# Technological pedagogical content knowledge: Exploring new perspectives

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Recognising the challenges involved in understanding the knowledge that teachers need to develop to use technology in their teaching dynamics, we examined the prior research that has not clearly revealed strategic changes for teacher preparation in the digital age. The goal was to expand on the current understandings of the nature of technological pedagogical content knowledge (TPCK/TPACK) and provide a launchpad for future research by teacher educators as they contemplate revisions in the education of teachers to better prepare them for teaching in the digital age. To do so, we conducted qualitative meta-synthesis research. Within this context, we identified interpretations and comprehensions that pushed us forward in defence of new perspectives on the nature of this knowledge, regarding the comprehension of TPCK/TPACK as a transformative and homogenous knowledge; TPCK/TPACK's levels of development, including a new first level; and the need for and challenges of redesigning teacher education.

*Implications for practice or policy:*

- To better prepare teachers to teach, teachers' educators should understand TPCK/TPACK as a homogeneous and transformative knowledge.
- Teachers' training programmes should realize that often teachers are not aware of the of the possibilities of using technologies to teach.
- Teachers should have access to continuous learning to keep developing their own TPCK/TPACK during their entire career.
- Teachers and teachers' educators should understand TPCK/TPACK developing as a continuous and individual process and not as something standardised.

*Keywords*: digital age, teacher education, technological pedagogical content knowledge, meta-synthesis, transformed teacher knowledge

## Introduction

Almost all students are immersed in virtual experiences where they can find formulas, theorems and corollaries in a few seconds, using their smartphones or laptops connected to the Internet. They interact with other people in different ways and access information by surfing on the Internet waves. Living in a digital world frequently raises a concern about how to bring digital information and communications technology (ICT) to teaching and learning environments.

If society has been changing as a result of digital innovations, education and teaching practices must change as well. To transform teaching practices, teachers must understand the new reality and the relevance of bringing schools into this new era. According to Niess and Gillow-Wiles (2017, p. 79), to bring digital ICT to today's classes, teachers need to know how to "transform the content, as they know it, into content meaningful for their students while using technological learning tools".

With the beginning of the 21st century, discussions about how to prepare teachers for technology integration have evolved through the development of the technological pedagogical content knowledge (TPACK, previously referred to as TPCK) framework as the knowledge that teachers need for teaching. This movement started with Niess (2005) working with mathematics education, which was broadly extended to multiple teaching and learning contexts through key scholarly works (Angeli & Valanides, 2009; Herring et al., 2016; Mishra & Koehler, 2006).

After nearly 20 years, teacher educators, researchers, and scholars have been and continue to be challenged in describing the very nature of TPCK/TPACK. How does this knowledge differ from prior descriptions of teachers' knowledge? During this time, as noted by Niess (2019), two distinct views were advanced to clarify the nature of TPCK/TPACK:

- The *integrative, heterogeneous vision* highlights the distinctness of the multiple subsets in the TPCK/TPACK model and calls for specific preparation in each of the domains as key to developing teacher knowledge for the digital age. Although the integrative view was perhaps initiated from the original model for the knowledge construct proposed in Koehler and Mishra (2008), multiple scholars have relied on this vision in their research (e.g., Cox & Graham, 2009; Harris & Hofer, 2011; Koehler & Mishra, 2005; Mouza et al., 2017; Phillips et al., 2017; Schmidt et al., 2009; Yan et al., 2018).
- The *transformative, homogeneous vision* describes teachers' knowledge as a distinct whole, created through the amalgamation of the multiple subsets created by the intersections of content, pedagogy and technology, such that they are rearranged, merged, organized, integrated and assimilated so that none are any longer individually discernible. This view developed from connections made with Shulman's (1986) conceptualisation of pedagogical content knowledge (PCK) in early works using ICT-related PCK and TPCK as initially described by Angeli and Valanides (2005) and Niess (2005). As time progressed, multiple scholars upheld this vision through their work (e.g., Angeli & Valanides, 2013, 2015, 2018; Archambault & Barrett, 2010; Archambault & Crippen, 2009; Graham, 2011; Krauskopf et al., 2020; Lee & Kim, 2017; Lyublinskaya & Tournaki, 2013; Niess et al., 2010).

The dissimilarity in these two visions has challenged teacher educators in determining how they need to design programmes that adequately prepare teachers with the knowledge for teaching in the digital age. This issue has raised the concern expressed by Saubern et al. (2020), that "there is a need for a fundamental shift in the trajectory of TPACK research, that is, to pay greater attention to understanding the knowledge that teachers need to use technology effectively for teaching and learning" (p. 1).

Recognising the challenge, this paper proposed to more carefully examine the prior research that has not clearly revealed strategic changes for teacher preparation in the digital age. The goal was to expand on the current understanding of the nature of TPCK/TPACK and provide a launchpad for future research by teacher educators as they contemplate revisions in the education of teachers to better prepare them for teaching in the digital age.

