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# Running in circles: A systematic review of reviews on technological pedagogical content knowledge (TPACK)

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ABSTRACT

Extensive research exists on the Technological Pedagogical Content Knowledge (TPACK) model and has led to a substantial number of systematic reviews and meta-analyses. These publications vary greatly in their focus and provide overviews of specific aspects of TPACK research. This paper aims to consolidate these insights and investigate the following research questions: What do systematic literature reviews and meta-analyses reveal about the current state of the art of TPACK research? What is the methodological quality of systematic reviews and meta-analyses of TPACK? This study identified 21 systematic reviews and 2 meta-analyses eligible for analysis. Overall, the review of the reviews revealed that many of the recurring theoretical or methodological issues of the TPACK framework remain unresolved. To address these issues, research on TPACK needs to simultaneously account for the complex, situated, and dynamic nature of TPACK and clarify the concept of professional knowledge. The review engenders several directions for future research, including a better operationalization of knowledge, more experimental and longitudinal studies, and a more comprehensive measurement and integration of student learning as a dependent variable in research on TPACK.

## 1. Introduction

Technology integration in education has turned out to be challenging in many countries. Next to first-order barriers, such as the lack of technological infrastructure and other resources, second-order barriers, including teacher beliefs, skills, and—quite fundamentally—teachers' (lack of) competencies, are among the most important factors hindering technology integration in schools (Davies & West, 2014; Niederhauser & Lindstrom, 2018). The Technological Pedagogical Content Knowledge (TPACK) framework was developed to conceptualize the core knowledge that teachers need to successfully integrate technology into their teaching (Koehler & Mishra, 2008; Mishra & Koehler, 2006). Currently, TPACK is one of the most cited frameworks within the field of educational technology research (e.g., Davies & West, 2014; Hew et al., 2019; Niederhauser & Lindstrom, 2018; Zou et al., 2022). In a large number of articles, pre-service and/or in-service teachers' TPACK competencies are examined using different approaches and instruments. In such a large and vibrant field of research, review articles, together with meta-analyses, play a decisive role in describing, summarizing, and systematically analyzing former research to give a comprehensive overview of the field (see, e.g., Pigott & Polanin, 2020).

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Moreover, these reviews and meta-analyses provide implications for urgently needed research on the reviewed topic.

### 1.1. TPACK framework

The TPACK framework is based on Shulman's (1986, 1987) Pedagogical Content Knowledge (PCK) model and extends it with a third, technology-related core component for teaching effectively in the digital era (Mishra & Koehler, 2006). Thus, the TPACK framework consists of three core components: pedagogical knowledge (PK), content knowledge (CK), and technological knowledge (TK). At the intersections of these three core components, four additional hybrid areas of knowledge have emerged: pedagogical content knowledge (PCK), technological pedagogical knowledge (TPK), technological content knowledge (TCK), and technological pedagogical content knowledge (TPCK). Since teaching and learning are highly situated activities, in 2008, Koehler and Mishra included *context* as part of the TPACK model. However, how context is understood—for example, as the external factors that influence teachers' knowledge or as a domain of knowledge itself (i.e., the contextual knowledge of students, schools, or school policy)—has long been unclear and has been described (if at all) differently by various authors (see Brianza et al., 2022). Recently, Mishra (2019) explicitly emphasized this point, upgrading "context" to "contextual knowledge" (XK) to capture what teachers know about context. This includes "everything from a teacher's awareness of available technologies to the teacher's knowledge of the school, district, state, or national policies they operate within" (Mishra, 2019, p. 76).

### 1.2. More than 15 Years of TPACK research

Since its introduction, the TPACK framework has inspired a large amount of research. Today, hundreds of studies employ the TPACK framework (see Figs. 1 and 2). For example, the article "Technological pedagogical content knowledge: A framework for teacher knowledge" by Mishra and Koehler (2006) has been cited almost 15,000 times (Google Scholar, December 2022).

