Brianza, E., Schmid, M., Tondeur, J., & Petko, D. (2022). Situating TPACK: A systematic literature review of context as a domain of knowledge. *Contemporary Issues in Technology and Teacher Education, 22*(4), 707-753.

Situating TPACK: A Systematic Literature Review of Context as a Domain of Knowledge

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The technology, pedagogy, and content knowledge (TPACK) framework describes seven domains of knowledge that teachers rely on for teaching with technology. The framework includes an eighth element labelled “contexts,” representing the situated nature of instruction. This latter construct has been inconsistently represented and defined across the literature as well as interchangeably considered both the settings surrounding teachers’ TPACK and an additional domain of knowledge. Disentangling these two conceptually different constructs and viewing context as a domain of knowledge may be a crucial addition to teachers’ TPACK, given that teachers’ abilities to account for contextual complexity is a feature of teaching expertise. This systematic review focused on the literature addressing context specifically as a domain of knowledge (XK) of TPACK. Database searches retrieved 675 records, of which 47 contained substantial references to XK and were retained for final analyses. Findings present XK as a complex construct described by three levels (micro, meso, and macro) and three dimensions (social, resources, and content). Based on these findings, the authors discuss the structure of XK and propose an extension of the TPACK framework for promoting a more systematic approach to TPACK as a situated construct relevant for research on teacher expertise and teachers’ professional development.

Digital technologies have significantly influenced the educational landscape, not only by reshaping what needs to be taught and how, but also by reshaping the roles and relations of all the actors involved (i.e., learners and teachers as well as administrators, parents, and policymakers; Lingard et al., 2021). To prepare individuals to be active members of society, today schools are also called to develop learners' technical skills, know-how, and "critical digital literacy" (UNESCO, 2021, p. 72). Additionally, educational technologies have extended and redefined approaches to teaching and learning (Zinger et al., 2017). Thus, teaching in the digital era, not only requires teachers to possess a degree of tech-savviness but, more importantly, to also have a deeper understanding of the educational potential of these tools and the knowledge for teaching learners using technology (Starkey, 2019).

The technological pedagogical content knowledge framework (or technology, pedagogy, and content knowledge [TPACK]; Mishra & Koehler, 2006) is currently one of the most prominent frameworks for describing the knowledge teachers need to teach subject matter effectively with technology (e.g., Hew et al., 2019). This framework extends Shulman's (1986, 1987) framework for pedagogical content knowledge (PCK) to include knowledge of technology as another distinct domain of knowledge for teaching in the current technological age.

The basic TPACK framework (see Figure 1) consists of three overlapping circles, which result in seven unique knowledge domains: pedagogical knowledge (PK), content knowledge (CK), technological knowledge (TK), pedagogical content knowledge (PCK), technological content knowledge (TCK), technological pedagogical knowledge (TPK), and technological pedagogical content knowledge (TPCK). The TPACK framework emphasizes teaching as a dynamic activity, rather than taking a prescriptive stance, and presents teachers' understanding for ways the core domains (i.e., TK, PK, and CK) can be optimally combined and fit together to enhance learning as key to effective teaching with technology (Koehler & Mishra, 2008).

Since its introduction, the TPACK framework has contributed to research on teacher knowledge (e.g., Willermark, 2018), teacher education (e.g., Wang et al., 2018), and instructional design (e.g., Chai et al., 2013), emphasizing it as a valuable framework for these fields. Nevertheless, TPACK research is associated with a number of critiques and limitations (e.g., Brantley-Dias & Ertmer, 2013; Kimmons, 2015; Zinger et al., 2017), and recently, publications appear to have somewhat stagnated, despite the literature outlining a number of unaddressed conceptual and empirical points for advancing the field (Petko, 2020).

One crucial aspect that calls for attention is the contextualized nature of teachers' knowledge (e.g., Chai et al., 2013; Koehler & Mishra, 2008, 2009; Putnam & Borko, 2000). The lack of systematically accounting for context in TPACK research has, at least in part, contributed to issues of fuzziness surrounding the framework (Kimmons, 2015, p. 58). The need for acknowledging context is supported, on one hand, by empirical reports of the contextualization of assessment instruments to have benefits for measuring TPACK (Chai et al., 2011; Wang et al., 2018). On the other hand, from a practical perspective, integrating educational technologies into teaching and learning settings has amplified the importance of considering context (e.g., cultural factors, students' home environments, etc; Zinger et al., 2017).

In fact, recently Mishra (2019) emphasized the need to upgrade the TPACK framework by regarding its context as an additional domain of teachers' knowledge (i.e., contextual knowledge; XK). This view of context as a domain of knowledge not only promotes conceptual consistency within the framework, but also highlights contextual knowledge as a construct that supports teachers' instruction and one that can be assessed and developed, highlighting it as a key component for extending research on teachers' knowledge and teacher education.

Educational contexts, though, are complex, dynamic, and ill-structured settings, each presenting its own unique constellation of features (Koehler & Mishra, 2008). Perhaps the very complexity of this construct has led it to be under- and inconsistently represented in TPACK research (Kelly, 2008; Rosenberg & Koehler, 2015b). Yet, in addition to the points mentioned previously, from a psychological perspective, when considering TPACK as a framework describing a *knowledge* construct, attention to context is crucial.

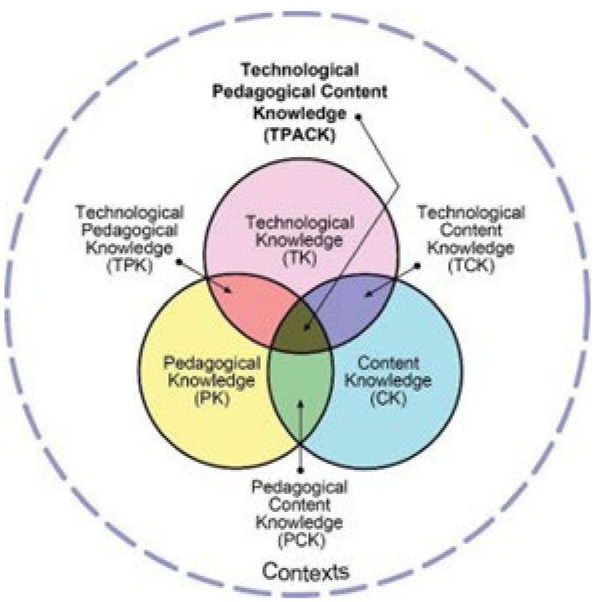
Not only is context acknowledged by previous literature in this field (e.g., Gess-Newsome et al., 2019; Grossman, 1990; Shulman, 1986, 1987), but also the highly contextualized nature of teachers' knowledge (e.g., Putnam & Borko, 2000) defines it as a form of expertise (Stigler & Miller, 2018). In fact, expert teachers distinguish themselves from novices for their richer and more context-sensitive knowledge representations (Berliner, 2001), thus suggesting that the inclusion of context plays a key role for fostering a complete picture of the knowledge underlying teachers' effective practice. In other words, when it comes to teaching, there are no recipes but rather, teachers are confronted with highly complex and dynamic environments which require them to constantly "think on their feet" (Barnett & Hodson, 2001, p. 428).

With regard to TPACK, the importance of context becomes apparent when considering that a teacher possessing TPACK could design numerous theoretically well-fitting lessons for a single topic (CK), using different teaching approaches (PK) and technologies (TK). Yet in practice, regardless of the soundness of the pedagogical design, the success of a lesson would be context-dependent, arising from the continuous interplay of knowledge and practice (Koehler & Mishra, 2008). Ultimately fitting technology, pedagogy, and content requires teachers to consider and tailor their lessons to the day-to-day realities of each unique educational context, calling for contextual knowledge.

To date, attention to context in TPACK research has been inconsistent (Rosenberg & Koehler, 2015b) and subject to a degree of conceptual confoundment, with the literature not differentiating between interpretations of (a) the contextual factors influencing instruction (i.e., context) and (b) teachers' knowledge of their contexts (i.e., XK). Considering the importance of context for expert teachers' knowledge representations (Berliner, 2001; Stigler & Miller, 2018), the inclusion of context in TPACK is fundamental for completing the picture. Thus, explicitly addressing it as a knowledge domain is a crucial distinction for upgrading TPACK (Mishra, 2019) and rebooting the framework for further contributing to research on teacher expertise and teacher education.

This article presents a systematic review of the TPACK literature with a refined focus on context as a domain of knowledge and aims to (a) describe how XK has been represented in the literature so far and (b) set the groundwork for systematically including this missing domain to upgrade TPACK as a valuable framework for advancing research on teachers' knowledge in the digital era.

Figure 1
The TPACK Framework Proposed by Koehler and Mishra (2009)



Note. Retrieved from http://tpack.org and reproduced with permission of the publisher, © 2012.

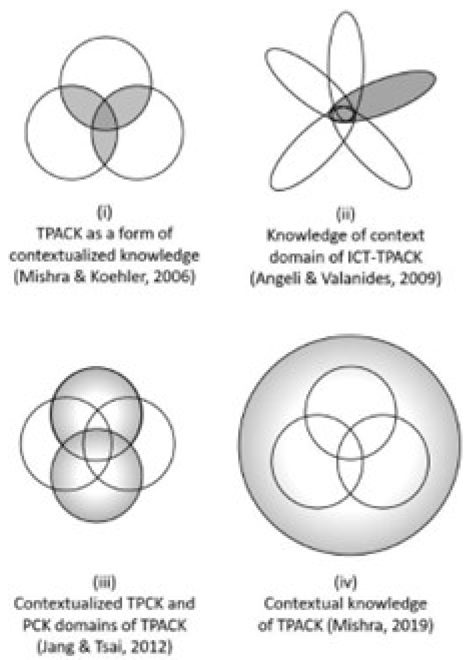
Theoretical Background

Tracing Context in the TPACK Framework

Since its first conceptualization, the fact that TPACK is contextually bound was acknowledged at least on the side lines (Mishra & Koehler, 2006). Regardless, a couple of years passed before context was depicted for the first time as a cloud embedding TPACK (Koehler & Mishra, 2008), which quickly became an overarching outer circle (Koehler & Mishra, 2009; see Figure 1). Although not clearly defined, the circle of contexts appears to represent the range of factors influencing TPACK, for example, student characteristics, social networks of the school, and parental concerns (Koehler & Mishra, 2008).

Since then, the definition of context and how it is integrated in the TPACK framework has been diversely represented in the literature (see Figure 2). A first conceptualization described context as bound to teaching activities, presenting TPACK as intrinsically contextualized by the affordances and constraints (Chai et al., 2011; Mishra & Koehler, 2006). It remains unclear, though, if or how this approach accounts for additional factors that may lead to an identical lesson (i.e., same topic, pedagogy, and technology) to be effective in one educational setting (e.g., a specific class) but not in another.

Figure 2
Four Representations of Context in the TPACK Framework



A second perspective presented context as an additional core component along with PK, CK, and TK of TPACK (e.g., ICT-TPACK, proposed by Angeli & Valanides, 2009). Nevertheless, it remains questionable whether the nature of TK, PK, CK, and context are to be considered homogeneously (Phillips et al., 2017).

A third perspective defined context as an integral part of PCK or TPCK (e.g., Jang & Tsai, 2012, 2013; Jimoyiannis, 2010). Although this approach aimed to render PCK and TPCK as contextualized, it is limited by acknowledging only the influence of context on these hybrid areas, ignoring more fundamental contextual aspects (e.g., availability of technology regardless of educational use).

A fourth view maintained and extended Koehler and Mishra's (2008) proposal, depicting context as the outer construct within which TPACK is embedded. Similar to the second approach, context in this approach is intended to capture those factors which, in addition to the abilities for combining pedagogy, content, and technology, influence teaching and learning and may vary across situations. In contrast to the previous three, this approach presented context externally to TPACK, mirroring teacher practice as situated within unique and dynamic environments.

Following this fourth approach, several variants are found in the literature. Chai et al. (2013) proposed that contextual factors could be represented by four dimensions: intrapersonal (e.g., teachers' epistemological and pedagogical beliefs), interpersonal (e.g., skills and abilities for cooperation and collaboration), cultural/institutional (e.g., school culture and views on technology), and physical/technological (e.g., availability and access to technological infrastructure).

Another variant proposed that context is even broader than Chai et al. (2013) described and, based on Bronfenbrenner's (1999) ecological developmental model, situated TPACK at the center of three hierarchical levels of context: the classroom (microlevel), the institutional or community environments (mesolevel), as well as social, political, technological, and economic conditions of society (macrolevel). (See Koh et al., 2015; Porras-Hernández & Salinas-Amescua, 2013). In their conceptual model, Porras-Hernández and Salinas-Amescua additionally described two actors, namely teachers and students, to be regarded as important contextual elements.