## Theoretical premises

TPCK was initially proposed as a specialised amalgam of technology, content and pedagogy through the work of multiple scholars (Angeli & Valanides, 2005; Koehler & Mishra, 2005; Niess, 2005; Pierson, 2001; Zhao, 2003). In 2006, Mishra and Koehler formally announced this knowledge using the abbreviation, later revised to TPACK (Thompson & Mishra, 2007). For multiple scholars and educators, the TPACK abbreviation points towards the integrative view of the construct, citing the importance of the various subsets in the model. However, several scholars and educators focused on a transformative view. Angeli and Valanides (2013) opted to continue using TPCK, "because TPACK appears to be more associated with the integrative view rather than the transformative view" (p. 202). In recognition of these two views, this paper used TPCK/TPACK to capture the worldwide understandings concerning teachers' knowledge for the 21st century.

Teacher knowledge has emerged through multiple scholars' recognition of important aspects of the knowledge that teachers rely on for guiding student learning. Much of the background leading to the TPCK/TPACK conception emerged from the 1980s to the 1990s in considering the concept of PCK. Discussions regarding the kinds of knowledge necessary for effective teaching practices can be traced to Shulman (1986) through his proposal, which revised the interpretation of teachers' knowledge when he claimed that PCK was needed for working in teaching and learning environments.

**The PCK construct**

Shulman (1986) proposed PCK explaining it as teachers' capacity to use the most productive forms of representation, examples, explanations, relations and demonstrations. Basically, he proposed PCK as knowledge that involved the most useful ways of representing and explaining scientific knowledge to make it more accessible to students. His notion of PCK included the understanding of what might make the learning process easier. He also proposed PCK as including the knowledge of possible preconceptions and/or misconceptions that exist in students' minds when they explore specific ideas in their classes.

With his proposal, Shulman (1986) argued that content knowledge (CK) and pedagogical knowledge (PK) should not be interpreted as two separate sets of teacher knowledge, but that the intersection of these two domains should guide teachers' work. He decried the notion of dismantling the dichotomy between these two kinds of knowledge because of the erroneous perception where teacher educators formulated their courses in segregated approaches with some curricular disciplines dealing only with content matter, while others dealt only with pedagogical issues. According to Angeli and Valanides (2009) "the construct of PCK constituted a special amalgam of content and pedagogy and was seen as the kind of knowledge that separated an expert teacher in a subject area from a subject area expert" (p. 155). In short, Shulman proposed that teachers' PCK was a distinct whole where content and pedagogy were merged and assimilated such that neither was any longer individually discernible.

Not only was the notion of PCK difficult to understand but it was soon confronted with the challenge of technology's role in education. With the widespread use of digital ICT by the 21st century, student needs and technology's role in education emerged and gained recognition through reflections on the teaching and learning processes. The question for teacher educators was not only how to guide teachers in developing PCK but also in understanding how technology might be used in the educational process.

**The TPCK construct**

Understanding what it means to teach and learn with technology was quickly viewed as an essential concern for educators to assure that technology would be an effective component in teaching and learning. With this concern, according to Harris et al. (2017), researchers began to investigate how this technological scenario could affect teachers' pedagogical practices. The challenge of understanding these aspects of teaching and learning with technologies was the core of the ideas that guided multiple scholars (Angeli & Valanides, 2005; Koehler & Mishra, 2005; Niess, 2005; Pierson, 2001; Zhao, 2003) in consolidating their thinking toward the idea of the TPCK/TPACK framework.

Focusing on the construct of TPCK/TPACK, Mishra and Koehler (2006) insisted that teachers must go beyond just learning about digital ICT tools. Teachers must be open to testing and experimenting, developing the habit of continuous adaptation, creating new abilities to be able to track the occurring changes. In doing so, teachers might learn how to revise their conceptions and constantly transform their practices.

Niess (2005) defined TPCK/TPACK components based on the central elements used by Grossman et al. (1989) for PCK. These components illuminated the transformations in teachers' knowledge in ways that supported them in teaching with technologies. With respect to these components, according to Niess (2015), teachers relied on these ideas:

- Overarching conception about the purposes for incorporating technology in teaching subject matter topics: This component describes what teachers know and believe about the nature of the subject matter, what is important for students to learn and how the technology supports learning as the basis for their instructional decisions.
- Knowledge of students' understandings, thinking and learning in subject matter topics with technology: For this component, teachers rely on and operate from their knowledge and beliefs about students' understandings and thinking when engaged in learning specific content topics with appropriate technologies.
- Knowledge of curriculum and curricular materials that integrate technology in learning and teaching subject matter topics: With respect to this curricular component, teachers examine and implement various technologies for teaching specific topics. Through this activity, they consider how concepts and processes within the context of a technology-enhanced environment are organised, structured and assessed in the curriculum.
- Knowledge of instructional strategies and representations for teaching and learning subject matter topics with technologies. This instructional knowledge focuses on teachers adapting their instruction for guiding students in learning about specific technologies as they learn the content with those technologies. They employ specific representations with technologies to meet specific instructional goals and the needs of the learners in their classes.