In recent years, the framework has evolved with regard to several aspects. On a theoretical level, the framework has undergone adaptations (e.g., Lee & Tsai, 2010), extensions (e.g., Angeli & Valanides, 2009; Porras-Hernández & Salinas-Amescua, 2013), and specifications relating to the school subject (e.g., Jimoyiannis, 2010), the technology (e.g., Jang & Tsai, 2012), or the pedagogical approach (e.g., Chai et al., 2011). In addition, TPACK has been examined in relation to other concepts, such as self-efficacy or teacher beliefs (e.g., Abbitt, 2011a). On a methodological level, a variety of instruments have been developed, empirically tested, and validated. TPACK is measured, for example, through lesson plans (e.g., Harris et al., 2010), self-reported questionnaires (e.g., Schmid et al., 2020; Schmidt et al., 2009), or test-based instruments (e.g., Backfisch et al., 2020; Lachner et al., 2019). Furthermore, the TPACK framework was used to design teacher training courses that enabled teachers to successfully acquire knowledge (e.g., Chai et al., 2010). In general, the knowledge acquired in teacher training courses positively affects the teaching practices of teachers, which in turn can have a positive impact on students' performance (Garrett et al., 2019; Kennedy, 2016). However, little is known about the impact of teachers' TPACK on student performance.

Few articles have summarized past TPACK research activities and partly suggested directions for future developments in TPACK research without conducting a systematic literature search. For example, Brantley-Dias and Ertmer (2013) raised the question of what TPACK looks like in practice, how it is measured, and how it can be promoted and developed in different disciplines. In the introduction to the special issue of future directions in TPACK research and development, Harris et al. (2017) emphasized the need for further studies dealing with the accurate measurement and validation of TPACK, the assistance in the development of pre-service and

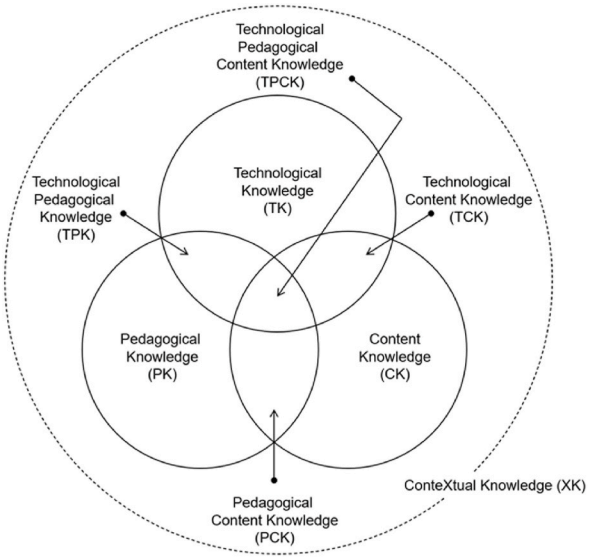



**Fig. 1.** TPACK framework (Koehler & Mishra, 2008; Mishra, 2019).

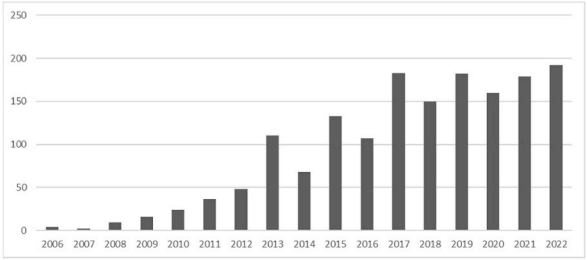



**Fig. 2.** Number of Publications on the topic of "TPACK" OR "Technological Pedagogical Content Knowledge" in Web of Science (01/2006-12/2022; Search string; ALL=("TPACK" OR "Technological Pedagogical Content Knowledge")).

in-service teachers' TPACK, the contextual influences, or the relationship of TPACK-based knowledge to teachers' decision-making and action. In his essay, Petko (2020) suggested the need to clarify the interplay of the TPACK factors, expand the model without changing its core, and combine the TPACK model with other models of technology integration. Furthermore, on a methodological level, Petko (2020) formulated the need for a broader set of valid and reliable measures as well as for experimental and longitudinal large-scale studies.

