2010; Schmidt et al., 2009) have focused on factor analyses and on examining the intercorrelations of the subscales investigating the questions of whether preservice teachers could differentiate between the proposed constructs in self-reported statements in their respective sub-domain knowledge. Most of these studies did not have any prior assumptions about which constructs should show stronger or weaker relations. Only one study (Chai et al., 2010) used regression analytic techniques to test TK, PK, and CK self-efficacy ratings, as predictors for TPCK, assuming that the basic sub-domains are prerequisites for TPCK. Qualitative studies (Graham, Borup, & Smith, 2012; Koehler & Mishra, 2005; Koehler, Mishra, & Yahya, 2007) similarly coded the occurrence of discourse that was attributable to each of the sub-domains, but did not elaborate on the relations between them, even when looking at TPCK development over time (Koehler et al., 2007). Similarly, studies using other methodologies, such as design-based research (Angeli & Valanides, 2005, 2009) or experimental designs (Kramarski & Michalsky, 2010), focused on participants in tasks designed to assess their overall TPCK, without looking into which constructs might act as prerequisites for performance on TPCK tasks.

Alternatively, we propose a mental model perspective on TPCK. Based on the identified contradictions and gaps in the existing literature, we claim that teachers need to construct a mental model of the functions of the respective technology in relation to the impact of these functions on learners' access to the subject matter. Constructing a mental model of the task, and the constraints for solving it, is necessary for drawing inferences and making predictions based on innately incomplete information, like in the classroom context.

In short, mental models are representations of elements in situations, and their interrelations that people construct based on their prior knowledge and beliefs. With regard to how they are represented, cognitive psychology assumes that they are analogue and continuous representations of elements and their interrelations that can be directly manipulated. They are more situated and specific than general beliefs or declarative knowledge (Brewer, 1987; Johnson-Laird, 1980, 1983; Westbrook, 2006). Mental models also exceed what is explicitly asserted in given premises, and are, therefore, effortful to construct. As a result, mental models signify a deeper understanding (Azevedo & Cromley, 2004; Chi, 2000)—compared to list-like propositional representations. Following Johnson-Laird (1980) and Brewer (1987), mental models are considered representations of deeper understanding, because they are cognitive structures that are constructed in the situation. In the present case, for example, when teachers are confronted with tasks such as lesson planning. Hence, we do not consider mental models long-term memory structures here (cf. the notion of mental models as rather long-term memory structures, Gentner & Stevens, 1983).

However, we do assume a feedback process: Over time, the creation of different solutions (=lesson plans) enables the teacher to characterize the commonalities of such a set of solutions (Johnson-Laird, 1983). From the set, the teacher can infer abstract characteristics across concrete task contexts and improve the construction of mental model representations. Thus, task solutions, such as lesson plans or experiences with implementation in class, are likely to be "*stored*" in propositional representations, that is, abstract and list-like. Nevertheless, such a propositional representation of combined knowledge of the sub-domains for a specific lesson does not suffice to accomplish the next task ahead. An example for a propositional representation could be to present cases of teachers' implementing a certain digital technology, which alone, as seen in the study by Angeli and Valanides (2005), was not sufficient to develop preservice teachers' identification, selection, or infusion of Information and Communication Technologies (ICT) for teaching purposes themselves.

Interrelations of the TPCK Sub-domains

When mapping the described notion of mental models onto the TPCK framework, how should we assume that the seven sub-domains relate to each other? Following Brewer (1987), generic knowledge provides a frame of reference that guides the construction of mental models. Thus, when getting to know a new technology or planning a lesson to apply technology, prior knowledge in the basic sub-domains contributes to the construction of knowledge in the higher-level sub-domains. The question following from this is: *how* is prior knowledge integrated into knowledge in the higher-level sub-domains? We propose that transforming knowledge in the basic sub-domains needs to happen in a specific way in order for teachers to solve the complex task of teaching subject matter utilizing emerging technologies (cf. Calderhead, 1996; Leinhardt & Greeno, 1991; see also Fig. 2). Teachers need to combine rather independent basic knowledge domains into more interrelated aspects, in order to solve the overall lesson planning and implementation task, *and* they need to transform their combined knowledge into a mental model representation. It is not sufficient to merely combine the factual elements of prior knowledge. Instead, elements need to be represented together with their interrelations in such a way that they can be mentally manipulated, so that inferences can be made.