A few years ago, Rosenberg and Koehler (2015b) conducted a systematic review investigating the inclusion of context in the TPACK literature and adopted Porras-Hernández and Salinas-Amescua's (2013) three levels (micro, meso, and macro) and two actors (teacher and students) framework of context for representing this construct. Database searches of the literature published between 2005 and 2013 retrieved 193 records related to TPACK, of which only 70 were identified as explicitly including elements of context. Upon finer investigation, Rosenberg and Koehler found evidence for all five elements of context, which were included with the following frequencies: 84% microlevel, 61% mesolevel, 14% macrolevel, 57% teacher factors, and 44% student factors.

Overall, their findings indicated that (a) context appears to be a multifaceted construct (i.e., micro, meso, and macro levels, along with teacher and student factors) and that (b) these categories were included nonsystematically and with significant variation among the studies. Consequently, from a general perspective, context appears to represent the physical (Kelly, 2008) and social factors (Porras-Hernández & Salinas-Amescua, 2013) affecting teaching and learning, and the literature presents multiple studies discussing different contextual variables in relation to teachers' TPACK (e.g., Koh et al., 2014; Phillips et al., 2019; Swallow & Olofson, 2017). Yet, the variation of factors adopted across studies for representing context results in an array of findings, which can only be regarded as fragments of a greater picture. This heterogeneity may be a symptom of the underlying need for greater clarity for this broad and complex construct.

Toward Contextual Knowledge

In addressing this call for shedding light on this construct, one starting point consists in tackling the underlying questions surrounding context within the TPACK framework. At present, one of the reasons contributing to the stagnation of the field's understanding of the contextual component of TPACK could be related to a point of fundamental conceptual confusion: the lack of distinguishing between considering the outer circle as (a) the environmental factors influencing TPACK (i.e., knowledge in-context) or as (b) an additional domain of knowledge (i.e., knowledge of context; Rosenberg & Koehler, 2015a).

Although Rosenberg and Koehler (2015a) later described this dual interpretation of context, in their review of the literature (2015b), this distinction was not explicitly acknowledged. Their literature review, rather, reflected the undifferentiated approach to this construct of the time, regarding it as both the external settings and a domain of knowledge. Nevertheless, "teacher knowledge – and, by extension, teacher's actions – are rooted in particular contexts (Bruner, 1996), making contextual knowledge an important part of what teachers need to know and be able to do" (Hamilton, 2017, p. 30) and emphasizes the need for distinguishing between the two interpretations of context.

In fact, recently Mishra (2019) drew attention to this lack of clarity surrounding the contextual component of TPACK latently embedded in the literature and explicitly upgraded context to a domain of knowledge. This distinction marks an important shift from approaching teaching and learning environments objectively to addressing teachers' subjective views and understanding of their environments. This perspective not only promotes conceptual consistency within the TPACK framework, labelling the outer circle as contextual knowledge (Mishra, 2019), but also, more importantly, centers this framework at the person level, emphasizing knowledge as a psychological construct. In this way, as Mishra pointed out, contextual knowledge is something that can be actively focused on and developed.

In fact, contextual knowledge is not a novel construct nor is it unique to the TPACK framework. Again, context has been repeatedly recognized as a component of teachers' knowledge in the literature (e.g., Gess-Newsome et al., 2019; Grossman, 1990). Shulman (1986, 1987) described knowledge of context as one of the active ingredients contributing to the transformation of PK and CK into PCK, accounting for the highly situated nature of the latter. Along these lines, the importance of contextual knowledge has been associated with teachers' practice and with their ability to adapt to different educational settings (Cochran et al., 1993; Grossman, 1990; Richards, 1998). Within the PCK literature this construct includes

> . . . knowledge of districts in which teachers work, including the opportunities, expectations, and constraints posed by the districts; knowledge of the school setting, including the school 'culture', departmental guidelines, and knowledge of specific students and communities, and the students' backgrounds,

> families, particular strengths, weaknesses, and interests. (Grossman, 1990, p. 9)

Considering TPACK and contextual knowledge, though, two main points call for attention: First, whether these elements found in the PCK literature naturally apply to TPACK or how they may extend and evolve with the introduction of TK has not yet been clearly investigated. Second, although a number of extended frameworks exist and may appear suited for representing the elements of context (as an external setting), the fact that these may not automatically translate into the knowledge of context teachers actually rely on for teaching has yet to be openly addressed. The need for clarity on these points is supported by findings in TPACK research, which highlight the relevance of zooming in on teachers' internal processes and their abilities to understand and adapt to these different contextual variables as these play fundamental roles in their instructional decision-making (Angeli & Valanides, 2009). Furthermore, empirical literature focusing on technology integration in teaching reaffirms the need for understanding how TPACK and contextual knowledge contribute to instructional design (e.g., Koh et al., 2015).

In fact, from the very beginning Mishra and Koehler (2006) claimed that technology integration into educational practice is inherently contextually bound, thus generic approaches to technology do not take full advantage of these tools' true potential. They proposed "learning technology by design" (p. 1020) as the basis of their TPACK research due to this approach being grounded in developing knowledge within authentic contextual settings and connecting theory with practice.

Since then, others have continued investigating TPACK in relation to instructional design, with the argument that design, like teaching, is context specific and, thus, supports teachers in accounting for contextual factors determining their practice (Pareto & Willermark, 2018). From this perspective, the value of teaching experience and practice is at least partially linked to the opportunity for integrating knowledge of context within teachers' TPACK. In fact, several extensions of TPACK geared toward instructional design or practice share a primary emphasis on context for determining TPACK (e.g., technology-mapping, Angeli & Valanides, 2009; TPACK-based ID model, Lee & Kim, 2017; TPACK-practical, Yeh et al., 2014).

Nevertheless, even among these models, context is addressed generically, and the question of the content and structure of teachers' contextual knowledge remains yet to be investigated in depth. Considering XK as a fundamental component of TPACK in practice, providing greater clarity for this construct is crucial for advancing TPACK's theoretical and practical significance.

The Present Systematic Review

The relevance of context in the TPACK framework has been widely acknowledged (at least in passing), yet the literature on this construct reveals great conceptual diversity and operational inconsistencies. The present systematic literature review picked up where Rosenberg and

Koehler (2015b) left off and extended it by following Mishra's (2019) suggestion to focus on investigating context specifically as a knowledge construct. Addressing this aim, it is important to note that until this point we have widely made use of the label proposed by Mishra (2019), namely, contextual knowledge. In the literature, however, this construct is similarly referred to under a number of variant key terms.

To gain a comprehensive overview of context as a form of knowledge, we investigated this construct across its various labels. To avoid confusion between labels and construct, from this point forth, we adopt the acronym XK for referring to context as a domain of knowledge in a general, label-free manner. Thus, this review addressed the following overarching question: How is XK understood in the current TPACK literature?

Due to the breadth of this goal, the main question was deconstructed and addressed through two consecutively organized research questions (RQ):

- How frequently is XK currently included in the TPACK literature (RQ1)?
- When included, how is XK defined or operationalized in the literature (RQ2)?

RQ1 aimed to situate XK within the literature through identifying the key terms used to reference this construct and then investigate its frequency of inclusion within the current TPACK literature. Subsequently, RQ2 deepened the understanding for this construct and, based on records making substantial references to XK, led to our summarizing definitions and operationalizations of the construct. To this end, and to draw a comparison with Rosenberg and Koehler's (2015b) previous review, we investigated the adequacy of the three dimensions of scope (micro, meso, and macro) as well as the two categories of actors (teacher and students; Porras-Hernández & Salinas-Amescua, 2013) for representing XK.

Methods

Systematic literature reviews consist of procedures for searching and analyzing existing literature to gain an overview of the current state of knowledge on a given topic. These approaches enable providing information that would be beyond the scope of any individual study and can be used for theory generation and validation (Page et al., 2021). Rigor in the approaches is crucial for ensuring the quality of the results.

At present, one of the most popular approaches for guiding a rigorous systematic review of the literature is described by the PRISMA statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses; Moher et al., 2009; Page et al., 2021). The PRISMA statement aimed to support authors in defining clear and replicable steps for analyzing the literature: from adequately identifying records pertinent to a specific topic to screening the retrieved sample, applying eligibility criteria, and resulting in a final sample of records relevant to the research question at hand (Moher et al., 2009).

The present systematic review provided a comprehensive overview of the existing literature on TPACK and contextual knowledge. We analyzed the literature in two segments: (a) a preliminary sample, derived from Rosenberg and Koehler's (2015b) previous review of the literature published between 2005 and 2013, and (b) a main sample based on a systematic review of the subsequent literature published between 2014 and 2020. For both segments, XK was analyzed in two steps corresponding to the two research questions.

Step 1 consisted of data collection and screening phases, aimed at detecting the frequency of XK, whereas Step 2 focused on a more sophisticated coding of the data. Although the goals of both steps were the same across subsamples, we used the preliminary sample to familiarize with XK (i.e., identify key terms, Step 1; and assess the adequacy of the coding scheme, Step 2) and based the subsequent analyses of the main sample on these preliminary findings. Thus, in the following segments the approaches applied to the preliminary sample are described first, followed by implementations used for the main sample.

Data Collection, Screening, and Eligibility Criteria

The first step served to identify literature relevant to TPACK and XK and investigate its frequency of inclusion (RQ1). With regard to our preliminary sample, considering Rosenberg and Koehler's (2015b) review as representative of the literature published between 2005 and 2013, we did not repeat a database search for these years but rather directly adopted the 70 records relevant to context identified by these authors. To meet the eligibility criteria of this study, records were required to contain at least one instance in which context was referred to as a form of knowledge. Thus, within this sample we manually traced the keyword "context" and retained the record if it contained at least one instance in which this term was used to reference a knowledge domain. In addition, these relevant key terms for identifying XK were noted and adopted for the subsequent systematic search of the literature published between 2014 and 2020 (i.e., our main sample).

The main sample was retrieved following the STARLITE (Sampling strategy, Types of studies, Approaches, Range of years, Limits, Inclusion criteria, Terms used, and Electronic sources; Booth, 2006) standards for systematic reviews (see Table 1). We conducted searches across the five databases, Web of Science (WoS), Scopus, Education Resources Information Center (ERIC), PsycInfo, and Google scholar, chosen for their relevance in educational research, as well as the TPACK Newsletter (retrieved from https://activitytypes.wm.edu/TPACKNewsletters/index.html). In addition, the PRISMA (Moher et al., 2009) statement was adopted for guiding the literature screening processes.

Table 1
Operationalization of the STARLITE Standards for Systematic Reviews

Element	Operationalizations of the Present Review
Sampling strategy	Selective search for literature on TPACK and XK published between 2014 and 2020.
Types of studies	Quantitative, qualitative, and conceptual studies published as journal articles, book chapters, editorials, or doctoral dissertations.
Approaches	Search on databases (see *Electronic sources* below), manual tracing and coding within retrieved records of references to XK.
Range of years	2014 - 2020; records published prior to 2014 are represented by the preliminary sample.
Limits	Published in English and publicly available.
Inclusion criteria	Includes at least one TPACK term (see *Terms used*, below) in title, keywords, or abstract (or in introduction, for records without an abstract); as well as at least one of the XK terms (see *Terms used*, below) in text (excluding terms found in record reference lists).
Terms used	"technological pedagogical content knowledge," "TPACK," "TPCK," "context knowledge," "contextual knowledge," "contextualized/contextualised knowledge" (or truncated, "context* knowledge"), and "knowledge of (educational) context" (see Table 2 for exact search query per database).
Electronic sources	WoS, Scopus, ERIC, PsycInfo, Google scholar, and TPACK newsletters as an additional electronic source, retrieved from https://www.punyamishra.com/research/tpack/tpack-newsletter-archive/.
Note. The first three terms used for targeting TPACK were adopted from Rosenberg and Koehler's (2015b) review, whereas the subsequent four targeting XK were derived from the preliminary sample.	