In summary, these examples illustrate gaps in the current TPACK research with regard to theoretical (e.g., clarifying the interplay of factors in TPACK; Petko, 2020) and methodological demands (e.g., providing more valid and reliable measures for TPACK; Brantley-Dias & Ertmer, 2013; Harris et al., 2017; Petko, 2020). Recently, Saubern et al. (2020) even argued for a "reset in TPACK research" (p. 6) instead of drawing up a list of research desiderata in TPACK.

Today, there are numerous reviews that examine TPACK in general or for specific target groups (mostly pre- or in-service teachers), domains, or countries. However, even after more than 15 years of TPACK research and a myriad of reviews, the field still lacks fundamental knowledge that exceeds the common study results clustered by target groups or domains. In other words, to the extent of our knowledge, a systematic study analyzing the findings of TPACK reviews across various target groups, domains, methods, and contexts has yet to be done. To close this research gap, a global overview of the framework and its current research activities is needed. Nevertheless, this endeavor encounters various challenges, among which the overwhelming number of unsystematic and more systematic reviews that approach TPACK from diverse perspectives complicates the drawing of overarching parallels between these studies. Further, the findings of different reviews are often not directly compatible, as they frequently have a specific focus (e.g., focusing on TPACK in one specific domain) or are very narrative in nature. As a result, a condensed picture of fundamental insights, as well as the black boxes and problems that remain unsolved, is urgently and equally needed by researchers, practitioners, and policymakers. Thus, there is a need for reviews and meta-analyses that go beyond simple descriptions and summaries of an existing research topic or the current state of the research (see Gruber et al., 2020).

### *1.3. The present study*

The abbundance of TPACK research published over the past 15 years has led to numerous systematic reviews and meta-analyses summarizing different aspects of the literature on the concept. The aim of this study is to provide an overarching view of the various systematic reviews and meta-analyses that goes beyond mere narrative summaries to identify developments and trends in TPACK research.

The main research questions are as follows.

1. What do systematic literature reviews and meta-analyses reveal about the current state of TPACK research?
   a. What aspects of TPACK have been sufficiently addressed in the literature?
   b. What aspects of TPACK require more research?
2. What is the methodological quality of current systematic reviews and meta-analyses of TPACK?

## 2. Methods

### *2.1. Systematic review of systematic reviews and meta-analyses*

Systematic reviews play an important role in increasing knowledge and understanding in a particular subject area, as they summarize, analyze, and describe previous evidence-based research in a systematic and traceable way. Systematic reviews are thus analyses on a secondary level that combine primary research to answer a specific research question (Newman & Gough, 2020). As several of them become available, these reviews can be combined on a third level into systematic reviews of reviews (sometimes also called meta-meta-analysis, meta-synthesis, overview, overview of reviews, second-order meta-analysis, summary of systematic reviews, synthesis of reviews, tertiary review, or umbrella reviews; Aromataris et al., 2015, p. 133; Newman & Gough, 2020, p. 17; Polanin et al., 2017, p. 173). Such reviews of reviews give an overall picture of previous research findings without going into the details of primary or original research and can therefore be, for example, an efficient method for examining former research for particular

questions or serve as a decision basis for policymakers (Aromataris et al., 2015; Gough & Richardson, 2019; Polanin et al., 2017).

Similar to systematic reviews, systematic reviews of reviews must follow clearly defined rules that ensure the application of similar procedures (Aromataris et al., 2015; Polanin et al., 2017). Two reporting standards have been established in the field of education and psychology to guide the authors of reviews and meta-analyses in reporting their research procedures from the first literature search to the analyses and summary of results in a transparent and standardized way. These are the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) by Moher et al. (2009) and recently updated by Page et al. (2021a, b) and the Meta-Analysis Reporting Standards (MARS) by the American Psychological Association (2010). Further, the Sampling strategy, Types of studies, Approaches, Range of years, Limits, Inclusion criteria, Terms used, and Electronic sources (STARLITE; Booth, 2006) is a practical tool for describing the standards for literature searches.