For example, on the one hand, a teacher may know about the possibility to edit, annotate, and comment on YouTube videos (TK), including examples, which former users have created for different contexts. On the other hand, this teacher may also know about constructivist or inquiry-based approaches that support students in

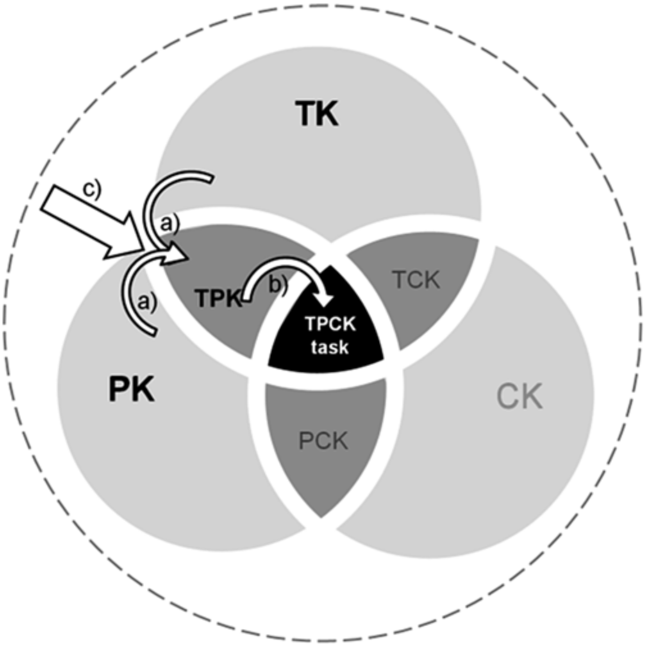

Fig. 2 The notions of independent knowledge domains (*light gray*), mental models (*dark gray*), and lesson plans (*black*) mapped onto the TPCK framework. *Curved arrows* indicate the cognitive process for translating aspects of pedagogical and technological knowledge into mental models (*a*) here of TPK, as an example, and subsequently into lesson plans for concrete content and technology (*b*), considering that these processes might need external support (*c*)

discovering their own understanding of a topic based on sources (PK). In order to come up with a lesson plan that leverages the potential of the YouTube functions for inquiry-based learning (arrow b in Fig. 2), the teacher is challenged to first construct a mental model that contains how specific technological functions open up new possibilities for students (arrow a in Fig. 2). This includes that the mental model needs to contain elements that allow inferring, whether these functions can support students' individual learning or whether certain potential can only be leveraged in collaborative settings, such as the collaborative annotation of a video segment influencing the discussion about the content (e.g., Zahn, Krauskopf, Hesse, & Pea 2010; Zahn, Pea et al., 2010). However, because this mapping of technological and pedagogical information can be considered an effortful cognitive process, it is likely that this teacher requires support to be able to transform the pedagogical knowledge and technological knowledge into a mental model (arrow c in Fig. 2).

To illustrate this point, it seems appropriate to also alter the Venn diagram shown in Fig. 1 (Cox & Graham, 2009; Graham, 2011). As a first step, the sub-domains should be clearly separated, and the different levels of transformation could be further visualized by the intensity of the shading. By doing so, it becomes apparent that crossing the depicted borders is related to cognitively effortful processes and that the complexity of the knowledge representation also increases from the periphery to the center. With regard to TPCK as a construct, this has broader implications, which are discussed in a later section.

Keeping the constructs of PCK, TPK, and TCK in the model suggests that these are actually helpful for describing the complexity of what teachers need to understand when teaching with technology. Keeping these constructs also allows for making more precise assumptions about the cognitive processes involved in developing TPCK. Figure 2 depicts these changes to the framework, as an attempt to illustrate the relations between the content of the sub-domains, representational form of knowledge, and knowledge building processes, the following can be considered relevant in teaching with digital media: For a teacher to get from the outer areas (light gray) to the inner areas (gray and black), it is not only a matter of connecting different content areas, but rather a matter of transforming the knowledge (see arrow a in Fig. 2) representation by constructing a mental model of elements within this domain and the interrelations between them. The subsequent steps should then be in part concerned with combining mental models based on prior knowledge into possible solutions for planning a lesson (for the example of TPK, see curved arrow b in Fig. 2). However, it is also of importance to consider whether the construction of mental models happens spontaneously or, if not, how this process needs to be supported (see arrow c in Fig. 2).

Following Fig. 2 as a tentative visualization, our description of the TPCK framework also includes that the light gray shapes in the periphery refer to knowledge in the three basic domains, technology, pedagogy, and content. These are independent from each other and also rather unrelated to the task of teaching a specific content with the support of emerging technology, when considered separately. Regarding their representational format, these knowledge domains can be represented *propositionally,* as a linear string of symbols in an abstract mental language, as well as in analogue *mental models* that contain elements and their interrelations (cf. Johnson-Laird, 1980). In this respect, a propositional representation signifies a more superficial understanding, and a mental model a deeper understanding. It is an open question whether new information is always translated into propositional representations and whether mental models are based on such propositional representations; however, to solve complex tasks that require drawing inferences, mental models need to be constructed (Johnson-Laird, 1980, 1983). This is because propositional representations only include given information, but do not integrate prior knowledge or further constraints (cf. also Shulman, 1986).