Construct Analysis and Coding

Records meeting all eligibility criteria (see inclusion criteria in Table 1) were retained for coding. For each record, the coded content-analytic units (Mayring, 2015) consisted of (a) the paragraph within which XK keyword occurred, (b) the whole respective chapter or subchapter for cases in which XK was included in headings [a], or (c) the instrument's operational definition of XK among empirical records measuring XK. Early into this process, analysis of records revealed XK to be included in one of three ways: (a) not in direct relation to TPACK (e.g., mentioned only in relation to PCK framework but not directly to the TPACK framework, as in Tzavara & Komis, 2015); (b) in relation to TPACK but not substantially explicated (e.g., "Contextual knowledge is also included as part of the model" in Mouza et al., 2014, p. 207); and (c) in relation to TPACK and substantially referenced (e.g., "Contextual knowledge encompasses the many physical, interpersonal, technological, social, political, economic, cultural, geographic, and other characteristics of students' and teachers' current and past experiences and attributes, both in school and outside it" in Harris & Hofer, 2017, p. 1).

Subsequently, only records falling in this third category (i.e., making substantial references to XK) were suitable for further coding. The first two authors independently coded all eligible records from the preliminary sample into one of these three categories and achieved acceptable intercoder reliability (Krippendorff's alpha = .80; Krippendorff, 2004). In cases of disagreement, the record was discussed, and the two coders jointly decided on a code.

Mirroring the approach adopted in Rosenberg and Koehler's (2015b) review, content coding of XK followed the definitions of dimensions and scope proposed by Porras-Hernández and Salinas-Amescua (2013): classroom (microlevel), school and near surrounding community (mesolevel), overarching global or national structures (macrolevel), as well as characteristics of teacher/self (teacher) and of students (students). Given that the aim to of this study was to investigate how XK is described in the literature, for records which explicitly associated XK with one of the above listed categories, we maintained the coding of XK as described in the original record (e.g., beliefs as both a microlevel factor in Porras-Hernández & Salinas-Amescua, 2013, as well as a teacher factor in Jang & Tsai, 2013). In addition, only the factors explicitly related to XK in text were included for coding, whereas factors which were compatible but not presented as elements of XK were not coded (e.g., "knowledge of students" presented as an additional domain of knowledge separate from XK in Angeli & Valanides, 2009).

As in Step 1, the second step consisting of coding the preliminary sample again served to familiarize us with the data. The first author Brianza investigated this sample in two steps: (a) assessing the adequacy of the categories derived in the previous literature (i.e., micro, meso, macro, teacher, and students; Porras-Hernández & Salinas-Amescua, 2013); and (b) investigating whether, based on the data, additional categories could be inductively developed, thus leading to a revision of the coding scheme.

The validity of the revised coding frame was subsequently evaluated by the first two authors independently coding the preliminary sample records, and they achieved acceptable intercoder reliability (Krippendorff's alpha = .82). In cases of disagreement, the final coding of a record was discussed and jointly decided upon. The revised coding scheme was subsequently adopted to code the main review sample.

Given the richness of the coding scheme, to simplify the interpretation of the findings and offer a visual representation, nonmetric multidimensional scaling using binary codings (Simmen, 1996) was conducted on the final records of the main sample (i.e., those substantially referencing XK). Each record was described by the presence (coded as 1) or absence (coded as 0) of the defined variables. The number of plotted dimensions and the respective goodness-of-fit were determined considering a stress value of < 0.10 to indicate good ordination, for which higher dimensionality is not likely to improve the representation (Clarke, 1993). Analyses were conducted in the R software environment (version 4.0.2; R Core Team, 2020) using the *vegan* package (version 2.5-7; Oksanen et al., 2020).

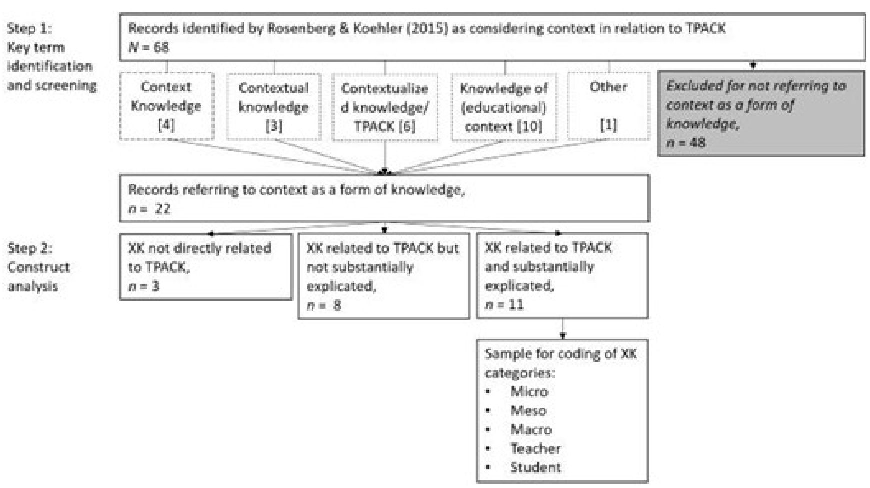
Results

The results of the two steps of analyses reflecting the two research questions, are presented in parallel at each step for the two samples of this literature review. For each step, the preliminary sample is presented first, as it was used to familiarize us with data and direct the subsequent analyses of the main sample.

XK Key terms and Screening (Step 1; RQ1)

Originally, the preliminary sample previously reported by Rosenberg and Koehler (2015b) as relevant to TPACK and context consisted of 70 records. Two records could not be retrieved. Thus, the 68 remaining records were manually searched for references to "context." Findings revealed that only 20 (less than 30%) of the records included at least one explicit reference to context as a knowledge construct. Among these, XK was found to be repeatedly referred to under four different root key terms ("context knowledge," "contextual knowledge," "contextualized/contextualised knowledge/TPACK," and "knowledge of [educational] context"), with the exception of one record proposing the term "context-specific TK" (labelled as "other" in Figure 3). Three of the records used more than one key term interchangeably when referring to XK.

Figure 3
Screening and Identification of XK in the Preliminary Sample



Note. Numbers in squared brackets indicate the frequency of records referencing the respective key term in text. A number of records made reference to more than one key term, thus the sum of these numbers is not equivalent to the subsample size.

Based on the findings from the preliminary sample, we focused on the four recurrent root key terms and their variants (Table 1) and adopted these for the main systematic review database searches. In our main sample, to investigate the frequency of mentioning XK in the TPACK literature (RQ1), we conducted progressively refined searches and found that across databases the number of records retrieved for selective algorithms targeting both TPACK and XK consisted of 0.5-4,3% of the total number of records retrieved for broad queries targeting only TPACK and of 2.2-4.5% of those retrieved by narrower searches for TPACK and context (as a general construct; see Table 2).

Table 2
Search Algorithms and Initial Number of Results Per Database

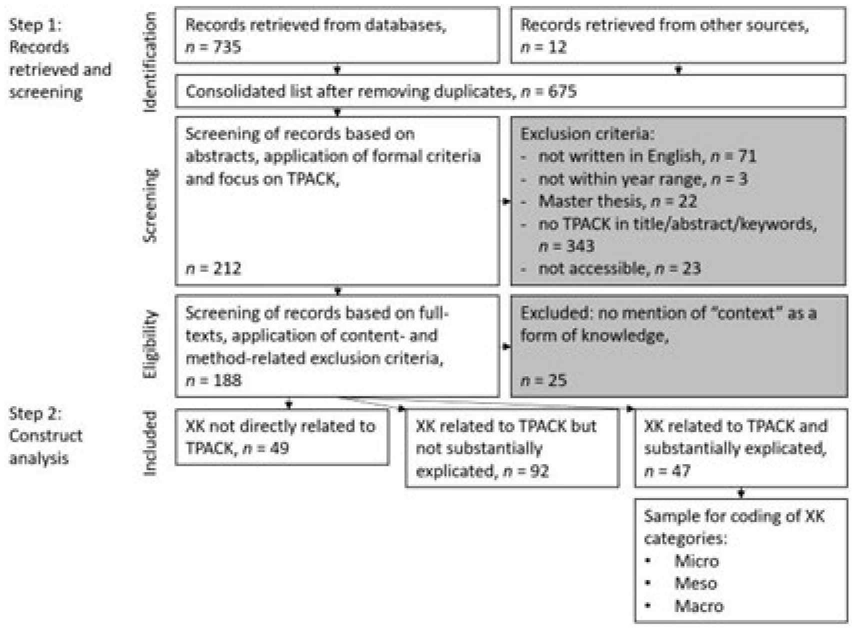
Database	**Final Search Algorithm**	**Progressively Refined Search Results**		
		Only TPACK Keywords	Including "Context*"	Including XK Key Terms
WoS	TS = ("technological pedagogical content knowledge" OR "TPACK" OR "TPCK") AND TS=("context* knowledge" OR "knowledge of context" OR "knowledge of educational context") Databases = WOS, BCI, BIOSIS, CCC, DRCI, DIIDW, KJD, MEDLINE, RSCI, SCIELO, ZOOREC Timespan = 2014-2020	1,187 (100%) -	204 (17.2%) (100%)	6 (0.5%) (2.9%)
Scopus	TITLE-ABS-KEY ("technological pedagogical content knowledge" OR "tpack" OR "t pck") AND TITLE-ABS-KEY ("context* knowledge" OR "knowledge of context" OR "knowledge of educational context") AND PUBYEAR > 2 014	1,102 (100%) -	188 (17.1%) (100%)	5 (0.5%) (2.7%)
ERIC [a]	TI (("technological pedagogical content knowledge" OR "TPACK" OR "TPCK") AND ("context* knowledge" OR "knowledge of context" OR "knowledge of educational context")) OR AB (("technological pedagogical content knowledge" OR "TPACK" OR "TPCK") AND ("context* knowledge" OR "knowledge of context" OR "knowledge of educational context")); Publication year filter: 2014 - 2020	580 (100%) -	105 (18.1%) (100%)	4 (0.7%) (3.8%)
PsycInfo [a]	TI (("technological pedagogical content knowledge" OR "TPACK" OR "TPCK") AND ("context* knowledge" OR "knowledge of context" OR "knowledge of educational	403 (100%) -	91 (22.5%) (100%)	2 (0.5%) (2.2%)

Database	Final Search Algorithm	Progressively Refined Search Results		
		Only TPACK Keywords	Including "Context*"	Including XK Key Terms
	context")) OR AB (("technological pedagogical content knowledge" OR "TPACK" OR "TPCK") AND ("context* knowledge" OR "knowledge of context" OR "knowledge of educational context")); Publication year filter: 2014 - 2020			
Google scholar [b]	"technological pedagogical content knowledge" OR "TPACK" OR "TPCK" "contextual knowledge" OR "context knowledge" OR "contextualized knowledge" OR "contextualised knowledge" OR "knowledge of context" OR "knowledge of educational context" Publication year filter: 2014 - 2020	~16,400 (100%) -	~15,600 (95.1%) (100%)	706 (4.3%) (4.5%)
Additional sources	TPACK Newsletter (2014-2020): manual search for XK key terms	1640 (100%)	360 (22.0%) (100%)	10 (0.6%) (2.8%)

Note. Search results retrieved from individual databases on January 30, 2021. Progressively refined searches provide an overview of the frequency of including context in recent TPACK literature and an additional specification for the frequency of acknowledging context as a domain of knowledge (respective percentages for comparisons with TPACK-only and context-focused samples displayed in parentheses). Search options of the various databases are not always directly compatible (e.g., WoS allows for searches in record's title, abstract, author, keywords, and keywords plus; Google scholar only offers the option of searching in either the title or full text) thus, individual search algorithms are composed to identify the broadest yet still relevant scope of literature on each database.
[a] Database searched via EBSCOhost.
[b]Google scholar set for full text search which accounts for the great differences in number of records retrieved and comparative percentages.

After removing duplicates, 675 records were retrieved, of which screening for eligibility criteria resulted in 188 having a focus on TPACK and including XK (see Figure 4). Thus, combining the preliminary and main sample, 210 records were retained for subsequent coding in Step 2.

Figure 4
Adapted PRISMA Statement Applied to the Main Sample



Note. A number of records (n = 23; see Appendix A) were not accessible to us within the timeframe of this study. With the exception of one record retrieved through the TPACK Newsletter, the remaining were retrieved only through Google scholar. Among these 15 consisted of conference proceeding papers, four were doctoral dissertations, and four were books or book chapters.

Construct Analysis and Coding (Step 2; RQ2)

Considering the combined samples (see Figures 3 and 4), a total of 210 records resulted from the search and screening processes as meeting the initial eligibility criteria. Among these we found XK to be included in three ways. In 52 records, XK was referenced but not directly in relation to TPACK. The majority of these (> 60%) consisted of mentioning XK in relation to the PCK framework and referencing literature upon which TPACK is derived, yet dated prior to its proposal (e.g., Gess-Newsome, 1999; Grossman, 1990; Magnusson et al., 1999; Shulman, 1986, 1987). Thus, these studies did not explicitly address if or how XK relates to TPACK itself.