### 2.2. Literature search and inclusion criteria

In our literature search, we systematically searched for reviews and meta-analyses of TPACK. To this end, we considered two non-subject-specific electronic databases and one academic search engine (Scopus, Web of Science, and Google Scholar), as well as two subject-specific electronic databases (Education Resources Information Center [ERIC] and PsycINFO). As search terms, we employed four terms and used the Boolean operators 'OR' and 'AND' to combine them: "Technological Pedagogical Content Knowledge" OR "TPACK" AND "review" OR "meta". The terms had to appear in the title, since it is assumed that the title provides information about the type of publication (review or meta-analysis; see also the first checklist item in PRISMA) and the topic (TPACK). Table 1 provides an overview of the standards used here for reporting literature searches (STARLITE; see also Section 2.1; Booth, 2006).

To ensure including as many relevant publications as possible, we followed the well-established PRISMA procedure, which allowed us to also add articles identified through other sources (e.g., tpack.org). All the databases were searched on December 1, 2022, and yielded a total of 240 hits (see Table 2).

### 2.3. Selection criteria and exclusion of reviews and meta-analyses

After the literature search, we examined the hits found more closely, following the four phases of the PRISMA flow diagram (Moher et al., 2009). After removing all duplicates, 95 records remained (identification phase). In the screening phase, we initially excluded all documents that were not written in English, followed by all documents that were not publicly available, which reduced the number of records to 73. These records were then screened on the basis of full texts (eligibility phase). First, texts that were not reviews or meta-analyses were excluded (for example, instead of a review of primary studies, it was a review of a TPACK-related book; e.g., Oliver, 2011). Second, texts that could not be identified as systematic reviews or meta-analyses were excluded because the procedure was not or insufficiently described (see Pigott & Polanin, 2020 for guidance on what should be reported in meta-analyses). Based on PRISMA (see Moher et al., 2009, p. 4), the reviews/meta-analyses had to meet the following criteria: (a) specification of search databases or information sources, (b) clear description of the words or strings used in the search queries with the inclusion of "TPACK" or "Technological Pedagogical Content Knowledge," (c) clear specification of inclusion and exclusion criteria, and (d) description or depiction of the stepwise algorithm applied in implementing these criteria. As Fig. 3 shows, applying these conditions resulted in a list of 23 systematic reviews and meta-analyses included in our final sample.

#### 2.3.1. Coding and intercoder-reliability

One author screened all articles and decided, based on the inclusion and exclusion criteria, whether an article would be considered for further analysis. These decisions were validated by a second author. Based on the inclusion criteria, about 20% of the 73 articles were double-coded by these two authors (Cohen's Kappa = 0.81; Landis & Koch, 1977). The authors discussed the disagreements until they reached a consensus.

**Table 1**
Operationalization of the STARLITE Standards for Systematic Reviews (see Booth, 2006).

| Elements | Operationalizations in present review of reviews |
|---|---|
| S: Sampling strategy | Selective search for reviews and meta-analyses of TPACK |
| T: Types of studies | Reviews and meta-analyses |
| A: Approaches | Search in electronic databases + Records from other sources (e.g., TPACK newsletter, tpack.org) |
| R: Range of years | 2006–2022 |
| L: Limits | Published in English and publicly available |
| I: Inclusion criteria | No restrictions regarding subject, teacher population, instrument used, geographical location, or date of publication (neither for the reviews nor for the primary studies)<br>Any type of review or meta-analysis (e.g., published as a dissertation or conference paper) |
| T: Terms used | "technological pedagogical content knowledge" OR "TPACK" AND "review" OR "meta" in title |
| E: Electronic sources | ERIC, Google Scholar, PsycINFO, Scopus, Web of Science |

**Table 2**
Overview of the Search Strings.

| Database | Search strings |
|---|---|
| ERIC | (title(TPACK) OR title(Technological Pedagogical Content knowledge)) AND (title(Review) OR title(Meta)) |
| Google Scholar | (a) allintitle: Review OR Meta "Technological Pedagogical Content Knowledge"<br>(b) allintitle: Review OR Meta "TPACK" |
| PsycINFO | TI ("tpack" OR "technological pedagogical content knowledge") AND TI ("review" OR "meta") |
| Scopus | (TITLE(tpack) OR TITLE(technological AND pedagogical AND content AND knowledge)) AND (TITLE(review) OR TITLE (meta)) |
| Web of Science | TI=(tpack OR "technological pedagogical content knowledge") AND TI=(review OR meta)<br>Databases: WOS, BCI, BIOSIS, CCC, DRCI, DIIDW, KJD, MEDLINE, RSCI, SCIELO, ZOOREC |