For example, considering content knowledge separately, a physicist's knowledge of electronic circuits can be propositionally represented, so that she can name important elements and a set of rules related to the building of electronic circuits. When being confronted with the task of evaluating the functionality of an existing circuit or planning for building a new one, however, following Johnson-Laird (1980, 1983), a propositional representation is not sufficient to accomplish these tasks. The physicist needs to construct a mental model of the relevant elements and interrelations of electric circuits, integrating the new information that was presented in the task problem. This analogue representation can then be manipulated mentally and different versions can be simulated. This allows the physicist to predict which modifications to a circuit should still be acceptable to create a functioning exemplar. This example illustrates that taking the general definitions of mental models into account a superficial propositional representation might be necessary, but not sufficient to accomplish a domain-specific task that requires drawing inferences. Instead, the accomplishment of such a task requires the construction of a mental model. Similar cases could be made for the technological knowledge of a software developer or the pedagogical knowledge of a social worker.

As argued above, this should also hold true for the task of (planning for) teaching a specific content, while utilizing emerging technologies. The specific aspect here is that the deep understanding (mental model) of a teacher in one of the TPCK sub-domains should be sufficient to perform well in a respective sub-domain-specific task, such as, editing a video with a specific software (TK), instructing a collaborative learning task (PK), or interpreting an historical source (CK); however, it should not be sufficient to perform the overall TPCK task of teaching supported by emerging technologies. To accomplish this task, the different components need to be combined. Based on the considerations above, we propose that this combination must happen in a specific way: Teachers need to construct mental models (form of representation), when they combine knowledge of the independent basic sub-domains (content of representation), meaning that a transformative (process) needs to take place.

Even though constructing such mental models is considered more effortful, the respective knowledge is subsequently more economically accessible (Johnson-Laird, 1980, 1983). If knowledge in the higher level sub-domain is represented in this form, teachers can utilize it to "*compute*" solutions to the task at hand (see arrow b in Fig. 2). First and foremost, the value of this conceptualization emerges for solving the complex tasks of teaching that necessitate teachers to infer concrete hypotheses about the classroom situation and student learning. This assumption is also evident in the operationalizations of teachers' knowledge in the overlapping sub-domains on the second level, as well as in more general approaches to teachers' reasoning and planning for technology use (Webb, 2011).

The assumption that teachers' knowledge needs to be represented in mental models to solve their professional tasks is also implicit in the operationalization of *Pedagogical Content Knowledge* (PCK) tests, in the work of Baumert and colleagues in the COACTIV project with a representative sample of German mathematics teachers (Krauss et al., 2008; Kunter et al., 2007; Voss, Kunter, & Baumert, 2011) as well as in the international TEDS-M project of the IEA (for the German sample, see Blömeke, Kaiser, & Lehmann, 2008; for the overall framework see Tatto et al., 2008). Participants in these studies were asked to generate multiple solutions for solving the given tasks of answering a student's "*why*" question, predicting students' errors in given scenarios, or asking them to come up with various explanations for mathematical solutions. All these tasks require teachers to go beyond what they know, and to construct a mental model to produce task solutions.

Similarly for *Technological Pedagogical Knowledge* (TPK), this assumption can also be found in operationalizations as teachers' decision-making and providing rationales for lesson plan decisions (e.g., Graham et al., in press). In a similar fashion, Krauskopf and colleagues (Krauskopf, Zahn, & Hesse, 2012) followed a procedure applied in cognitive psychological research (e.g., Azevedo & Cromley, 2004). Participants were prompted to describe the three most *relevant* functions of YouTube (Krauskopf et al., 2012), or select the most *relevant* functions of a newly encountered video tool (WebDIVER) from all the functions that they had recalled. Because mental models are considered more elaborate representations exceeding mere facts, participants were asked here to prioritize functions of respective tools and additionally justify their decision. Following Angeli and Valanides (2009) claim that the role of the learners needs to be considered by the TPCK framework, we would suggest that the structural indicators of teachers' mental models (relations among elements) could be the point in the framework to anchor respective theoretical efforts.

For *Technological Content Knowledge* (TCK) this should be assumed as well, considering the specific task here to use technology in a way to represent content and single out specific features or concepts; however, as mentioned earlier, there is a lack of research on this construct and therefore no operationalizations to review here. Thus far, the discussion of TCK has pointed out that it might be subsumed under PCK or CK in the teachers' own perceptions (Hofer & Harris, 2012), but theoretically this construct needs to be considered more thoroughly first before dismissing it.