In an additional 100 records, XK was mentioned in direct relation to TPACK but without providing further explications or information on this construct. In the majority of these records (> 80%), XK was merely listed as a component of the TPACK framework through citing literature (most frequently cited sources: Angeli & Valanides, 2005, 2009, 2013; Chai et al., 2013; Harris et al., 2009; Koehler & Mishra, 2008, 2009; Mishra & Koehler, 2006; Porras-Hernández & Salinas-Amescua, 2013; Rosenberg & Koehler, 2015b). Finally, the remaining 58 records were found to describe XK in direct relation to TPACK as well as include substantial information on this construct, resulting in only this subsample of records being suitable for content coding.

Thus, the final sample of records retained for content coding consisted of 11 records from the preliminary sample and 47 from the main systematic review sample. Considering our aim of investigating the content of XK and the adequacy of describing XK along three levels and two actors (RQ2), we again adopted the preliminary sample to familiarize ourselves with both the construct and the coding approach. Although within this sample we found evidence for each category, these emerged as being inconsistently and diversely included across records: The microlevel was most frequently mentioned (91.7%), followed by knowledge of students (41.6%), the mesolevel (33.3%), and finally the macrolevel and teacher domain (both 25.0%). Furthermore, as displayed in Appendix B, the subcomponents associated with these categories presented even greater diversity.

Concerning knowledge of actors (i.e., teachers and students), during coding we noted an overlap of components associated with these domains and with the microlevel (e.g., considering the factor "beliefs"). Furthermore, additional actors were found to be mentioned at other levels of context (e.g., "teacher peers" at the mesolevel). These two findings suggested not only that teachers and students do not operate in isolation, but also that additional actors are found to be relevant elements of context across levels. Thus, teacher and student factors were reanalyzed for compatibility of being coded at the micro level.

Subsequent to this decision, inductive content analysis was used to investigate additional patterns within elements of contexts and revealed that the data could further be organized across micro-, meso-, and macrolevels along three dimensions, representing (a) social, (b) resource, and (c) content-related factors (see Appendix B). This refined coding frame of three levels and three dimensions was adopted for coding the records of the main review sample (Tables 3-5).

As observable in Tables 3-5, in our main sample the coding revealed substantial diversity regarding the frequency of including levels and dimensions, as well as variations in the specified settings of each level and the range of factors associated with the three dimensions. The microlevel was included in 74.5% of the records and defined either explicitly as the classroom setting or more generally as the teaching and learning environment. The mesolevel was mentioned in 78.7% of the records and related to either one or more of the following settings: the educational institution (i.e., school), the local community, or the district. Finally, the macrolevel was mentioned in 48.9% of the records and inconsistently used to represent either the state, national, or the global settings. Nevertheless, only approximately a third (34.0%) of the records included factors at all three levels.

Combinations of two levels were mentioned in 20 records (42.6%), among which the micro-meso level combination was the most frequently mentioned (n = 13). Less than a sixth (14.9%) represented XK only on a single level. A small number of records (n = 4) could not be coded, as it was unclear at which levels the mentioned factors were intended to be represented: Three records referenced overly general factors including "policies" (Bergeson & Beschorner, 2020, p. 331), "cultural and educational issues" (Lim, 2016, p. 70), and "prototypical practices or problem situations" (Lachner et al., 2019, p. 4). Another record (Espinoza & Neal, 2018) proposed a novel model defining context along the dimensions of resources, legitimacy, and positionality, for which it was unclear how these were related to context levels. Due to their lack of clarity for coding, these four records were not considered in the subsequent quantitative analysis.

Table 3
Microlevel Components

Records	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
Level setting	X	X	X	[X]	X			X	X	X	X	X	X	[X]	X	X	X	X	X			X	X	X	X	X	X	X	[X]	X	[X]	X			X	X	X		X	X	X	X	X	X	X	X	
Classroom	X	X			X					X		X	X		X		X	X				X	X	X		X						X			X		X		X	X				X	X		
Learning environment			X													X			X								X	X								X						X					
Resources	X	X			X							X	X		X	X	X	[X]				X	X			X	X					X		[X]	X		X			X					X		
Physical infrastructure												X														X											X			X					X		
Classroom size												X	X																																		
Technology					X	[X]						X	X			X		[X]								[X]	X							[X]	X		X							[X]			[X]
Time																X																															
Social factors	X	X	X		X			X	X	X	X	X	X		X	X	X	X	X			X	X	X	X	X	X	X		X		X			X	X	X		X	X	X	X	X	X	X	X	
Individual	TS	TS	S		+S			S	S	TS	T	TS	X		S	S	TS	TS	S		+S	TS	TS	T	S	S	S	S		TS		TS			S	S	S		TS	S	TS	S	T		S	S	
Beliefs, subjective norm	T	T								X			T				TS					TS	X	T						T		X							T		T						
Values, attitudes										TS		S	T				TS					T																	S								
Expectations	X	X											X									TS	X																								
Goals	TS	TS											TS									TS	X									TS															
Motives, motivation													T																			S							T								
Preferences	S	S											X									TS	X									X															
Interests												S																											S								
Experiences									S			TS			S		TS	TS																													
(Prior) knowledge	S	S						S	S				T																							S			S		S						
Self-awareness/concept										TS	T	T																																			
Self-efficacy	T	T											T									T																									
Abilities												TS			S	S	TS	S	S			T								S																	
Needs/disabilities	S	S								TS						S		S																							S	S					
Sociodemographic	TS	TS	S					S		TS		TS						S							S	S				S					S		S			S					S		
Culture	TS	TS	[X]							X						[X]		[X]								S				S		S			S										S		
Daily life/home environm.								S	S							S									S					S										S					S		
Technology access												S				S														S		S															
Collective (class)	X	X			X								X		X																	X							X			X		X			
Grade level															X																					X											
Dynamics					X																											TS				TS			X					X			
Size													X																			X															
Composition																																										X					
Norms and policies	X	X		[X]									X			[X]	X					X	X																								
Social roles																																							X								
Content (lesson)																			X			X		X			X	X				X							X								
Learning activity/objective																			X			X		X			X												X								
Assessments																																															
Class format																																X															

Note. Rows in boldface represent a summary of including elements for the respective dimension. See supplementary Appendix C for the list of records numbered 1-47. T = category specified to teachers, S = category specified to students, +S = record mentions knowledge of students/learners as an independent domain of knowledge, [X] = unclear relation to levels.

Table 4
Mesolevel Components

Records	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
Level setting	X	X	[X]	[X]	X	X	X	X	X	X	X	X	X	[X]	X	X	X	X		X	X	X	X		X	X	X	X	[X]		[X]	X	X	X	X		X	X	X	X	X	X		X	X	X	X
Educational institution, school	X	X			X	X	X	X	X	X	X	X	X		X	X	X	X		X	X	X	X		X	X	X	X				X	X	X	X		X	X	X	X	X	X		X		X	X
Local community	X	X			X					X			X									X										X						X	X	X					X		
Local district					X	X				X			X				X					X										X		X										X			X
Resources	X	X			X							X	X		X	X	X	[X]				X										X		[X]	X		X	X	X					[X]			[X]
Physical infrastructure		X										X	X																																		
Technology						[X]							X			X		[X]														X		[X]	X		X							[X]			[X]
Economic	X	X			X								X			X	X	[X]				X										X							X								
Services																																						X									
Social factors	X	X			X	X				X	X	X	X		X	X	X	[X]		X	X	X	X		X			X				X	X	X	X			X	X	X	X	X		X	X		X
Individual												ST									S		S																						T		
Concerns, issues		P											X																																		
Support															P						S							X												T		X			X		
Culture, school culture	X	X	[X]		X								X			[X]		[X]							X							TS									X						
Expectations, values													PST							X	X											TS															
Sociodemographic																																						X									
Collective (organization)	X	X			X					PS	X		X					[X]			X	X						X						X				X	X								
School size																X																															
Social network, community		X			X																																										
Social interactions																					X																										
Governance, power hierarchies											X		X																					X							X						
Political aspects	X	X											X					[X]				X										X							X								
Policies, regulations				[X]		X				X						[X]												X				X	X	X	X			X						X			X
Initiatives																	X																														
Content (curriculum)							X		X																		X	X														X		X			
Pedagogical demands																											X																				
Standards, assessment							X																																			X					
Relevance betw. subj.									X																																						

Note. Rows in boldface represent a summary of including elements for the respective dimension. See Appendix C for the list of records numbered 1-47. T = teacher-peers, S = stakeholders (including school principals, administrations, board members, educational policy makers), P = parents, [X] = unclear relation to levels.

Table 5
Macrolevel Components

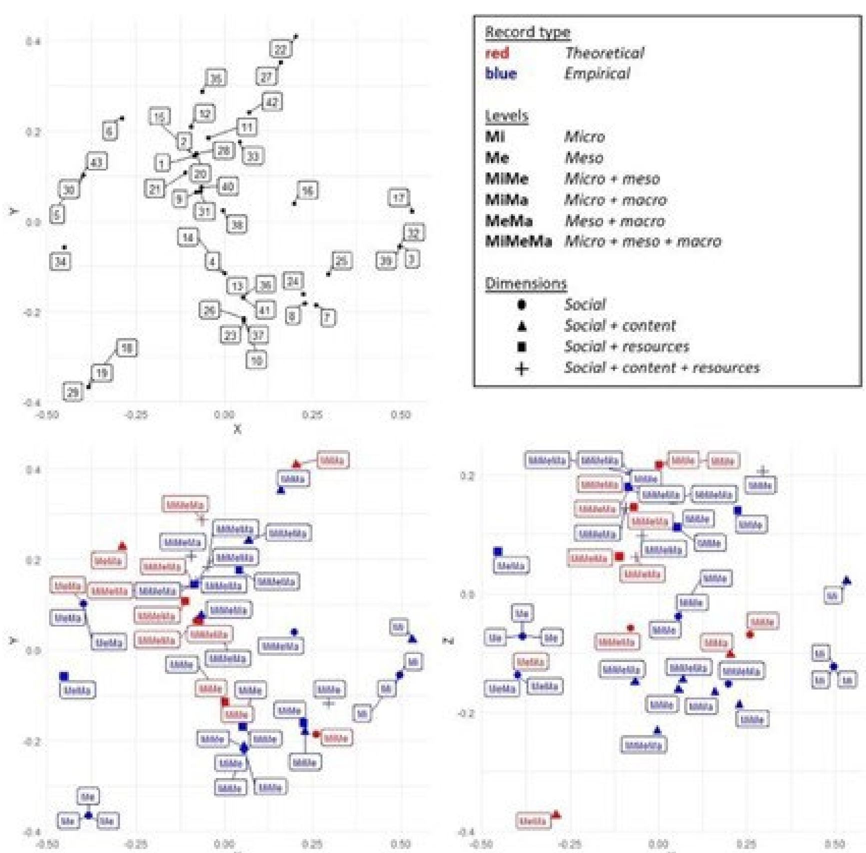
Records	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
Level setting	X	X	[X]	[X]		X	X			X		X	X	[X]		[X]	X	X				X	X	X		[X]			[X]	X	[X]	X		X	X		X	X	X			X		X		X	X
Global	X	X															X	X				X										X															
National, State						X							X				X	X												X		X		X	X			X	X			X		X			X
Education system												X																		X																	
Resources	X	X											X				X	[X]				X	X			[X]						X							X								
Physical resources																																							X								
Technology	X	X				[X]							X				X	[X]					X			[X]						X		[X]										[X]			[X]
Economic	X	X											X					[X]				X	X									X							X								
Professional development													X																																		
Social factors	X	X				X	X			X		X	X				X	[X]				X	X	X						X		X		X	X		X		X					X		X	X
Culture, ideologies			[X]							X						[X]		[X]																					X								
Educational culture												X												X								X															
Organizational						X																																	X								
Hegemonic structure																														X							[X]										
Policies, regulations				[X]		X	X									[X]																		X	X			X						X			X
Political aspects	X	X					X						X				X	[X]				X	X									X							X								
Access, equity													[X]																	X																	
Initiatives, reforms							X						X																																		
Content (education requirements)												X	X											X						X									X			X				X	
Educational goals												X	X											X						X												X					
Explicit curriculum																														X																	
Hidden curriculum																														X																	
Standards, assessment																																										X					
Ed. system alignment													X																																		
Workforce opportunities, demands																																							X							X	

Note. Rows in boldface represent a summary of including elements for the respective dimension. See Appendix C for the list of records numbered 1-47. [X] = unclear relation to levels.