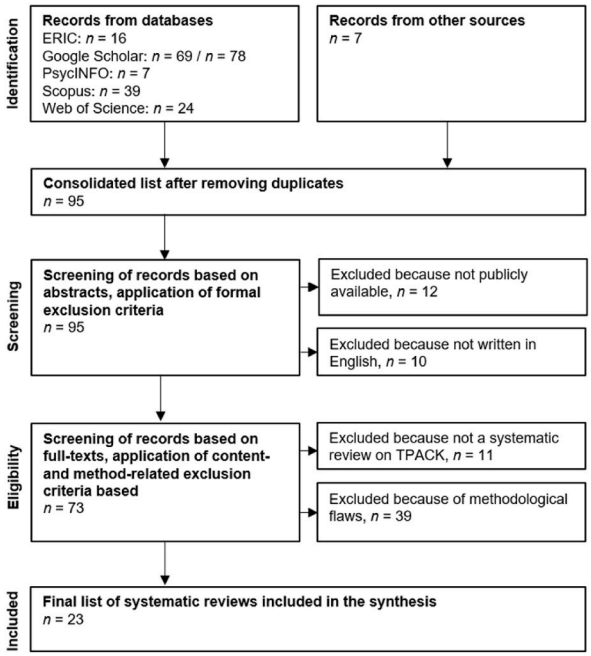



**Fig. 3.** PRISMA statement of the present study.

### *2.4. Coding of the systematic reviews and meta-analyses*

The results of a review of reviews can be synthesized in different ways: (a) each review can be described individually, (b) a descriptive synthesis can be conducted, or (c) the reviews can be quantified using meta-analytical techniques (Polanin et al., 2017; see also Pigott & Polanin, 2020). However, according to Polanin et al. (2017), the first approach to synthesis is problematic, and the other two procedures are very complex. In addition, "techniques for qualitatively or quantitatively synthesizing reviews are in their infancy and must be further developed" (Polanin et al., 2017, p. 197). In this review of reviews, on the one hand, we are interested in the content of the reviews and meta-analyses (RQ1) and, on the other hand, in their methodological quality (RQ2). Since the majority of the investigated records are reviews and therefore meta-analytical techniques cannot be used, we chose a descriptive synthesis to address our first question, conducting a content analysis of records retained in the final sample (see Section 2.4.1). For the assessment of the methodological quality of the reviews (RQ2), we used existing assessment instruments and adapted them to the present context (see Section 2.4.2).

#### *2.4.1. Content and thematic trend analysis*

Given that one major aim of this second-order review was not to present an overview of individual TPACK findings but rather to identify overarching thematic trends across the literature. Accordingly, our research first question (RQ1) is twofold: What aspects have been sufficiently addressed in the literature (RQ1a), and what aspects require more research (RQ1b)?

For our thematic coding, we focused on the discussion or, if no such section was outlined, the conclusion sections to identify the main messages of records retained in the final sample. To identify the main messages, we adopted the paragraph as our unit of analysis. Analyses were conducted in four steps: (1) content reduction, (2) content analysis, (3) thematic trend analysis, and (4) chronological pattern analysis.

### 2.4.2. Content reduction

Following the logic of the definition of the paragraph as a unit of "a short part of a text, consisting of at least one sentence and beginning on a new line. It usually deals with a single event, description, idea, etc." (Cambridge Advanced Learner's Dictionary & Thesaurus, n.d.), the first step served to extract the main messages of each record beyond the findings of individual studies. To this end, the first authors considered one paragraph at a time and formulated a single sentence to capture its main focus, noting it either as an established aspect of TPACK research (RQ1a) or as a point requiring future study (RQ1b). The reliability of this approach was tested on six records (~25% of the final sample), for which the two authors independently formulated single sentences for a total of 33 paragraphs (see examples in Table 3). Among these, the two authors formulated sentences reflecting agreement of focus for 26 paragraphs (~79%), whereas for the 7 divergent cases, a sentence was formulated through collaborative discussion. Given the satisfactory level of agreement with this approach, sentences for the remaining 17 records were formulated by one of the two first authors, and ambiguous paragraphs were discussed collaboratively.