To sum up, except for the study of Krauskopf et al. (2012), there have been few studies specifically defining teachers' knowledge about teaching with technology, or trying to tap the represented elements and their functional relations more directly with instruments, such as concept mapping techniques (Kagan, 1990). Given this assumption, it follows that integrating all sub-domains, on a second level into TPCK as a construct, needs further to lead to a specific quality beyond the integrated sub-domains of PCK, TPK, and TCK. Otherwise, the construct would not add much to the understanding of teachers' reasoning for utilizing technology. In the next section, it will therefore be discussed how to conceptualize TPCK as a *construct* with regard to its representational form and its content in ways that add to its theoretical power.

Second Level of Transformation: TPCK as Meta-conceptual Awareness

So far, we described a first level of cognitive transformation of teachers' knowledge for teaching with technology, leading from rather separate basic sub-domains of Technological, Pedagogical, and Content Knowledge to mental models in the overlapping sub-domains of Technological Pedagogical Knowledge, Pedagogical Content Knowledge, and Technological Content Knowledge. However, the issue remains how to conceptualize the construct by supposedly integrating all these aspects, namely, TPCK. Our second theoretical claim is that TPCK can be conceptualized as meta-conceptual awareness of the demands of the teaching task, the teachers' knowledge in the sub-domains, and the context.

This claim takes into consideration Cox and Graham (2009), for example, who defined TPCK as knowledge of how to "*coordinate the use of subject-specific activities[…] or topic-specific activities […] with topic-specific representations using emerging technologies", when understanding emerging technologies as "not yet […] a transparent, ubiquitous part of the teaching profession's repertoire of tools*" (p. 64). The definition of TPCK as knowledge of "*how to coordinate*" different knowledge domains clearly alludes to the notion of a meta-conceptual construct. In line with this, this notion is repeated throughout the TPCK literature. Harris et al. (2009) defined TPCK as concerned with the "*multiple interactions*" (p. 401) of the sub-domains, Koehler, Mishra, Kereluik, Shin, and Graham (2014) as the knowledge to orchestrate and coordinate the different sub-domains, and Abbitt (2011) as the knowledge "of the complex interaction among the principle knowledge domains" (p. 283). In conclusion, all these definitions and descriptions allude to the specific theoretical and practical value of the TPCK construct itself, as knowledge *about* the knowledge being at the teacher's disposal in relation to the context and the instructional task.

From this, we conclude that that the second level of transformation is characterized by meta-knowledge of what—according to the TPCK approach—is necessary for mastering the domain of teaching with emerging technology. Vosniadou and others (diSessa et al., 2004; Ioannides & Vosniadou, 2002) specify that such an elaborate, scientific understanding is characterized by a meta-conceptual awareness of what a theory is about and what it is for. Therefore, we will hence refer to the knowledge representation of TPCK as a construct, as *meta-conceptual awareness*. The use of this term is in line with Shulman's work, who defined a teacher's knowledge about his or her knowledge and the capability of explaining their decisions, as being a central point for defining themselves as professionals (he uses the term meta-cognitive awareness, Shulman, 1986, p. 13). It can also explain how TPCK emerges from an initially naïve understanding of technology.

Stepping forward from a naïve understanding of technology to TPCK, how do novices in the domain of teaching with (emerging) technology develop TPCK? A naïve understanding of a new concept compared to that of an expert is considered to exhibit a relation analogous to that of children to that of adults (cf. Hatano & Inagaki, 1986). Discussions with regard to children's naïve conceptual understanding of new (complex) phenomena, and the development of more scientific understandings of important theoretical ideas and empirical research, can be found in the literature dealing with conceptual change (Clark et al., 2011; diSessa et al., 2004; Ioannides & Vosniadou, 2002; Mason, 2001; Vosniadou, 1994; Vosniadou & Brewer, 1992, 1994). If we follow this analogy and assume that inexperienced teachers—or in the present case inexperienced with utilizing technology—can be considered novices (Berliner, 1992, 2001; Leinhardt & Greeno, 1991), it is possible to apply findings and theoretical considerations of the conceptual change literature to teachers' developing a conceptual understanding of TPCK.

Considering the conceptual change literature, it becomes apparent that there are two theoretical perspectives on how naïve conceptual understanding is cognitively represented: The view of conceptual understanding assumes novices to construct a fragmented system of "*Knowledge in Pieces*," that is, a rather large number of fragmented explanatory primitives that are activated in specific contexts (Clark et al., 2011; diSessa et al., 2004). The "*Theory Theory*" view assumes novices to construct a rather coherent framework theory by which any specific explanation is constrained (Ioannides & Vosniadou, 2002; Vosniadou & Brewer, 1992).