With more than 5 years of research-based observations of teachers exploring spreadsheets as mathematical learning tools and teaching mathematics with spreadsheets, Niess et al. (2007) and Niess et al. (2010) formulated and clarified five TPCK/TPACK levels to describe teachers' acceptance or rejection of specific technologies as subject matter learning tools. Niess and Gillow-Wiles (2013, p. 223) formulated these levels to describe teacher actions with appropriate technologies with respect to their specific content and grade level expertise:

"*Recognizing* (knowledge) where teachers are able to use technologies and recognize the alignment of the technologies with the content but are not yet integrating the technologies in teaching and learning in their content and at their grade level.
*Accepting* (persuasion) where teachers form a favorable or unfavorable attitude toward teaching and learning the content with appropriate technologies, at their specific grade levels.
*Adapting* (decision) where teachers engage in activities that lead to a choice to adopt or reject teaching and learning specific content topics with appropriate technologies.
*Exploring* (implementation) where teachers actively integrate teaching and learning of content topics with appropriate technologies.
*Advancing* (confirmation) where teachers evaluate the results of the decision to integrate teaching and learning the content with appropriate technologies and are willing to make changes in the curriculum to take advantage of the affordances of the technologies."

Porras-Hernández and Salinas-Amescua (2013) framed the importance of context in the TPCK/TPACK model, identifying the micro-level context to clearly describe the in-class conditions for learning. From their perspective, the context in which teachers learned to teach significantly shaped their vision of teaching. An important aspect of how teachers learn to teach is that they typically do so within the context of a face-to-face environment – as in their K-12 and college classes and their teacher preparation programmes where they focus on methodologies that work in face-to-face instruction, through their participation in student teaching and through their teaching in K-12 classrooms.

As we can see in Figure 1, Mishra (2019) reconfigured the TPCK/TPACK visual description to more accurately describe the interactions among the three kinds of knowledge. In particular, this revision recognised the importance of the context to highlight the ConteXtual Knowledge (XK) .

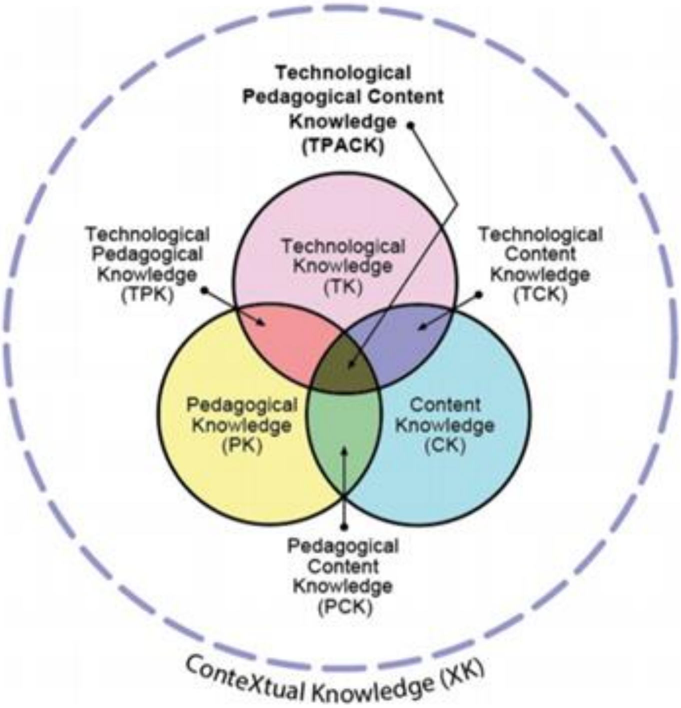


*Figure 1.* The TPACK image. Source: © Punya Mishra, 2019.

The new conception of TPCK/TPACK reframed the thinking about teachers' knowledge from ideas proposed in previous conceptualisations. This new recognition suggested that revised approaches were needed to develop a better understanding of the work teachers must do and the knowledge they need in order to do that work.

As argued by Romeo et al. (2012, p. 958), TPCK/TPACK highlights "the connections, interactions and affordances, and constraints between and among content, pedagogy and technology". The relationships among the three domains of TPCK/TPACK are then dynamic, complex and permeated by different nuances. Some digital ICT may restrict a few actions in class or increase representation possibilities, for example. Teachers must consider these effects within their pedagogical decisions. According to Lyublinskaya and Kaplon-Schilis (2022, p. 2), "the central TPACK domain is then considered as an integrated knowledge, a distinct form of knowledge where the inputs have been integrated in such a way that none are individually discernible".

This conception not only recognised the nature of TPCK/TPACK but also challenged teacher educators to identify how to improve teaching and learning with technology. How must teacher preparation change to better prepare teachers and pre-service teacher education students to use technology effectively in their teaching? Examination and analysis of the past 20 years of the research results may bring clarity to this question.

## The research and the methodological approach

The research described in this paper has a qualitative nature and can be understood as a meta-synthesis, which is defined as research that "uses qualitative methods to analyze, synthetize and interpret" previous studies (Major & Savin-Baden, 2010, p. 10). Meta-synthesis aims to perform a critical evaluation of

previous research to develop new knowledge. Although this kind of methodological approach is more intensively used in nursing research, it is common in education studies (Aspfors & Fransson, 2015; Brown & Lan, 2015; Romli et al., 2022).
To perform the meta-synthesis, we followed the steps suggested by Major and Savin-Baden (2010). The first step identified relevant studies in the area of the present paper. Therefore, we searched in the first months of 2022 through online databases such as Educational Resources Information Center, Google Scholar, ResearchGate, and ScienceDirect.