As a final step in the construct analyses of XK, we conducted nonmetric multidimensional scaling using 12 binary-coded variables necessary for describing the data: three levels (micro, meso, and macro) and nine variables representing one of the three dimensions (i.e., resources, social, and content) by level of context. A three-dimensional solution for representing the data was found to show good ordination (stress value = 0.068) as well as proposing axes along which it was possible to describe records in a meaningful way (see Figure 5): (a) From records primarily meso-focused to those primarily micro-focused (meso - micro; *x*-axis); (b) from records not including a macrolevel to those including it (no macro - macro; *y*-axis); and (c) from records not mentioning resources as part of XK to those including this dimension (no resources - resources; *z*-axis).

A further distinction was made based on the nature of the records, distinguishing between theoretical and empirical records (which among the latter group did not always imply an attempt to address XK empirically). In addition, the visual representation emphasized three of descriptive patterns of the data: (a) all theoretical records present XK as a multidimensional structure, consisting of at least two levels and only among empirical records is XK sometimes reduced to a single level; (b) the social dimension is an overarching common factor, being included on at least one level in all records; and (c) the macrolevel is never considered in isolation.

Figure 5
Nonmetric Multidimensional Scaling of Coded Records



Note. Only records including elements, which could be specified through coding, are considered (n = 43). As reference for identifying the records, the upper left diagram displays records by their numeric label in the XY space. Given the complexity of the 3x3 possible combinations of dimensions per levels, labels describing records were reduced to representing records by their combinations of levels (point labels: Mi = micro, Me = Meso, Ma = macro) and by inclusion of dimensions (irrespective of specific levels).

Discussion

The aim of this review was to provide a comprehensive overview of how context is currently conceptualized as a domain of knowledge in the TPACK literature. Addressing our first research question, and in line with previous research on context from a generalized perspective (see Kelly, 2008; Rosenberg & Koehler, 2015b), as a domain of knowledge XK appears to be underrepresented, being substantially included in ~20% of retrieved records acknowledging this construct in the TPACK literature (RQ1). Furthermore, even among this minority of records, explicit references to XK unveiled a wide range of diverse definitions and operationalizations associated with this construct (RQ2). At face value, such inconsistencies could be assumed to indicate a lack of construct clarity and, thus, an incompatibility of findings across the literature. Yet, through closer consideration and analyses, we found evidence suggesting that these factors might instead be multiple pieces of a bigger picture depicting XK as a broad, complex, multifaceted, yet structured construct.

The Structure of XK in TPACK

Based on the findings of this literature review, acknowledging context as an additional and unique domain of knowledge in the TPACK framework appears to be supported on both a theoretical (e.g., Cherner & Smith, 2017; Everett & Otto, 2015; Mishra, 2019) and an empirical level (e.g., Cohen, 2020; Karakaya Cirit & Canpolat, 2019; Maloney, 2018; Slaughter et al., 2019). Thus, considering the array of diverse representations of XK led to discussions on the structure of this construct.

Levels of XK: Immediate, Proximal, and Distal

In both conceptual and empirical records, we found evidence of representing XK along the three levels micro, meso, and macro of context described in the previous literature (e.g., Porras-Hernández & Salinas-Amescua, 2013; Rosenberg & Koehler, 2015b). Interestingly, in all theoretical records XK included elements pertaining to multiple levels (e.g., Angeli et al., 2016; Cherner & Smith, 2017; Everett & Otto, 2015; Mishra, 2019). In contrast, in a handful of empirical records XK was represented by only a single level (e.g., Aydın Günbatar et al., 2017; Hsu & Chen, 2019; Ünal Çoban et al., 2016). Rather than indicating contrasting approaches, this pattern might suggest that, although theoretically XK is universally acknowledged as a multilevel construct, its complexity poses challenges for empirical approaches, leading the latter, in some cases, to attend only to select aspects (or levels) of XK at a time.

The most frequently mentioned levels were, on one hand, the microlevel, associated with the setting of the classroom (or more generally, the learning environment; see Table 4) "… where teachers enjoy greater independence and deals with in-class conditions for learning" (Angeli et al., 2016, p. 18), and on the other hand, the mesolevel, defined as the school or education institution, as well as occasionally including the local community and district (see Table 4). These two levels share the characteristic of each representing a setting within which teachers are not only embedded but are directly and actively involved, leading them to be related to teaching and learning processes through the teacher.

In contrast, the macrolevel was mentioned less frequently and inconsistently, associated with either the national or the global setting (see Table 5). Although conceptually different, both these settings characterize the macrolevel as an external and overarching system, which influences an individual and local environment but are, generally, beyond an individual's own realm of influence. We also observed that the macrolevel was the only level never to be represented in isolation, but rather always associated with the micro or meso levels. This pattern may imply that for contextual elements to be regarded by teachers as meaningful for practice they must either directly fall within their realm of influence or at least be perceived as related to these realms.

In fact, evidence suggests the importance of knowledge of higher level factors for influencing that of lower levels (e.g., national educational reforms linked to ICT programs in schools and individual responses in teachers' practice; Cohen, 2020). Considering these findings and the critiques to the misuse of Bronfenbrenner's ecological model (e.g., Tudge et al., 2009), we suggest viewing XK from a perspective of teacher agency and reconceptualizing the levels based on their proximity of influence on teaching and learning processes: *immediate*, *proximal*, and *distal* levels of context (see Figure 6). In this way, XK is no longer constrained to physical settings (e.g., classroom and schools), but rather process-oriented and applicable across both face-to-face and virtual educational contexts.

Dimensions of XK: Social, Resources, and Content Factors

In addition to the three levels, the second structural aspect emerging from this review concerns the inclusion of the two actors proposed by Porras-Hernández and Salinas-Amescua (2013) namely, teachers and learners (also see Rosenberg & Koehler, 2015b). With only a few exceptions (e.g., Bibi & Khan, 2017; Hsu & Chen, 2019), all records in the final sample mentioned knowledge of actors as part of XK. Nevertheless, a number of these records did not describe teachers and learners as distinct subcomponents of XK, but rather directly associated these with the micro/immediate level (e.g., Angeli et al., 2016; Cohen, 2020; Maloney, 2018).

Furthermore, we found this redefinition of actors as integral elements of levels of XK to be compatible across records and to be supported by two theoretical arguments. First, including social components as part of context levels consequently enables acknowledging the relations and reciprocal influences between social factors and the other components as integral parts of teachers' contextual knowledge (e.g., teachers' understanding of the implications of a lesson's learning goals for specific students in their class; Koh et al., 2015). Second, it alleviates the misconception of these two being the only social actors relevant to educational contexts.

In fact, at each of the three levels of XK, we found mention of numerous social factors ranging from knowledge of other actors, such as peer teachers, parents, and administrators (e.g., Cohen, 2020; Hsu & Chen, 2019; Karakaya Cirit & Canpolat, 2019; Maloney, 2018) to knowledge of collective social aspects, such as cultures, norms, and policies (e.g., Maloney, 2018; Njiku et al., 2020; Wang, 2020). Thus, not only was the three-level structure of XK supported, but additionally the extension of this common theme across levels suggests a sort of social dimension (see Figure 6).

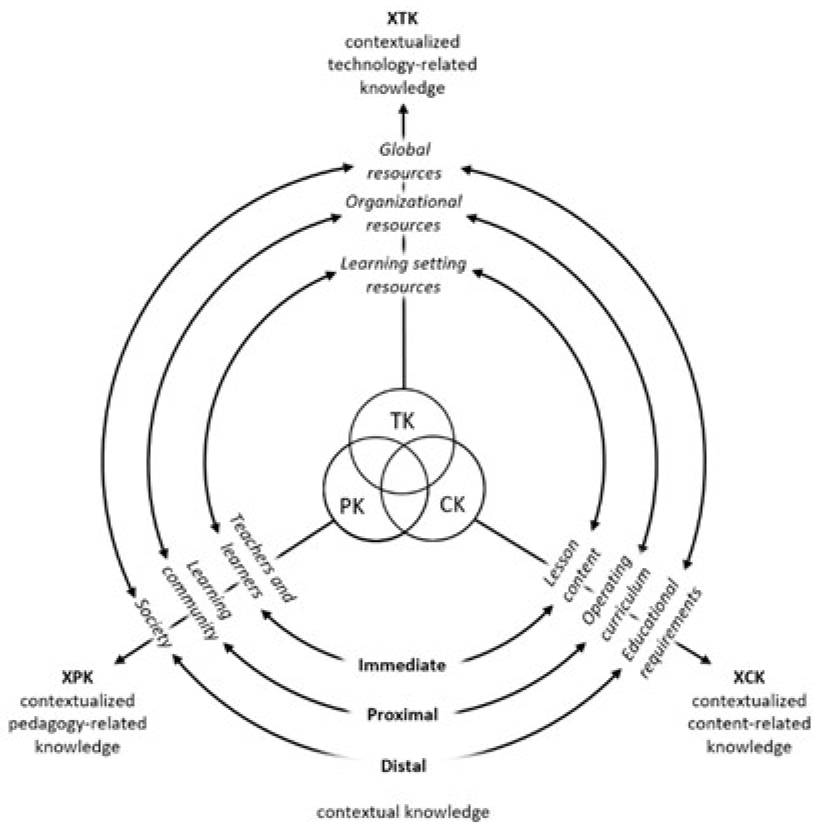
Upon further analyses, we found similar interlevels patterns for two more themes, that of resources and that related to content. The resource dimension includes both the relevant tangible and intangible elements of context levels, whereas the content dimension describes level-specific epistemic content-related factors (see Figure 6). Additional support for the relevance of this triad for educational contexts could be drawn from previous literature. From a general perspective, the very model upon which the levels of XK are derived (Bronfenbrenner's, 1995, model of ecological development) characterizes individual-environment interactions as consisting of "persons [social], objects [physical infrastructure, resources], and symbols [epistemic content]" (p. 620).

Considering more education-specific examples, literature from the field of educational design breaks down instructional factors into those related to learners, settings, or tasks and the reciprocal interactions between these (e.g., Wilson, et al., 1993, in Kirschner et al., 2002). Similarly, the more recent Activity-Centered Analysis and Design (ACAD) framework (Goodyear et al., 2021), conceptualized student activity in complex learning settings as being socially (i.e., related to individuals, communities, and interactions), physically (i.e., related to settings and resources), and epistemically (i.e., related to content and tasks) situated.

Of these three, we found the social dimension to emerge as particularly relevant. In fact, not only was it found to be associated with the vastest number of factors across levels, but nonmetric multidimensional scaling revealed it to be the only category of XK to be consistently included across all records. This predominance could arise from a focus on social aspects in research or it might suggest that teachers perceive social factors to play a primary role in accounting for variation across contexts, reflected in the literature by findings of diverse effects in teaching the same subject to different students even within the same school (e.g., Valli & Chambliss, 2007). In other words, XK represents the body of knowledge that supports teachers in effectively adapting their practice for teaching the same subject to different learners in diverse settings (Barnett & Hodson, 2001; Karakaya Cirit & Canpolat, 2019).

Educational settings are characterized by complex and dense interactions between factors (see Kelly, 2008) leading to intricate relations between levels and dimensions of XK and resulting in a form of networked knowledge. Figure 6 is a visual summary of the findings of this systematic literature review. It represents the orchestration of the dual components (i.e., levels and dimensions) of XK. We will refer to this proposed extension of the TPACK framework as XTPACK (abbreviated form of the mnemonic "conteXTPACK") and will describe its conceptual nature in more depth in the following section.

Figure 6
Networked Contextual and Contextualized Knowledge Forming XTPACK



The Conceptual Nature of XTPACK

The evidence discussed until this point emphasizes two crucial aspects of XK: (a) every educational context is its own unique constellation of contextual factors, leading teachers to develop specialized knowledge for each educational setting; and (b) although each is different and potentially subject to change over space and time, educational contexts can be described in a structured manner by means of contextual levels and dimensions, which interact with each other forming a knowledge network (i.e., XTPACK; see Figure 6). To better understand these components, their interactions, and their practical relevance, we will describe the significance of levels and dimensions of context for teachers' contextual and contextualized knowledge, as well as the symbiotic relations between these two (i.e., networked knowledge).

Contextual Knowledge

Teachers' knowledge of each level of context (i.e., immediate, proximal, or distal) represents their *contextual knowledge*. This form of knowledge reflects a teacher's understanding of the factors cooccurring at that level and of how they reciprocally influence each other within this shared setting. In other words, a teacher's contextual knowledge of their immediate, proximal, or distal educational context consists of teachers' knowledge of the specific constellation of social (i.e., pedagogy-related), resource (i.e., technology-related), and content-related factors and their interactions characterizing that level of context (i.e., intralevel relations; see Figure 6).