TPCK as Incoherent Knowledge in Pieces

In the Knowledge in Pieces approach (Clark et al., 2011; diSessa et al., 2004), conceptual understanding is considered to be made up of a large number of "*intuitive elements*," whereas some of these elements might have a wider scope (covering more than one context) and others a narrower scope (covering only one context). Elements here are defined as *phenomenological primitives* that are always activated as a whole and describe "*what happens naturally in the world*," and thus can be characterized as sub-conceptual entities (diSessa et al., 2004, p. 857). Each element is specified by itself and therefore a compact specification of an overall concept is hardly possible. Boundaries are expected to be unprincipled and instable, and elements are expected to overlap between contexts (diSessa et al., 2004). Although following independent developmental trajectories, sub-groups of elements can be cued in the same situation and therefore show *local* coherence; that is, the Knowledge in Pieces perspective does not assume purely random interactions between elements. Inconsistencies in phenomena, however, can only be explained at the vague level of resolution that *something influencing the phenomenon in question must act somehow differently* (diSessa et al., 2004, p. 857).

Following this approach, learning then is defined as a process of reorganizing elements and their interrelations that *may* result in an overarching understanding (Clark et al., 2011). So, through reorganizing these elements (phenomenological primitives), learners will start making connections between contexts and they will also prioritize elements by importance, that is, by their value for explaining a certain situation. Yet, even if there are elements with common attributes, their great number and independent developmental paths constitute an "*intrinsic difficulty of developing an integrated view*[…]" (diSessa et al., 2004, p. 857). As a consequence of this, no *meta-conceptual awareness* of one's own theories can be attained.

Conceptualizing TPCK as incoherent or locally coherent, respectively, leads to the assumption that teachers abstract "'*self-explanatory' schemata*" (diSessa et al., 2004, p. 857) from everyday situations of the teaching profession. This then results in a large number of context-specific elements (phenomenological primes) that could take, for example, the following form: *In this class, using teamwork in the computer lab leads to chaos.* There may be common attributes of several elements that would lead to locally coherent explanations for related contexts, such as, *in the afternoon, when students are tired, teamwork in the computer lab leads to chaos*, or differentiation between or within domains.

When we apply these considerations to the example of digital video technology applied in our research (e.g., Krauskopf et al., 2012), this could be *Using digital video technologies as a supplement is helpful for discussing expository texts, but not for literary texts*. Accordingly, there would be loosely connected abstractions for the basic sub-domains, technology, pedagogy, and or content, as well as those on the second level: content-specific teaching strategies (PCK), the impact of different technologies on learning (TPK), and content-specific technological representations (TCK). Finally, TPCK would be assumed to also consist of a subsample of these elements, each applying to specific contexts, topics, technologies, or teaching strategies. These can be locally coherent, such as: *Using graphing calculators in project teamwork is beneficial for a number of mathematical topics*. Overall, however, this conceptualization is similar to a number of example lesson plans that do not go beyond the given facts of the examples (like propositional representations, as defined previously).

In conclusion, conceptualizing TPCK as a framework, in this manner, is less helpful for reasoning about changing constraints, such as new classes or emerging hard- and software. Finally, it is unlikely that an overall understanding on the meta-conceptual level develops systematically, that is, what a teacher understands about the factors involved in teaching with technology and how they interact.

TPCK as Coherent Theory Theory

Conceptual understanding, as a '*Theory Theory'* by Vosniadou and colleagues in the context of learning physics (e.g., Vosniadou & Brewer, 1992), assumes that learners initial ontological and epistemological presuppositions are organized into general framework theories. The framework theories are causal and explanatory frameworks organizing physical phenomena (Clark et al., 2011). Constrained by these framework theories, specific theories (e.g., mental models) and beliefs are constructed based on everyday observations and culturally transmitted information (beliefs) to explain, interpret, or predict specific phenomena (Vosniadou, 1994). Constraining framework theories are such that only a few specific theories are extrapolated, and they are considered rather stable and hard to change. Learning following this conceptualization is thought of as a developmental progression from mental model to mental model by incorporating new information and forming of interim models (Clark et al., 2011), by processes of *enrichment* or *revision* (Vosniadou, 1994). Whereas revision varies between weak restructuring, referring to increasing differentiation and hierarchical formation of existing structures, and radical restructuring, referring to the emergence of new theoretical structures out of several preexisting ones (Vosniadou & Brewer, 1992), this kind of change is considered difficult to achieve. One reason is that changes in the ontological and epistemological presuppositions are bound to have serious implications on all the knowledge structures based on them (Vosniadou, 1994). To further develop such naïve theories into a scientific understanding, a person would need to acquire meta-conceptual awareness of her framework theory, which insinuates a different cognitive representational form (Ioannides & Vosniadou, 2002).