We conducted an initial reading of the abstracts of the findings (more than 150 papers), excluding some studies to reduce the analysis corpus. This careful selection was based on the relevance of these studies to the present meta-synthesis. Next, we conducted a whole reading of the remaining papers and used as criteria to refine the analysis corpus the relevance of the studies and the superposition of ideas. After this work, the data set was reduced to 18 studies.

In the next meta-synthesis' phase, we grouped these studies, as described in Table 1, into three categories: visions of TPCK/TPACK, development levels of TPCK/TPACK, and teachers' education.

Table 1
*Categories in the meta-synthesis*

| Category | Studies |
|---|---|
| Visions of TPCK/TPACK | Angeli and Valanides (2009, 2015, 2018)<br>Niess (2013)<br>Aldemir (2017)<br>Oliveira et al. (2018)<br>Cejas-Léon and Navío-Gámez (2020)<br>Sauber et al. (2020) |
| Development levels of TPCK/TPACK | Niess et al. (2009)<br>Niess (2013)<br>Tatar et al. (2018)<br>Bueno, Ballejo et al. (2021)<br>Bueno, Lieban et al. (2021) |
| Teachers' education | Koehler and Mishra (2005)<br>Tondeur et al. (2012)<br>Niess (2015)<br>Niess and Gillow-Wiles (2017)<br>Lyublinskaya and Du (2021)<br>Lyublinskaya (2022) |

In the third phase, we compared and synthesised the studies in each category, carefully considering them to help us develop new perspectives about TPCK/TPACK. These new perspectives "result from making 'inferences' based on the findings that emerged through the process of data analysis and synthesis" (Brown & Lan, 2015, p. 4).

This process has its limitations, so we did not, nor was it our intent to, consider the entire set of TPCK/TPACK research publications. Thus, we chose to conduct the meta-synthesis, limiting our evaluation through the selection of specific categories of research studies. For the subject matter, we focused more on mathematics as this content was consistently represented through research publications throughout the 20 years involving research that considered multiple K-12 teacher education levels. Also, as argued by Gadamer (1997), despite our receptiveness to the alterity of the texts we read, our results are limited by our previous ideas that are explicitly involved in the analysis.

## Visions of TPCK/TPACK

The review of the literature revealed two distinct views for clarifying the nature of TPCK/TPACK: the integrative, heterogeneous vision; and the transformative, homogenous vision.

### Integrative, heterogeneous vision of TPCK/TPACK

Multiple researchers have focused on TPCK/TPACK as an integrative construct. This view may have arisen from the initial model proposed by Koehler and Mishra (2008), highlighting the various subsets exposed by the intersections of CK, PK and technology knowledge (TK) that resulted in technological pedagogical knowledge (TPK), technological content knowledge (TCK), pedagogical content knowledge (PCK) and technological pedagogical content knowledge (TPCK/TPACK). This vision recognises and values the multiple subsets in the model and is described as “the total package required for integrating technology, pedagogy, and content knowledge in the design of curriculum and instruction” (Jang & Chen, 2010, p. 555).

As researchers sought to assess teachers’ TPCK/TPACK, according to Koehler et al. (2012), they frequently measured the construct through surveys. The most widely used survey instrument for pre-service teachers was the survey created by Schmidt et al. (2009), which consisted of 55 items focused on the pre-service teachers’ self-assessment of each of the TPCK/TPACK subsets and its intersections. The vision that resulted from several researchers promoted a more integrative view of TPCK/TPACK, highlighting the distinctness of the multiple subsets and their interactions as important constructs for developing TPCK/TPACK.

Multiple descriptions provide a sample of this work that drew from the heterogeneous vision. Saengbanchong et al. (2014) developed a TPACK-S model, by adding a student component to TPCK/TPACK. They declared that, in this extended TPCK/TPACK model, the teacher should be able to recognise the information required for teaching individually to students. Lee and Kim (2014) proposed a model for developing pre-service teachers’ TPCK/TPACK as TPACK-IDDIRR (introduce, demonstrate, develop, implement, reflect, and revise). This instructional design model called for multi-disciplinary technology integration courses grounded in the learning by design approach developed by Koehler and Mishra (2005).

Hsu et al. (2015) created the TPACK-Practice (TPACK-P) framework, which reflected how teachers applied TPCK/TPACK while teaching science in their classrooms. They studied eight dimensions of knowledge and 18 indicators. Huang (2018) developed a T-TPACK framework for mathematics teachers that included TTP (technological teaching pedagogy), TPACK, and TTCK (technological teaching content knowledge). Arifin et al. (2020) developed a new model for building knowledge with special expertise in the field of vocational education and learning, also shifting pedagogical concepts towards andragogy. This model was referred to as “technology, andragogy, work, and content knowledge,” or TAWOCK. Guggemos and Seufert (2021) built a new structure using both the TPCK/TPACK framework and the will, skill, and tool model. This structure consisted of the components of TK, TPK, TPCK/TPACK, technological collaboration knowledge (TCoK), and attitudes. Essentially, as with the previous proposals, these researchers viewed TPCK/TPACK as the intersection of the multiple subsets that were identified in the original TPCK/TPACK model or were revised with additional subset considerations. Moreover, from this position, the separate, individual domains of the knowledge are considered as consistently in action and observable as teachers rely on their TPCK/TPACK for decision-making, prompting Phillips et al. (2017) to recommend that TPCK/TPACK be considered as the “heterogeneous considerations of teacher knowledge” for “researching teacher knowledge” (p. 26).