Every context (and level of context) is unique and, thus, will be reflected by its own unique constellation of factors (see also Koehler & Mishra, 2009; Mishra & Koehler, 2006; Rosenberg & Koehler, 2015). For example, in Classroom A (i.e., the immediate level), implementing a lesson to meet an instructional goal (content-related factor) might require a teacher to consider the needs of learners X, Y, and Z (social factors), whereas in Classroom B, the same teacher teaching the same lesson might have a more homogenous group of learners yet may need to consider limitations of technological infrastructure (resource factors).

Contextualized Knowledge

In addition to understanding the levels of context within which teachers' knowledge is embedded, TPACK has been described as *contextualized knowledge*. At the most basic level, Mishra and Koehler (2006) initially described the heart of TPACK (i.e., TPCK) as contextualized by the intersections of its core domains PK, CK, and TK. This level of contextualization is intrinsic to the framework itself and supports theoretical considerations of combining PK, CK, and TK but remains context-free, as it does not take external settings into account.

In practice though, TPACK does not exist in a vacuum, and "teachers constantly negotiate a balance between technology, pedagogy, and content in ways that are appropriate to the specific parameters of an ever-changing educational context" (Koehler & Mishra, 2008, p. 21). Given the multilevel structure of educational contexts, teachers' TPACK is embedded within multiple contexts, which are not independent of each other. Rather, TPACK is contextualized by being situated within contextual knowledge of a specific level as well as by relations between factors extending across levels of context (interlevel relations; see Figure 6).

Pedagogical considerations, for example, are based on immediate knowledge of classroom factors with a focus on who is interactingand attends to the social aspects of educational settings (e.g., students' needs will be related to their home environments and parental expectations, which in turn, reflect the skills for being active members of society; *contextualized pedagogy-related knowledge*). Similarly, selecting subject matter (that is, whatis taught) will be aligned across levels based on content-related factors (e.g., a lesson on chemical reactions will be grounded in the school's chemistry curriculum, which is geared toward meeting the requirements for degree or qualification for working in the chemical industry; *contextualized content-related knowledge*). Finally, teachers' technological decisions will depend on which resources can be usedwithin educational settings (e.g., using educational programs in class will depend on school's software licences, which ultimately reflect the current developments in educational technological software; *contextualized technology-related knowledge*).

Networked Knowledge

To be meaningful, the levels and dimensions of XK need to be viewed holistically as the contextual knowledge of levels of context (i.e., knowledge *of* context; Rosenberg & Koehler, 2015a) within which TPACK is embedded as a form of contextualized knowledge (i.e., knowledge *in* context; Rosenberg & Koehler, 2015a). Viewing this construct as consisting of simultaneous intra- as well as interlevel relations of context is crucial, as the very success of teachers' instructional practice appears to depend on their orchestrated understanding of this network's systemic potential (Mishra & Warr, 2021).

Recalling the ill-structured and complex nature of educational environments (Kelly, 2008), XK may not be directly transferable across settings, given that each environment presents its own unique and dynamic constellation of contextual factors. Thus, rather than taking a prescriptive stance, XTPACK might function as a descriptive lens supporting both practicing and preservice teachers and other stakeholders (e.g., researchers, teacher education program designers, and policy makers). It may do so by offering a framework for systematically identifying and organizing the effects of contextual factors teachers encounter across their experiences, promoting the construction of knowledge networks that can flexibly consider contexts and more similarly resemble those of experts (e.g., Putnam & Borko, 2000; Shulman, 1987; Stigler & Miller, 2018).

Particularly, for preservice and beginner teachers, promoting attention to the multiple facets of context might support their development of case knowledge (Berliner, 2001) and lead them to perceive the unique opportunities and limitations of their specific teaching settings more readily, which in turn, can be highly informative cues for effectively contextualizing their practice. Finally, considering the importance of situated approaches toward developing teachers' knowledge (e.g., Putnam & Borko, 2000), incorporation of contextual elements into teachers' TPACK might be a key ingredient in bridging the gap between theory and practice (also see phronetic knowledge, Phillips et al., 2017, p. 24).

Limitations

Although this systematic review attempted to be as comprehensive as possible, several pragmatic decisions were necessary for guiding this process, the limitations of which are worth noting. First, given the different search features of the various databases, search algorithms differed slightly across these, influencing the number of records retrieved on each. Nevertheless, we consider this a minor point, especially since all subsequent screening, application of eligibility criteria, and analyses were universally applied. Second, this review adopted only select key terms, which even though not chosen arbitrarily, led to excluding records, including potentially overlapping concepts under other terms (e.g., “situated knowledge,” as in Lachner et al., 2019) as well as literature not published in English. Third, we only considered XK when and as it was explicitly defined by the individual records. Although this decision was in line with the research goal of identifying contextual knowledge *as defined in the literature*, in some cases this approach led to the same factors being differently coded based on their in-text relations to XK. A fourth limitation concerns the restrictions arising from the attempt to be as extensive as possible and, thus, include all types of records (i.e., empirical as well as theoretical). This restriction resulted in a heterogeneous sample for which it was not possible to define quality criteria applicable to all. Thus, the quality of the individual records was not controlled for.

Furthermore, a couple of conceptual limitations are also important to note. Mainly, this review was limited to a conceptual focus, and the proposed extended framework needs to be considered for its descriptive value. With regard to this point, two important limitations are associated with attempting to represent visually a comprehensive, generalized framework capturing the complexity of educational contexts: (a) Not all elements and interactions presented in the framework may be pertinent to every context; rather, each context will be its own unique constellation of contextual factors; and (b) even when present, the significance of comparable factors may vary across contexts. Both these points are of critical importance when considering XTPACK to avoid misleading interpretations of the graphic representation. As a final limitation, given that this research presents an initial step toward deeper understandings for XK, additional aspects such as XK measures, effects on TPACK, or relations with other constructs were not considered and call for further research.

Future Research

This review focused on describing teachers’ knowledge of context in depth, yet many aspects of this element of TPACK remain yet to be investigated. First, future research is required to investigate the empirical relevance of this extended framework. Naturally, practical implications of this framework should be considered (e.g., the prevalence of XK among preservice teachers; Aydın Günbatar et al., 2017) as well as methodological considerations (e.g., developing assessment approaches and investigating existing instruments; Canbazoglu Bilici et al., 2013; Önal, 2016).

Exploring approaches for assessing XK is an essential next step for providing empirical evidence for this construct, as well as shedding light on its development and relations to practical experience. Furthermore, having established XK as a knowledge construct, it would be interesting to investigate its relations with other constructs (e.g., teachers’ experience level or school level) as well as the extent to which teachers’ subjective perceptions and research on the objective effects of context on instruction overlap.

Last, especially considering the recent (and partially ongoing) restrictions on traditional face-to-face instruction due to the COVID-19 pandemic, which revealed teachers' lack of both technological skills (e.g., Marshall et al., 2020) and understanding for teaching in foreign online contexts (e.g., Carrillo & Flores, 2020), it would be interesting to explore the differences between face-to-face and online settings from the perspective of contextual and contextualized knowledge.

Conclusions

Addressing the overarching question of this systematic literature review, contextual knowledge appears to be a complex multilevel and multidimensional component of the TPACK framework. Teachers have been described as "curricular-instructional gatekeepers" (Manfra & Hammond, 2008; Thornton, 2001), whose quality lies in their abilities to make "simultaneous judgment about the material itself and its arrangement for instructional use with a particular group of students" (Thornton, 2001, p. 237). We propose that the "missing knowledge component" in the TPACK framework, underlying this form of judgment, consists of teachers' competence for developing situation-specific *contextual knowledge* and using this knowledge to effectively *contextualize* their TPACK for the educational environment at hand.

Thus, in addition to the seven traditional TPACK domains, teacher training institutions need to include a focus on developing contextual knowledge to support preservice teachers' ability and flexibly to adapt to dynamic educational environments. Put simply, TPACK can account for designing a lesson of the highest quality on a general, theoretical level, but the success of its execution in practice requires a networked understanding of each context's social, technological, and content-related aspects, namely XTPACK.

Notes

[a] Exceptions to this procedure were made for four dissertations only available in hardcopy as well as for the two by Cohen (2020) and Maloney (2018). Given the length of these dissertations, the first author screened and selected the overarching definitions and findings presented in the texts relevant to XK for subsequent coding.

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Rosenberg, J. M., & Koehler, M. J. (2015a). Context and teaching with technology in the digital age. In J. Keengwe, M. L. Niess, & H. Gillow-Wiles (Eds.), *Handbook of research on teacher education in the digital age* (pp. 440–465). IGI Global. https://doi.org/10.4018/978-1-4666-8403-4.ch017

Rosenberg, J. M., & Koehler, M. J. (2015b). Context and technological pedagogical content knowledge (TPACK): A systematic review. *Journal of Research on Technology in Education*, *47*(3), 186–210. https://doi.org/10.1080/15391523.2015.1052663

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Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, *57*(1), 1–23. https://doi.org/10.17763/haer.57.1.j463w79r56455411

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Ünal Çoban, G., Akpınar, E., Baran, B., Kocagül Sağlam, M., Özcan, E., & Kahyaoğlu, Y. (2016). The evaluation of 'technological pedagogical content knowledge based argumentation practices' training for science teachers.

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Wang, J. G. H. (2020). *Developing teachers technological, pedagogical, and content knowledge (TPACK) through design thinking and community of practice* [Doctoral dissertation, San Jose University]. SJSU Scholar Works. https://doi.org/10.31979/etd.adxe-dre5

Wang, W., Schmidt-Crawford, D., & Jin, Y. (2018). Preservice teachers' TPACK development: A review of literature. *Journal of Digital Learning in Teacher Education*, *34*(4), 234–258. https://doi.org/10.1080/21532974.2018.1498039

Willermark, S. (2018). Technological pedagogical and content knowledge: A review of empirical studies published from 2011 to 2016. *Journal of Educational Computing Research*, *56*(3), 315–343. https://doi.org/10.1177/0735633117713114

Wilson, B.,Teslow, J., & Osman-Jouchoux, R. (1993). What does a constructivist ID model look like? A makeover of the traditional ID based on constructivist and postmodern ideas. In E.E. Smith & J.G. Smith (Eds.), *Building partnerships '93: Bridging technology, performance, and development* (pp. 64-74). American Society for Training and Development.

Yeh, Y.-F., Hsu, Y.-S., Wu, H.-K., Hwang, F.-K., & Lin, T.-C. (2014), Development and validation of TPACK-practical. *British Journal of Educational Technology, 45*(4), 707-722. https://doi.org/10.1111/bjet.12078

Zinger, D., Tate, T., & Warschauer, M. (2017). Learning and teaching with technology: Technolgical pedagogy and teacher practice. In D. J. Clandinin & J. Husu (Eds.), *The SAGE handbook of research on teacher education* (pp. 577–593). Sage Publications Ltd. https://doi.org/10.4135/9781529716627

Appendix A
Not Accessible Records From Main Systematic Review

Adams, C., & Lemermeyer, G. (2020). Attuning preservice teachers to the new media ecology: 24-hours unplugged and TPACK's arc of transparency. *SITE interactive conference* (pp. 315–322). Association for the Advancement of Computing in Education (AACE).

Alharbi, S., & Drew, S. (2018). The role of self-efficacy in technology acceptance. *Proceedings of the future technologies conference* (pp. 1142–1150). Springer.

Almusfar, L. A. (2020). *An assessment of design principles for blended learning courses*. [Doctoral dissertation, The Claremont Graduate University].

Alqallaf, N., & Williams, M. (2015). Teachers' perception about their competency in integrating technology in elementary classrooms using the technological pedagogical content knowledge framework (TPACK). *E-Learn: World conference on e-learning in corporate, government, healthcare, and higher education* (pp. 741–745). Association for the Advancement of Computing in Education (AACE).

Angeli, C., Valanides, N., & Ioannou, I. (2015). Developing computer science teachers' technological pedagogical content knowledge. *Society for Information Technology & Teacher Education international conference* (pp. 3050–3058). Association for the Advancement of Computing in Education (AACE).

Chaves Rojas, M. (2016). *Exploring ICT integration in pre-service English language teachers in Cali, Colombia using a TPACK framework*. [Doctoral dissertation, Universidad Icesi].

Cheah, Y. H., Chai, C. S., & Toh, Y. (2019). Teachers' TPACK devolvement in a technology-mediated elementary science innovation: A translation perspective. *Society for Information Technology & Teacher Education international conference* (pp. 2417–2422). Association for the Advancement of Computing in Education (AACE).