The notion of mental models in this approach is congruent with the one described above (Brewer, 1987; Clark et al., 2011; Vosniadou & Brewer, 1992, 1994). They are conceived of as analogue representations of "*the state of affairs*" that have a dynamic structure and are created on the spot for the purpose of solving problems. The creation of mental models is thought to be based on and constrained by underlying conceptual structures (framework theories, above) that act as presuppositions that are often based on everyday experiences. Thus, initial mental models are formed based on such a set of presuppositions. New information is assimilated into synthetic models, while trying to keep as many of their presuppositions intact. Learning in the sense of conceptual change would ultimately mean a reinterpretation of the underlying presuppositions. In conclusion, this debate about knowledge structure coherence of the naïve understanding of scientific concepts adds valuable theoretical perspectives to consider, with regard to how different conceptualizations of TPCK can inform the research on its development.

For TPCK, the task to be mastered is the use of technology in teaching. In this way, basic framework theories could hold ontological and epistemological presuppositions, such as, *There is educational software and there is software for private use* (ontological), *The use of emerging technologies is not different from using any kind of teaching material* (ontological), *That some technologies are not made for learning does not need to be explained* (epistemological), or *Why students learn better with certain representations needs to be explained* (epistemological, cf. Figures 1 and 2 of Ioannides & Vosniadou, 2002).

The cultural context of the teacher, where information for constructing specific theories with regard to technology use is received, is constituted by the epistemologies of the subject domains (Buehl, Alexander, & Murphy, 2002; Hofer, 2006) and the teaching profession itself. It can be assumed that preservice teachers in general and experienced teachers with a low rate of technology use, while not being able to provide pedagogical reasons for this low rate, have naïve conceptions of what is circumscribed by TPCK. In line with this, they would lack meta-conceptual awareness of which knowledge of the sub-domains discussed earlier they need to orchestrate, in order to provide added value for learning scenarios with emerging technologies.

Following the perspective of a coherent theory, developing TPCK means that by constructing initial mental models based on framework presuppositions, teachers would develop meta-knowledge of what presuppositions their local theories (e.g., lesson plans and classroom decisions) are based on and how they construct these local theories. This perspective also suggests that "*teaching*" teachers about innovatively utilizing emerging technologies should be difficult, because teacher educators will have to try to alter basic presuppositions. Changing these will not only be effortful, but most likely connected to unpleasant emotions, because it deconstructs trusted ways of understanding the teaching environment.

To sum up, two figures from diSessa et al. (2004, Figs. 1 and 2) were adapted trying to illustrate the difference between the Knowledge in Pieces and the Theory Theory perspectives, as they are mapped on the TPCK framework (see Figs. 3 and 4).

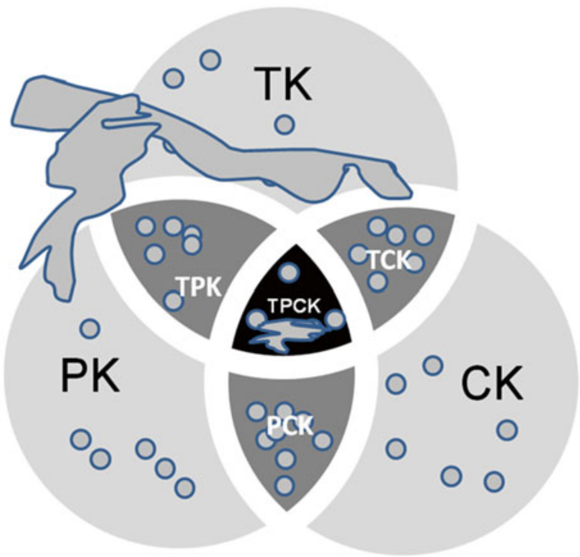

Fig. 3 TPCK as incoherent system of local explanatory elements (Knowledge in Pieces). The scientific framework theory of TPCK is "covered" by many independent elements. The boundaries of the single elements may be fuzzy, overlapping, and differ in width of scope

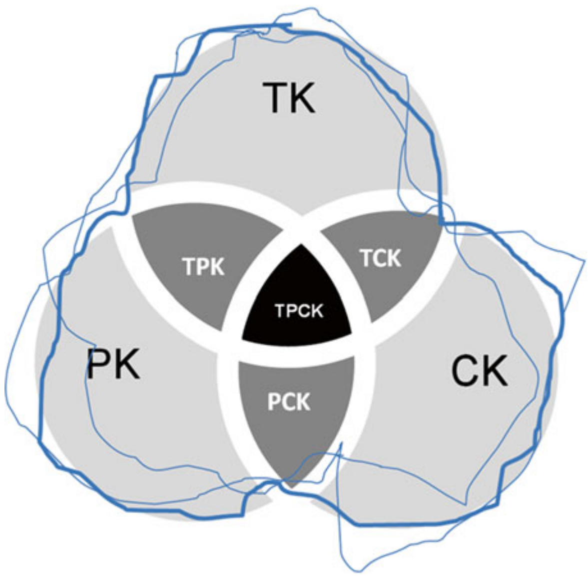

Fig. 4 TPCK as a coherent intuitive theory (Theory Theory). The conceptual boundaries roughly match those of the scientific framework theory of TPCK, while the boundaries are fuzzy and subject to change