### A transformative, homogeneous vision of TPCK/TPACK

Alternatively, multiple researchers have focused on TPCK/TPACK as a transformed knowledge that integrates the various subsets in the model. The transformation was initially described by Niess (2005) as she considered “the development of a PCK that integrates knowledge of technology with knowledge of the content and knowledge of pedagogy—a TPCK" (p. 511). Angeli and Valanides (2009) further amplified the description of the centre TPCK/TPACK domain as an extension of Shulman's concept of PCK stating that "This body of knowledge goes beyond mere integration or accumulation of the constituent knowledge bases, toward transformation of these contributing knowledge bases into something new" (p. 158).

After years of research, Niess et al. (2009) enhanced the teacher knowledge description by identifying a 5-level developmental process (recognising, accepting, adapting, exploring and advancing) as teachers' knowledge developed towards the notion of TPCK/TPACK as a distinct teacher knowledge. In 2013, Niess clarified the model, connecting the four TPCK/TPACK components for each of the five levels in order to emphasise the differences in teachers' knowledge levels. Lyublinskaya and Tournaki (2013) used this enhanced model to examine pre-service teachers' lesson plans in response to a variety of strategies and techniques for using instructional technology in teaching concepts.

Lyublinskaya and Kaplon-Schilis (2022) continued examining various learning trajectories in pre-service teachers' courses– assessing the influence on the participants' TPCK/TPACK level development and how the course redesigns in the were effective in transforming their TPCK/TPACK. They pointed out that the "TPACK framework quickly became a widely referenced conceptual framework within teacher education" (p. 2).

During this same time, other scholarly works focused on TPCK/TPACK as a distinct body of knowledge. Angeli and Valanides (2009) argued that the transformative view is better understood in terms of competencies that teachers need to develop for effectively teaching with technology. In 2013, they proposed technology mapping as an approach for developing teachers' knowledge for teaching with technologies. Koh and Divaharan (2011) presented a teaching process to advance the TPCK/TPACK of pre-service teachers during the teaching of ICT tools through three stages of fostering teachers' acceptance and technical proficiency, pedagogical modelling, and pedagogical application. Interestingly, Lee and Kim (2017) shifted their previous views on TPCK/TPACK development. They presented a TPCK/TPACK-based instructional design model that "incorporates the distinctive, transformative, and integrative views of TPACK into a comprehensive actionable framework" (p. 1627). Their new threefold model helped pre-service teachers strengthen their TPCK/TPACK by understanding TPCK/TPACK, experiencing TPCK/TPACK, and practising TPCK/TPACK. The key to their ideas was that they viewed the knowledge as a distinct body of knowledge.

As TPCK/TPACK is the focus of a wide range of scientific research (Bueno et al., 2022; Romeo et al., 2012; Saubern et al., 2020) and has started influencing the design of teaching foundation courses around the world, it is important to recognise how these visions have emerged and how they have influenced the preparation of teachers.

## New perspectives on TPCK/TPACK

According to Lyublinskaya and Kaplon-Schilis (2022), a gap does exist between the theoretical TPCK/TPACK framework and the results of practical research. Therefore, we understand that a deeper reflection on the TPCK/TPACK framework and its levels of development for teachers is essential. Based on the meta-synthesis, we focused our attention on three fundamental aspects in order to access a better definition so that the ideas and concepts of TPCK/TPACK potentially evolved: TPCK/TPACK as a transformative and homogenous knowledge; expansion of the development levels to include the pre-recognising level; and the importance of teachers never stopping in developing their knowledge for teaching with technology.

**Towards a homogeneous and transformed knowledge for TPCK/TPACK**

We propose that TPCK/TPACK should be seen more as a homogeneous mixture of knowledge rather than a heterogeneous one. Thus, TPCK/TPACK can be understood as a special amalgam of technological, pedagogical and content knowledge.

This perception means that TPCK/TPACK is greater than the simple sum of its parts. A teacher with a great deal of TPCK/TPACK will not think, for example, about their calculus class considering first mathematics issues regarding derivative or integrating functions followed by pedagogical aspects of how to teach this subject to finally wonder which technological tool they might use in this class. This teacher will plan everything at once, building bridges to connect, in the best possible way, technology, pedagogy and content.

This kind of thought is recursive. There are no preconceived steps that need to be followed, there is no order between the three domains of TPCK/TPACK to be taken. It is a back and forward reflexive movement that considers it all together. Teachers with a well-developed TPCK/TPACK could not say that they are thinking about technology, pedagogy or content – they think about it all at the same time.

In this context, in order to discuss TPCK/TPACK, there is no reason to focus on each one of the subsets or on the interceptions of only two of them. Teachers need to consider the homogeneous mixture when thinking about developing their TPCK/TPACK throughout their pre-service and in-service teacher development.