Christodoulou, A. (2018). Effects of learning with e-TPCK on pre-service teachers' technological pedagogical content knowledge. *Society for Information Technology & Teacher Education international conference* (pp. 2012–2018). Association for the Advancement of Computing in Education (AACE).

Dreamson, N. (2019). *Critical understandings of digital technology in education: Meta-connective pedagogy*. Routledge.

Foulger, T., Mourlam, D., Jin, Y., & Ebersole, E. (2020). The role of the TPACK SIG in the curation and maintenance of the TPACK Wikipedia page. *SITE interactive conference* (pp. 711–714). Association for the Advancement of Computing in Education (AACE).

Jang, S.-J., & Tsai, M.-F. (2018). Exploring the development of pre-service teachers' ICT-TPACK using a cognitive stimulation tool. *Teacher training and professional development: Concepts, methodologies, tools, and applications* (pp. 757–784). IGI Global.

Johnson, D. (2014). *Reading, writing, and literacy 2.0*. Teachers College Press.

Lyublinskaya, I. (2015). Evolution of a course for special education teachers on integrating technology into math and science. In J. Keengwe, M. L. Niess, & H. Gillow-Wiles (Eds.), *Handbook of research on teacher education in the digital age* (pp. 521–547). IGI Global.

MacKinnon, G. (2017). The utility of TPACK in deconstructing the impact of an innovative STEM curriculum in a Chinese international school. *Society for Information Technology & Teacher Education international conference* (pp. 2397–2403). Association for the Advancement of Computing in Education (AACE).

Magen-Nagar, N., & Unger, O. A. (2014). The effect of PICTK knowledge and instructional TPACK knowledge on sense of empowerment among ICT Instructors. *EdMedia+ Innovate Learning* (pp. 1903–1912). Association for the Advancement of Computing in Education (AACE).

Mann, B. O., & Mann, D. C. (2020). *A study of teacher perceptions on the impact of technology-enhanced practices and student engagement* (Publication No. 28259804) [Doctoral dissertation, Samford University]. ProQuest Diss. Publishing.

McCashin, Q., Adams, C., & Carbonaro, M. (2020). Adding gamification to a teacher education course. *SITE Interactive Conference* (pp. 657–659). Association for the Advancement of Computing in Education (AACE).

Mitchell, M. (2020). Transforming graduate inservice teaching and learning within a mathematics TPACK online course. *Society for Information Technology & Teacher Education international conference* (pp. 1948–1953). Association for the Advancement of Computing in Education (AACE).

Mitchell, M. (2020). Transforming mathematics teacher education in the digital age a course that can be applied to a Covid semester: Transforming teaching and pedagogical practices within an online preservice constructivist mathematics content and technology course. *Innovate Learning Summit 2020*, 123-133.

Mourlam, D., & Chestnut, S. (2020). Investigating differences in teacher candidate TPACK: Comparisons of a STEM professional development school and a standalone educational technology course. *Society for Information Technology & Teacher Education international conference* (pp. 899–904). Association for the Advancement of Computing in Education (AACE).

Porras-Hernandez, L. H., & Salinas-Amescua, B. (2015). The transformative power of context for teachers' knowledge and practice. *American Educational Research Association annual meeting*.

Pugh, K. L., Liu, L., & Wang, P. (2018). Technology integration in a K-12 frontier district. *Society for Information Technology & Teacher Education international conference* (pp. 2117–2122). Association for the Advancement of Computing in Education (AACE).

Wacker, A. T. (2017). *Undergraduate music students' perceptions of lesson and rehearsal planning*. [Doctoral dissertation, University of Missouri–Columbia].

Appendix B
Elements of XK Subcomponents Identified From Preliminary Sample

Domain	Component in record	Dimension	Records
Micro (*n* = 10)	Available resources	Resources	Porras-Hernández & Salinas-Amescua (2013)
	Restrictions posed by resources (textbooks)	Resources	Jimoyiannis (2010)
	Teacher's and students' expectations, beliefs, preferences, and goals	Social	Porras-Hernández & Salinas-Amescua (2013)
	Teacher-student interactions/relationship	Social	Jang & Tsai (2013), Liang et al. (2013)
	Practical knowledge, classroom workings, classroom organizational knowledge, learning environment management	Social	Angeli & Valanides (2009), Jang & Tsai (2013), Jimoyiannis (2010)
	Norms and policies	Social	Porras-Hernández & Salinas-Amescua (2013)
	Lesson topic and activities	Content	Lin et al. (2013), Pamuk et al. (2013)
	Demands for teaching a specific content (specific TK, PK, and CK), ICT integration	Content	Liang et al. (2013), Otrel-Cass et al. (2012)
	Evaluation of students' understanding	Content	Chen & Jang (2013)[a], Jang & Tsai (2012; 2013)
Meso (*n* = 4)	Curricular material	Resources	Jimoyiannis (2010)
	School-specific technological availability and use	Resources	Hsu (2012)
	Time	Resources	Jimoyiannis (2010)
	Economic conditions	Resources	Porras-Hernández & Salinas-Amescua (2013)
	Teacher-peers, administrators, parents	Social	Porras-Hernández & Salinas-Amescua (2013)
	Social, cultural, political, organizational conditions	Social	Porras-Hernández & Salinas-Amescua (2013)
	School culture	Social	Jimoyiannis (2010)
	School expectations and values	Social	Angeli & Valanides (2009)
	Curriculum	Content	Jimoyiannis (2010)
	Exam-oriented goals	Content	Jimoyiannis (2010)
Macro (*n* = 3)	Economic conditions	Resources	Porras-Hernández & Salinas-Amescua (2013)
	Equipment	Resources	Porras-Hernández & Salinas-Amescua (2013)
	National teacher training programs	Resources	Porras-Hernández & Salinas-Amescua (2013)
	Social, cultural, political, organizational conditions	Social	Porras-Hernández & Salinas-Amescua (2013)
	Educational policies and initiatives	Social	Porras-Hernández & Salinas-Amescua (2013)
	Educational purposes, values and goals	Content	Angeli & Valanides (2009), Jimoyiannis (2010)
	Relevance of ICT for human activities	Content	Porras-Hernández & Salinas-Amescua (2013)
Teacher (*n* = 3)	Self-awareness	Social	Porras-Hernández & Salinas-Amescua (2013)
	Experience	Social	Angeli & Valanides (2009)
	Pedagogical beliefs	Social	Angeli & Valanides (2009), Jang & Tsai (2013)
Student[b] (*n* = 5)	Individual characteristics	Social	Liang et al. (2013)
	Self-esteem	Social	Porras-Hernández & Salinas-Amescua (2013)
	Attitudes	Social	Porras-Hernández & Salinas-Amescua (2013)
	Motivation	Social	Porras-Hernández & Salinas-Amescua (2013)
	Interests	Social	Porras-Hernández & Salinas-Amescua (2013)
	Prior knowledge	Social	Chen & Jang (2013)[a], Jang & Tsai (2012; 2013)

Misconceptions, preconceptions	Social	Chen & Jang (2013)[a], Jang & Tsai (2012), Porras-Hernández & Salinas-Amescua (2013)
Strengths	Social	Porras-Hernández & Salinas-Amescua (2013)
Learning difficulties	Social	Chen & Jang (2013)[a], Jang & Tsai (2012)
Individual needs	Social	Jang & Tsai (2013)
Family/home environments and activities	Social	Porras-Hernández & Salinas-Amescua (2013)

Note. The first column presents the coded domain according to Porras-Hernández & Salinas-Amescua (2013) as well as the number of records including components (specified in the second column) falling within that domain. The third column presents the dimensions inductively derived. [a]Record adopted Jang and Tsai's (2012) instrument (including contextualized PCK and TPCK) but did not explicitly define the contextual elements of the scale in text, thus elements were inferred from the original source. [b]In one record (Angeli & Valanides, 2009), knowledge of students is recognized as its own domain of knowledge, independent of XK.

Appendix C

Overview of Records in Final Sample (N = 47) Retained for Substantial Coding of XK (Step 3)

#	Authors (year)	Type	Country	*N*	Level	Subject	Cited source(s) referring to XK in record
1	Angeli, C., Valanides, N., & Christodoulou, A. (2016). Theoretical considerations of technological pedagogical content knowledge. In M. C. Herring, M. Koehler, & P. Mishra (Eds.), *Handbook of technological pedagogical content knowledge (TPACK) for educators: Second edition* (pp. 11–32). Routledge. https://doi.org/10.4324/9781315771328	T	-	-	-	-	Koehler & Mishra (2008), Porras-Hernandez & Salinas-Amescua (2013)
2	Angeli, C., Voogt, J., Fluck, A., Webb, M., Cox, M., Malyn-Smith, J., & Zagami, J. (2016). A K-6 computational thinking curriculum framework: Implications for teacher knowledge. *Journal of Educational Technology & Society*, *19*(3), 47–57. http://www.jstor.org/stable/jeductechsoci.19.3.47	T	-	-	-	-	Porras-Hernandez & Salinas-Amescua (2013)
3	Aydın Günbatar, S., Boz, Y., & Yerdelen Damar, S. (2017). A closer examination of TPACK-Self-efficacy construct: Modeling elementary pre-service science teachers' TPACK-Self efficacy. *İlköğretim Online*, *16*(3), 917–934. https://doi.org/10.17051/ilkonline.2017.330232	E	Turkey	665 (in)	I	Science	Canbazoglu-Bilici et al. (2013)
4	Bergeson, K., & Beschorner, B. (2020). Modeling and scaffolding the technology integration planning cycle for pre-service teachers: A case study. *International Journal of Education in Mathematics, Science and Technology*, *8*(4), 330. https://doi.org/10.46328/ijemst.v8i4.1031	E	USA	27 (pre)	I	Literacy	Mishra (2019)
5	Bibi, S., & Khan, S. H. (2017). TPACK in action: A study of a teacher educator's thoughts when planning to use ICT. *Australasian Journal of Educational Technology*, *33*(4), 70–87. https://doi.org/10.14742/ajet.3071	E	Australia	1 (in)	III	Education	Markauskeite et al. (2011)
6	Boniface, A. (2020). *Breaking the code: A narrative inquiry into creating and implementing computer science curriculum into elementary classrooms* (Publication No. 27963661) [Doctoral dissertation, Northern Arizona University]. ProQuest Dissertations Publishing.	E	USA	3 (in)	I	Computer science	Mishra (2019)
7	Bower, M. (2017). *Design of technology-enhanced learning: Integrating research and practice.* Emerald Publishing. https://doi.org/10.1108/978-1-78714-182-720171004	T	-	-	-	-	Hofer et al. (2015)
8	Chai, C. S., Koh, J. H. L., & Tsai, C.-C. (2016). A review of the quantitative measures of technological pedagogical content knowledge (TPACK). In M. C. Herring, M. Koehler, & P. Mishra (Eds.), *Handbook of technological pedagogical content knowledge (TPACK) for educators: Second edition* (pp. 87–106). Routledge. https://doi.org/10.4324/9781315771328	T	-	-	-	-	Canbazoglu-Bilici et al. (2013), Jang & Tsai (2012)