Figure 3 depicts TPCK defined as a mostly incoherent system of single explanatory elements that are abstracted from everyday (teaching) experiences. This depicts how a novice teacher, who has not yet developed TPCK might represent his or her own understanding of professional knowledge about the domain of teaching with technology. TPCK itself in this illustration would be a subsample of these elements, where aspects of all sub-domains are considered. Figure 4 depicts TPCK defined as a coherent intuitive theory by a teacher. This depicts how a teacher who has developed TPCK would need to represent her or his own understanding of professional knowledge about the domain of teaching with technology. Following this perspective, possessing TPCK means developing a conceptualization that roughly covers the same sub-domains, their interrelations, and the role of context (as it is proposed by the TPCK framework).

Conclusion—TPCK Framework

Now, after describing these two different possible perspectives, how should TPCK be conceptualized as a scientific theoretical framework to describe teachers' competence in using technology? To our understanding TPCK needs to be conceptualized as a coherent theory. A more detailed description of this conceptualization becomes possible applying the three foci for the accountability, for details in conceptual understanding proposed by diSessa et al. (2004): *contextuality*, *specification,* and *relational structure*. As a result, TPCK as a coherent scientific framework theory is (1) a unitary shape with a clear application context (teaching with technology); (2) the assumption of a limited number of presuppositions about technology, pedagogy, and content (ontological and epistemological) that constrain the construction of more specific theories (mental models) derived from them; (3) the idea of a meta-conceptual frame for the systematic relations of these presuppositions and the teacher's knowledge of the sub-domains.

We suggest this normative conceptualization, while being aware that novices might be more likely to represent their understanding as Knowledge in Pieces. Thus, it is important that, depending on the form of the initial naïve concepts, the processes of changing these naïve concepts (conceptual change) are assumed to differ. The most relevant transformation seems to be the transition from a fragmented to coherent understanding of teaching utilizing technology.

TPCK as Meta-conceptual Awareness

Following the conceptualization of the TPCK framework as a coherent theory, we define the TPCK construct as meta-knowledge. This is essential for repurposing emerging technologies, because, here, a more fine grained understanding of technology for teaching is relevant (Graham, 2011). Leaving the definition of the TPCK construct unclear and open to be subsumed under other sub-domains bears the risk of developing a very individual understanding of TPCK for teachers coming from different backgrounds. For example, a skilled pedagogue using digital technology might then just expand the boundaries of his PK concept. Or for a technology expert entering the teacher profession, teaching could fall within the boundaries of a wide TK concept. However, if TPCK is also to serve as a normative standard of how

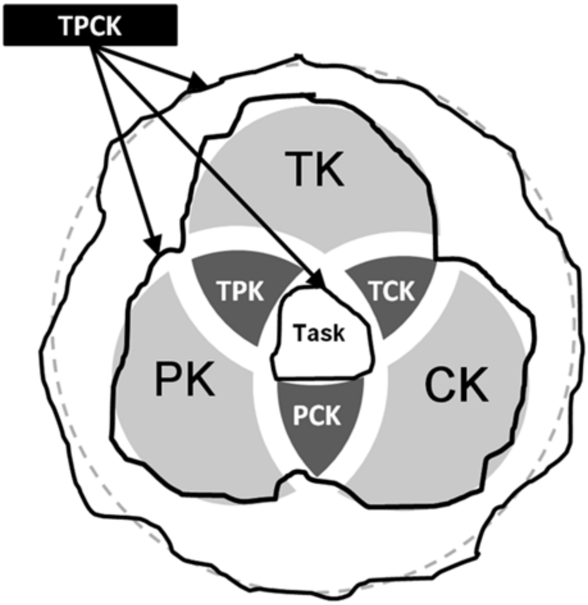

Fig. 5 Content of TPCK as a construct: Meta-conceptual awareness of the demands of the respective teaching *task*, the teacher's own *knowledge in the sub-domains,* and the *contextual* constraints. The conceptual boundaries of these elements roughly match those of the scientific framework theory

emerging technologies have to be understood in teaching, both of these examples are at conflict with the proposed conception of TPCK.