Aldemir (2017) suggested that TPCK/TPACK can be compared, using a new metaphor, to lemonade, that is, a homogenous mixture of lemon, sugar and water. In spite of being a structure consisting of these three elements, it is different from each one of them and transcends the simple sum of its ingredients.

The segregated, heterogeneous vision is exactly one of the biggest problems identified in teacher professional development courses. As Cejas-Léon and Navío-Gámez (2020) stated, there are many courses focused only on technological skills and many others aiming to develop pedagogical perceptions or content matter comprehension. But it is difficult to find courses that manage to work with a homogeneous perspective of technology, pedagogy and content. According to Oliveira et al. (2018), this context leads teachers to conceive of technology as a tool to make their job easier or an optional resource that they can use to reach curriculum goals.

There is still "a lack of progress towards the original goals of TPCK/TPACK, that is, understanding the knowledge that teachers need, and that pre-service teacher education students need to learn to teach effectively with technology" (Saubern et al., 2020, p. 2). With this same concern, we argue that the first step to helping teachers to develop their TPCK/TPACK is to provide them with formative experiences that improve their perception of TPCK/TPACK as a homogeneous and transformed knowledge.

To reach this kind of comprehension, these teachers need to know how it feels to learn with technology (Tondeur et al., 2012). We believe that this kind of experience can help teachers to understand how a well-structured didactical interaction, developed using TPCK/TPACK as a homogeneous knowledge, can affect learners and make the learning process more attractive and constructive.

**An additional level of TPCK/TPACK's development**

Tatar et al. (2018) conducted a study on solid objects with high school mathematics teachers in Turkey. They aimed to determine the TPCK/TPACK levels of teachers using the Niess (2013) model. An interesting situation emerged from this research, because they noticed that some teachers used the interactive whiteboards only as a projection device. While analysing the data, the recognising level, which is the initial level in the Niess (2013) model, was insufficient for explaining this situation.

When the researchers examined the teachers' lesson plans, they observed that the teachers did not mention any technology. Similarly, in the micro-teaching observation, the researchers also noticed that there was no use of a specific technology to teach the subjects. When they investigated the reason for the lack of mention, the teachers stated that they lacked knowledge about any technology that could be used in that context.

Niess et al. (2009) stated that a teacher at the recognising level sees mathematics as a lesson that is learned by memorising rules and procedures without technologies. They also stated that a teacher at this level knows that digital resources can be used as tools to help with mathematical thinking. In other words, the expression of knowing but choosing not to use comes to the fore at the recognising level.

On this level, there is also the teachers' view that if digital ICT are used in learning, it can do all the mathematical work while students end up not being involved in classes. In addition, a teacher at this level of TPCK/TPACK development may think that digital ICT hinders students' mathematical thinking and reasoning skills.

But Tatar et al. (2018) saw that teachers did not use technology in any way and that they did not take it into account in students' learning, understanding and thinking. In the interviews after the micro-teaching, teachers stated that they did not know the technology abilities of the students and they were not aware of the possibility of using digital ICT to increase their students' learning.

At the recognising level, according to Niess (2013), teachers have some comprehension of the impact of technology in students' learning, thinking and understanding. However, in related research, Tatar et al. (2018) noted that no idea about technology was stated or known.

In another situation pointed out by Tatar et al. (2018), teachers used interactive whiteboards only to solve some questions by reflecting shapes – in the same way as using a blackboard. A similar context can be seen in Bueno, Ballejo et al.'s (2021) research, which pointed out that presentation software (as PowerPoint) was the most used by teachers. These teachers also used technologies to keep doing the same thing teachers have been doing for the last 70 years or so: present the same texts and images in every single class, so students can copy and memorise the information from the display board or from the data shown on the screen.

In the fourth component of the recognising level, Niess (2013) explained that teachers at this level argued that digital ICT skills should be taught to their students independently of mathematics. They defended the notion that these resources can be used in class only after explaining mathematical ideas. They also stated that digital ICT should be seen as a teacher-centred tool. However, in the study of Tatar et al. (2018), teachers preferred to use conventional teaching methods in their classes instead of any technology. They focused on formulas, solutions to questions and traditional lectures.

Facing this reality, Tatar et al. (2018) were directed to a question: How accurate is it to place technology-unaware teachers at a level where there are teachers who know about subject-specific technologies in learning, teaching, curricula, and curriculum materials but do not prefer to use them for various reasons? The recognising level is the initial level in Niess' (2013) model. The teachers in Tatar et al.'s (2018) research, on the other hand, are excluded from the definitions made for this level. This situation then supported, as displayed in Figure 2, the creation of a new first level: the *pre-recognising* level.