9	Chai, C. S., Rahmawati, Y., & Jong, M. S.-Y. (2020). Indonesian science, mathematics, and engineering preservice teachers' experiences in STEM-TPACK design-based learning. *Sustainability*, *12*(21), 9050. https://doi.org/10.3390/su12219050	E	Indonesia	37 (pre)	II	STEM	(by authors)
10	Cherner, T., & Smith, D. (2017). Reconceptualizing TPACK to meet the needs of twenty-first-century education. *The New Educator*, *13*(4), 329–349. https://doi.org/10.1080/1547688X.2015.1063744	T	-	-	-	-	(by authors, based on Bronfenbrenner, 1994)
11	Chisholm, S. (2020). *Enhancing the EdTech ecosystem in a British Columbia school district* (Publication No. 127) [Doctoral dissertation, Western University]. https://ir.lib.uwo.ca/oip/127	E	Australia	-	-	-	Mishra (2019)
12	Cirit, D., & Canpolat, E. (2019). A study on the technological pedagogical contextual knowledge of science teacher candidates across different years of study. *Education and Information Technologies*, *24*(4), 2283–2309. https://doi.org/10.1007/s10639-018-9845-9	E	Turkey	36 (pre)	II	Science	Porras-Hernandez & Salinas-Amescua (2013), (RE-TPCK) (by authors)
13	Cohen, D. (2020). *Contextual issues of technology integration in teacher practice* (Publication No. 9921893312001341) [Doctoral dissertation, RMIT University]. https://researchrepository.rmit.edu.au/esploro/outputs/doctoral/Contextual-issues-of-technology-integration-in-teacher-practice/9921893312001341	E	Australia	5 (in)	II	Mix	Porras-Hernandez & Salinas-Amescua (2013)
14	Espinoza, B. D., & Neal, M. (2018). Incorporating contextual knowledge in faculty professional development for online teaching. *Journal on Centers for Teaching and Learning*, *10*, 24–44. https://openjournal.lib.miamioh.edu/index.php/jctl/article/view/196	T	-	-	-	-	TPACK-ConK (by authors)
15	Everett, S. A., & Otto, C. A. (2015). A graphic model for designing effective lesson plans incorporating technology. In M. S. Khine (Ed.), *New directions in technological pedagogical content knowledge research: Multiple perspectives.* Information Age Publishing Inc.	T	-	-	-	-	Otto & Everett (2013)
16	Forssell, K. (2016). Making meaningful advances. In M. C. Herring, M. Koehler, & P. Mishra (Eds.), *Handbook of technological pedagogical content knowledge (TPACK) for educators* (2467-257). Routledge.	T	-	-	-	-	(by author)
17	Grosser, D. A. (2017). *A multiple case study of co-teachers' technology integration knowledge: How it is held, built, and shared* (Publication No. 1499449939) [Doctoral dissertation, College of William and Mary]. https://doi.org/10.21220/W4KM2K	E	USA	8 (in)	II	Mix	Porras-Hernandez & Salinas-Amescua (2013)
18	Harris, J., & Hofer, M. J. (2017). 'TPACK stories': Schools and school districts repurposing a theoretical construct for technology-related professional development. *Journal of Research on Technology in Education*, *49*(1-2), 1–15. https://doi.org/10.1080/15391523.2017.1295408	E	USA, Canada	7[a]	-	-	Porras-Hernandez & Salinas-Amescua (2013), (by authors)

19	Hidayat, A. (2018). *Development of the instrument to measure technological pedagogical content knowledge (TPACK) of pre-service science teacher in Indonesia* [Doctoral dissertation, Hiroshima University]. https://core.ac.uk/download/pdf/197311290.pdf	E	Indonesia	1192 (pre)	n.d.	-	(by author)
20	Hj Besar, Dk Hjh Siti Norainna Pg. *Engaging higher education students with social media: Mib module case study* (Publication No. 0000 0004 7655 9054) [Doctoral dissertation, University of Manchester]. EThOS. https://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.764422	E	Brunei	6 (in)	III	MIB[b]	Angeli & Valanides (2009)
21	Hsu, L., & Chen, Y.-J. (2019). Examining teachers' technological pedagogical and content knowledge in the era of cloud pedagogy. *South African Journal of Education*, *39*(S2), 1–13. https://doi.org/10.15700/saje.v39ns2a1572	E	Taiwan	301 (in)	I-III	-	[TLPACK] (by authors)
22	Irmak, M. (2018). *Developing effective socioscientific issues teaching practices through educational design research* [Doctoral dissertation, Middle East Technical University]. https://etd.lib.metu.edu.tr/upload/12621776/index.pdf	E	Turkey	36 (pre)	I	Science	Koh et al. (2014), Porras-Hernandez & Salinas-Amescua (2013)
23	Jin, Y. (2017). *Longitudinal study of pre-service teachers' development of TPACK in a required educational technology course* (Publication No. 17223) [Doctoral dissertation, Iowa State University]. https://lib.dr.iastate.edu/etd/17223	T	-	-	-	-	Porras-Hernandez & Salinas-Amescua (2013)
24	Kadijevich, D. M., & Madden, S. (2015). Comparing approaches for developing TPCK. In M. S. Khine (Ed.), *New directions in technological pedagogical content knowledge research: Multiple perspectives* (pp. 125–146). Information Age Publishing Inc.	T	-	-	-	-	Angeli & Valanides (2009)
25	Kadıoğlu-Akbulut, C., Çetin-Dindar, A., Küçük, S., & Acar-Şeşen, B. (2020). Development and validation of the ICT-TPACK-science scale. *Journal of Science Education and Technology*, *29*(3), 355–368. https://doi.org/10.1007/s10956-020-09821-z	E	Turkey	332 (pre)	-	Science	Grossman (1990)
26	Kapici, H. O., & Akcay, H. (2020). Improving student teachers' TPACK self-efficacy through lesson planning practice in the virtual platform. *Educational Studies*, 1–23. https://doi.org/10.1080/03055698.2020.1835610	E	(Turkey)	38 (pre)	-	Science	Canbazoglu-Bilici et al. (2013), Mishra (2019)
27	Koh, J. H. L., & Chai, C. S. (2015). Towards a Web 2.0 TPACK lesson design framework: Applications of a Web 2.0 TPACK survey of Singapore preservice teachers. In T.-B. Lin, V. Chen, & C. S. Chai (Eds.), *New Media and Learning in the 21st Century* (pp. 161–180). Springer Singapore.	E	Singapore	270 (pre)	I	-	Cox & Graham (2009)
28	Koh, J. H. L. (2020). Three approaches for supporting faculty technological pedagogical content knowledge (TPACK) creation through instructional consultation. *British Journal of Educational Technology*, *51*(6), 2529–2543. https://doi.org/10.1111/bjet.12930	E	New Zealand	18 (in)	III	Mix	Koh et al. (2014)

29	Lachner, A., Backfisch, I., & Stürmer, K. (2019). A test-based approach of modeling and measuring technological pedagogical knowledge. *Computers & Education*, *142*, 103645. https://doi.org/10.1016/j.compedu.2019.103645	E	Germany	240 (in), 120 (pre)	-	-	De Jong & Ferguson-Hessler (1996)
30	Lewthwaite, B. E., Knight, C., & Lenoy, M. (2015). Epistemological considerations for approaching teaching in an on-line environment Aboriginal and Torres Strait Islander teacher education program: Reconsidering TPACK. *Australian Journal of Teacher Education*, *40*(9), 63–85. https://eric.ed.gov/?id=ej1076435	E	Australia	8 (in)	III	Mix	Porras-Hernandez & Salinas-Amescua (2013), (by authors)
31	Lim, S. H. (2016). *Teacher knowledge, information and communication technology and the teaching of Chinese-as-a-second-language in Singapore* [Doctoral dissertation, University of Western Australia]. https://doi.org/10.4225/23/59cdf9df5d6cd	E	Singapore	12 (in)[c]	II	Chinese	Hsueh (2008)
32	Maloney, J. (2018). *Fulbright FLTA CALL knowledge development and enactment: The role of context* (Publication No. 10812437) [Doctoral dissertation, Michigan State University]. ProQuest Dissertations Publishing.	E	USA	5 (in)	Mix	EFL	Porras-Hernandez & Salinas-Amescua (2013)
33	Mills, K. (2019). *Illuminating children's scientific funds of knowledge through social media sharing* [Doctoral dissertation, University of Maryland]. https://doi.org/10.13016/MBYA-JWKQ	E	USA	3 (in)	II	Science	Mishra (2019), Rosenberg & Koehler (2015)
34	Mishra, P. (2019). Considering contextual knowledge: The TPACK diagram gets an upgrade. *Journal of Digital Learning in Teacher Education*, *35*(2), 76–78. https://doi.org/10.1080/21532974.2019.1588611	T	-	-	-	-	(by author)
35	Njiku, J., Mutarutinya, V., & Maniraho, J. F. (2020). Developing technological pedagogical content knowledge survey items: A review of literature. *Journal of Digital Learning in Teacher Education*, *36*(3), 150–165. https://doi.org/10.1080/21532974.2020.1724840	T	-	-	-	-	Canbazoglu-Bilici et al. (2013), Mishra (2019), Önal (2016)
36	Ogan-Bekirogli, F., & Karabuz, O. (2017). Pre-service teachers' technology integration and their technological pedagogical content knowledge. In M. Pehlivan & W. Wu (Eds.), *Research highlights in education and science 2017* (pp. 156–165). ISRES Publishing.	E	-	10 (pre)	I-II	Physics	Burry-Stock & Oxford (1994)
37	Önal, N. (2016). Development, validity and reliability of TPACK scale with pre-service mathematics Teachers. *International Online Journal of Educational Sciences*, *8*(2), 97–103. https://doi.org/10.15345/iojes.2016.02.009	E	Turkey	316 (pre)	n.d.	Math	(by author)
38	Ortega-Sánchez, D., & Gómez-Trigueros, I. M. (2019). Didactics of historical-cultural heritage QR codes and the TPACK model: An analytic revision of three classroom experiences in Spanish higher education contexts. *Education Sciences*, *9*(2), 1–10. https://doi.org/10.3390/educsci9020117	E	Spain	-	I	Social sciences	Mishra (2019)

39	Rosenberg, J. M., & Koehler, M. J. (2015). Context and teaching with technology in the digital age. In J. Keengwe, M. L. Niess, & H. Gillow-Wiles (Eds.), *Handbook of research on teacher education in the digital age* (pp. 440–465). IGI Global. https://doi.org/10.4018/978-1-4666-8403-4.ch017	T	-	-	-	-	Porras-Hernandez & Salinas-Amescua (2013)
40	Sadaf, M., & Tariq, M., Haider, A. (2019). Measuring the impact of technological pedagogical content knowledge on teacher resilience in universities of Pakistan. *International Journal of Management Excellence*, *12*(3), 1872–1881. https://doi.org/10.17722/ijme.v12i3.1084	E	Pakistan	377 (in)	Mix	Mix	Canbazoglu-Bilici et al. (2013)
41	Şen, Ş. (2020). Modelling the relations between Turkish chemistry teachers' sense of efficacy and technological pedagogical content knowledge in context. *Interactive Learning Environments*, 1–14. https://doi.org/10.1080/10494820.2020.1712430	E	Turkey	201 (in)	-	Chemistry	Jang & Tsai (2012, 2013), Koehler & Mishra (2008), Koh et al. (2014)
42	Slaughter, Y., O'Brien, A., Hajek, J., & Smith, W. (2019). Distance education for languages: The role of technological knowledge. *Babel*, *54*(3), 12–17. https://afmlta.asn.au/babel/	E	Australia	2 (in)	I	Japanese/ Indonesian	Mishra (2019)
43	Ünal Çoban, G., Akpınar, E., Baran, B., Kocagül Sağlam, M., Özcan, E., & Kahyaoğlu, Y. (2016). The evaluation of 'technological pedagogical content knowledge based argumentation practices' training for science teachers. *TED EĞİTİM VE BİLİM*, *41*(188). https://doi.org/10.15390/EB.2016.6615	E	Turkey	37 (in)		Science	Canbazoglu-Bilici et al. (2013)
44	Wang, J. G. H. (2020). *Developing teachers technological, pedagogical, and content knowledge (TPACK) through design thinking and community of practice* [Doctoral dissertation, San Jose State University].	E	USA	18 (in)	I		Mishra (2019), Rosenberg & Koehler (2015)
45	Wright, B., & Akgunduz, D. (2018). The relationship between technological pedagogical content knowledge (TPACK) self-efficacy belief levels and the usage of Web 2.0 applications of pre-service science teachers. *World Journal on Educational Technology: Current Issues*, *10*(1), 52–69. https://doi.org/10.18844/wjet.v10i1.3332	E	Turkey	344 (pre)	-	-	Canbazoglu-Bilici et al. (2013)
46	Xu, X., & Sun, Y. (2019). A technological pedagogical content knowledge (TPACK) framework for ESP teachers in tertiary education in China. *The Asian ESP Journal*, *15*(3), 193–227. https://www.elejournals.com/asian-esp-journal/asian-esp-journal-volume-15-issue-3-december-2019/	E	China	125 (in)	III	English	TPACK-ESP (by authors)
47	Yanış, H., & Yürük, N. (2020). Development, validity, and reliability of an educational robotics based technological pedagogical content knowledge self-efficacy scale. *Journal of Research on Technology in Education*, 1–29. https://doi.org/10.1080/15391523.2020.1784065	E	Turkey	266 (pre)	I	Science	Mishra (2019)

Note. Type indicates whether the record is of theoretical/conceptual nature ('T') or of empirical nature ('E'). The column *N*, in addition to sample size in parentheses indicates whether this consisted of in-service ('in') or pre-service teachers ('pre'). The Level column presents the educational level being taught or trained for: I = primary level (including early childhood); II = secondary level; III = tertiary level.

[a]Schools/districts participating in symposium and presenting their own cases.

[b]Malay Islamic Monarchy.

[c]In addition to 12 in-service teachers, study included two teacher educators.