In contrast, if TPCK is defined as meta-conceptual awareness, there is no need to define boundaries or specify an array of sub-facets, as it has been done for the other sub-domains, for example, PK (Tatto et al., 2008; Voss et al., 2011), PCK (Baumert et al., 2010; Blömeke et al., 2008; Kunter et al., 2007), TPK (see previous statements and Graham et al., in press). By meta-conceptual, we refer to what a teacher knows about her or his own knowledge in the TPCK sub-domains, and their strategies to intertwine these for planning and implementing lessons that add value by technology or by consciously refraining from using technology, respectively. Furthermore, to successfully master an ill-structured and complex domain, such as teaching with emerging technologies, the current task at hand has to be understood as another source of varying constraints (Koehler & Mishra, 2008), an aspect that Berliner (1992) has described as the sensitivity to the demands of the teaching task and the situation. This is necessary for the teacher to determine the available (cognitive) resources and strategies for reaching the desired goal state of creating solutions for the task of teaching, namely, concrete learning opportunities. Overall, TPCK is then to be understood at the level of meta-conceptual awareness that provides a high level of organization to an expert's knowledge (Koehler & Mishra, 2008; Leinhardt & Greeno, 1991), but not as a body of knowledge that is circumscribable and fixed.

In sum, Technological Pedagogical Content Knowledge is defined as a construct comprising teachers' meta-conceptual awareness of the demands of the teaching task at hand, the teacher's knowledge in the sub-domains, and the contextual constraints. Figure 5 depicts this notion of TPCK by also determining these three elements as coherent concepts. The central area of the diagram, formerly pointing to TPCK as a construct, is here replaced by the teaching task at hand. This is because following the visual logic the most central area is the most specific one, which abides by more with the idea of a concrete lesson (plan) than with that of comprehensive knowledge.

Defining TPCK as meta-conceptual awareness is, furthermore, in line with operationalizations of developing TPCK in qualitative studies, as the increase in the complexity of participants' explicit argumentations for using technology in the ways they did or planned to do (Graham et al., in press; Koehler et al., 2007). Furthermore, Kramarski and Michalsky (2010) found direct empirical support of a positive influence of self-regulatory support on preservice teachers' performance in TPCK tasks (comprehension and design of study units intertwining specific technology, pedagogy, and content).

Conclusions

Emerging technologies are a relevant factor for teaching and learning, because they impact both the visible structures of the classroom activities as well as the students' learning processes (Angeli & Valanides, 2009; Koehler & Mishra, 2008). Thus, teachers need to plan carefully in order to leverage the potential of such technology in their teaching (Webb, 2011; Webb & Cox, 2004). The TPCK framework has provided a valuable common ground for discussing these issues (Angeli & Valanides, 2009; Harris et al., 2009; Mishra & Koehler, 2006; Niess, 2005). In this chapter, we suggested to promote the development of TPCK as a construct and framework toward a more comprehensive theoretical model. Basic theoretical assumptions of the TPCK framework were elaborated by introducing the concept of mental models (Brewer, 1987; Johnson-Laird, 1980, 1983) and perspectives from the adjacent conceptual change literature (Clark et al., 2011; diSessa et al., 2004; Ioannides & Vosniadou, 2002; Vosniadou, 1994; Vosniadou & Brewer, 1992, 1994).

This chapter focused on the following three issues. First, mental models that teachers construct of the (socio-)cognitive functions of a technology were proposed to play a significant role in determining how teachers leverage their specific potential in the classroom. Second, the issue whether knowledge in the sub-domains is a necessary prerequisite for TPCK was discussed. Based on an approach introducing the notion of mental models, mediating or moderating relationships between the proposed sub-domains of the TPCK framework, and a teacher's ultimate performance on teaching tasks, were suggested. Finally, as a consequence of the mental model approach, the question was addressed how to conceptualize TPCK as a framework and as a construct. This issue was discussed in the light of coherent versus fragmented theories, based on the conceptual change literature, and suggest an understanding of the TPCK framework as coherent, and the TPCK construct as a teacher's meta-conceptual awareness of the teaching task, the available knowledge in the TPCK sub-domains, and the context.

Overall, it can be concluded that the considerations presented here provide a valuable addition to the theoretical framework of the TPCK approach. With regard to further theoretical issues, it seems important to specify the sets of presuppositions that should ideally underlie a teacher's reasoning for utilizing emerging technologies. Furthermore, these considerations constitute a starting point to define a notion of *expertise* in TPCK supported by the framework. With regard to research, these then would provide a basis for comparing teachers' presuppositions found in empirical data. More important, the considerations presented in this chapter need to be followed up by empirical research to determine the actual role of teachers' mental models for lesson planning and instruction. Along with this, the assumed predictive roles of prior knowledge in the basic sub-domains, and pedagogic beliefs, need to be investigated.

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