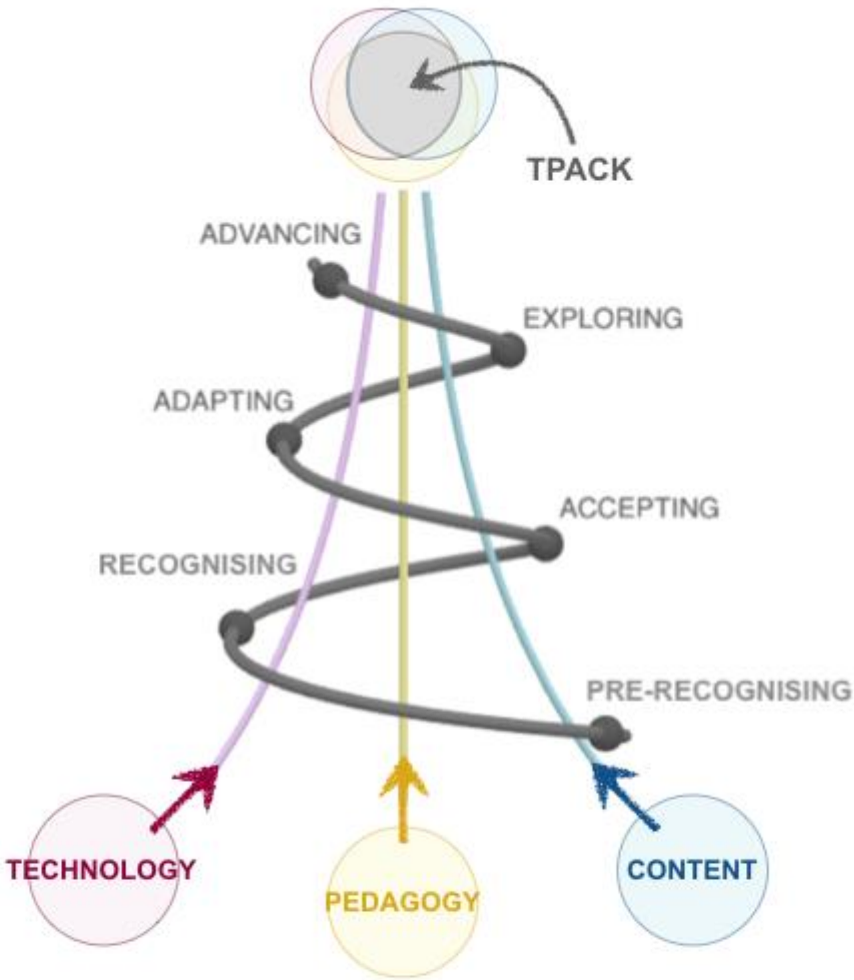


*Figure 2.* Description of TPCK/TPACK components including the pre-recognising level

This visual description of the TPCK/TPACK development is inspired by the drawing presented by Bueno, Lieban et al. (2021). In their work, they argued that the spiral movement leads to the idea of passing through proximal zones repeatedly along the TPCK/TPACK development pathway.

What has changed in this new visual is the addition of the pre-recognising level to recognise that often teachers are not aware of the possibilities of using technologies to increase the opportunities for their students to learn mathematics. More specifically, when focusing on the four TPCK/TPACK components, Tatar et al. (2018) described that in the pre-recognising level teachers do not have knowledge of technological resources that can be used in mathematics teaching and learning environments; are unaware of how students can use digital ICT to learn mathematics-specific subject matter; do not have knowledge of how to use technological resources to teach mathematics; and have no knowledge of how to use digital ICT to improve the mathematics curriculum or even to increase curricular materials.

**Redesigning teacher education**

Recognition of TPCK/TPACK as a transformed distinct knowledge that teachers rely on for teaching with technology mirrors that which happened after Shulman's (1986) identification of PCK in which teacher educators questioned, challenged, researched and redesigned more appropriate learning trajectories for preparing teachers to teach. Similarly, with TPCK/TPACK, teacher educators have investigated methods for preparing teachers to teach with technology. The challenge has been to identify learning trajectories for guiding teachers' knowledge development such that they are engaged in thinking that enhances their knowledge. They need opportunities that confront their current thinking, in which they are able to reflect and make revisions in teaching the content with appropriate digital ICT based on their new enhanced knowledge (Borko & Putnam, 1996). How do the enhanced developmental levels of TPCK/TPACK support the design of learning trajectories aimed at developing this knowledge through pre-service and in-service programmes? Some studies of teacher preparation programme development provide direction in the examination of the design of learning trajectories that support the continued development of TPCK/TPACK.

After years of research following mathematics teachers' knowledge development with respect to teaching with spreadsheets, Niess (2015) revealed enhanced descriptions of the five TPCK/TPACK levels with respect to the four components. She described multiple learning trajectories for transforming teachers' knowledge. An example of the learning trajectories for transforming in-service teachers' knowledge included efforts at using the Koehler and Mishra (2005) learning by design process. This model described a learning trajectory that spiralled stages of more complex instructional design where TPCK/TPACK reflection was at the end of the process. Throughout each phase, the in-service teachers investigated and experienced the technology through their educational lenses.

Considering pre-service teachers' TPCK/TPACK development, Lyublinskaya and Du (2021) described pedagogical practices and teaching states with instructional technologies in an online summer course. Their study identified effective practices with technologies supporting the pre-service teachers' development of TPCK/TPACK. The results revealed that an online immersive experience created a virtual student-centred space to nurture collaborative inquiry and contributed to the growth of their knowledge for teaching with technologies.

Lyublinskaya (2022) continued her efforts exploring patterns of pre-service teachers' learning trajectories specifically using digital timelining analysis to select and organise the experiences, online artefacts and self-reported data along with TPCK/TPACK learning trajectories for gaining a deeper understanding of contextual and personal factors leading to variations in individual learning trajectories.

In addition to the work describing various learning trajectories, Niess and Gillow-Wiles (2017) relied on ideas that evolved with the development of PCK, specifically that of expanding teachers' pedagogical reasoning. They claimed the challenge is to identify and describe a 21st-century technological pedagogical reasoning process that incorporates multiple technologies. Their studies focused on the incorporation of a system of technologies as a pedagogical tool, where the group of technologies are engaged in concert and combine to reshape the teachers' technological pedagogical reasoning. The result is a transformation of their TPCK/TPACK through engagement in a system of multiple technologies in inquiry, communication and collaboration. They recommended implementing such a pedagogical approach to refine teachers' mental models for integrating multiple technologies when teaching mathematics, through reliance on their increasingly complex technological pedagogical understanding as they learned about technologies and teaching with those technologies.

Tondeur et al. (2012) highlighted the relevance of the teacher educators' practices as examples to their students. They argued that ICT should be present in the teachers' entire training curriculum courses to help these teachers to understand the educational reasons for using ICT in class and to experience the impact of ICT on teaching and learning different subject matters. In these contexts of formative experiences, in-service and pre-service teachers can understand how technologies can support learning, from the student point of view.

## Final considerations and understandings

Given today's technological world, the concern with pedagogical practices that use digital resources has been gaining more space for discussions. The present study initially focused on expanding the current understanding of the nature of TPCK/TPACK to then raise new themes that provide future research related to teacher education.

Almost 20 years of TPCK/TPACK studies have passed, fostered by ideas for teacher preparation programmes as initially described in Niess (2005). During this period, several elements of this theory were explored and investigated, highlighting the discussion about the different contexts of teaching and learning and the insertion of the instructional context.

Through the meta-synthesis, we found two distinct views on the nature of TPCK/TPACK. The first view has a clear distinction among its subsets. This view suggests that teachers' education must recognise and attend to building knowledge in each of the subsets, indicating that specific preparation in each domain is the key to developing teacher knowledge for the digital age.

The second vision of TPCK/TPACK presents a transformative and homogeneous view, describing knowledge as the amalgam of multiple subsets and their multiple intersections, such that in TPCK/TPACK none of them is individually discernible. The key understanding gathered from this examination is that this vision of TPCK/TPACK is a discrete knowledge much like that of PCK that continues to evolve as teachers are engaged in a technological pedagogical content reasoning to guide teaching and learning with digital ICT. Although this knowledge is seen as a transformed distinct body of knowledge, it is continually evolving and developing as content, pedagogy and technologies change.

Our study revealed three perspectives that we consider promising for future investigations. The first concerns TPCK/TPACK as a homogeneous and transformed knowledge. Recognising that such a model can be understood as a special amalgamation of technological, pedagogical and content knowledge, it is homogeneous and, thus, greater than the simple sum of its parts. We think that this comprehension of TPCK/TPACK allows researchers and teacher educators to focus and work on TPCK/TPACK as a whole, rather than thinking about seven types of knowledge (subsets and its intersections) one by one. Therefore, it is important that researchers and scholars extend the direction in teacher preparation programmes towards the amalgamation. Consider such questions as: What are the important skills and beliefs that must be formed and cultivated throughout these programmes? How does TPCK/TPACK change for different content areas? What happens when the context in which these ideas are occurring changes, as was realised during the pandemic? What experiences are essential in building a TPCK/TPACK? What support do student teachers need as they practice teaching with technologies?

The second perspective is related to the insertion of the pre-recognising level of teachers' TPCK/TPACK development. The spiral movement indicates that the development leads to the idea of passing through proximal zones repeatedly along the TPCK/TPACK development pathway. Moreover, since there are still teachers who do not have knowledge of technological resources and are unaware of how their students can apply digital ICT to learning, it is necessary to include the pre-recognising level of TPCK/TPACK development. Therefore, researchers and scholars might develop special programmes for teachers, related to this first TPCK/TPACK level, so that teachers have the chance to learn about digital ICT and how it can operate in teaching and learning environments to enhance student learning.

The third perspective highlights that digital ICT and the contexts in which teachers teach are constantly changing. Therefore, teachers need ongoing support to continue the transformation of their TPCK/TPACK. This requires teachers to rethink and relearn ways for teaching with these technologies. Their technological pedagogical reasoning must shift so they are able to transform their practices to make content more meaningful for their students by using ICT. The significance is that teachers must have opportunities to continue learning to nourish their mental models for teaching with technologies. In this sense, we agree with Tondeur et al. (2012), when they argued that it is important that teacher educators act as role models in using ICT in teacher training courses.

Theses perspectives suggest that future researchers, scholars and teacher educators should focus on professional development opportunities directed towards newer technologies and on how digital ICT can support teachers in transforming their thinking about how technologies are useful in various content areas with supportive pedagogical strategies. Our final challenging question is: Are there new directions for guiding teachers while they are also teaching?

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