### 2.4.3. Content analysis

In this study, we referred to the approach to content analysis described by Mayring (2015). Given the great diversity among records addressing different angles and aspects of TPACK research, we began with an inductive approach to organizing the content contained in records through a broad coding scheme. Based on the content they had both worked through in a previous step, the first two authors discussed the six records and devised five broad categories for coding (see examples in Table 3).

1) *Conceptual* aspects (e.g., theoretical considerations of the framework),
2) *Methodological* aspects (e.g., research methods and instruments),
3) *Practical* aspects (e.g., relating to teachers' practice),
4) *Developmental* aspects (e.g., relating to teacher education),
5) *Generic* aspects (e.g., research descriptives: number of publications, journals, etc.).

The adequacy of these non-mutually exclusive categories was then tested: both authors independently coded the single sentences of the six records (1 = sentence related to category; 0 = not related), obtaining substantial levels of agreement across the categories (Cohen's Kappa > 0.78; Landis & Koch, 1977). Thus, the remaining records were single-coded by one of the two authors. Subsequently, one of the authors reviewed all codings and, within each category, proceeded to deductively organize the single sentences based on

**Table 3**
Examples of Content Reduction and Analysis.

| Original paragraph | Single sentence | Coding | | | | |
|---|---|---|---|---|---|---|
| | | C | M | P | D | G |
| We see TK as conditional to TPACK, together with pedagogical knowledge and domain knowledge. However, this review revealed many different views on TK. Beyond the various views about the scope of technology (all technologies versus digital technologies), there is a more fundamental debate between an instrumental and a functional perspective on TK. Technology has immersed in our society and changes not only teaching and learning but also the curriculum (Voogt et al., 2011a). A functional view on TK seems more robust to changes in technology tools and applications. In our view, only a functional understanding of TK (Anderson 2008) justifies TK as a separate knowledge domain. (Voogt et al., 2013, p. 119, 3rd paragraph) | Different understandings and conceptualizations of TK emerge from the literature. | 1 | 0 | 0 | 0 | 0 |
| As a measure of perceived knowledge, the self-reporting instruments described by Schmidt et al. (2009b) and Mishra and Koehler (2006) provide insight into both the development of knowledge in TPACK domains as well as how students think about the connections among these areas of knowledge. The nature of how this thinking evolves is further revealed using the qualitative procedures such as those described by Koehler and Mishra (2008). When examining the outcome expectations of preservice teachers and their teaching practices during teaching internship experiences, the Technology Integration Assessment Rubric described by Harris et al. (2010) can serve as an effective and efficient performance-based measure of student work, whereas the qualitative procedures described by Graham, (2011) may reveal additional intricacies of students' understanding of technology integration during the process of instructional planning. (Abbitt, 2011b p. 296, 3rd paragraph) | Different measures assess different TPACK aspects from different sources. | 0 | 1 | 0 | 0 | 0 |
| In addition, effective PD programs or interventions often provided teachers with modeling on how to teach in technology-rich environments. This finding was also reported by Wang et al. (2018), who found that modeling offered by teacher educators and in-service teachers could foster pre-service teachers' TPACK development. In this sense, it is critical for pre-service teacher education courses and in-service teacher training workshops to include modeling on how to skillfully intertwining technology, pedagogy, and subject matter content. (Tseng et al., 2022, p. 964, 5th paragraph) | Modeling found to be an effective approach for developing TPACK. | 0 | 0 | 0 | 1 | 0 |

*Note.* C = conceptual aspects; M = methodological aspects; P = practical aspects; D = developmental aspects; G = generic aspects.

their content-relatedness to define subcategories. The grouping of single sentences and the definition of subcategories were then discussed with the other authors until agreement was reached.

#### 2.4.4. Thematic trend analysis

Working through the data, we noted recurring thematic trends, with implications extending across the five categories identified above. Thus, in the final step, we applied thematic trend analysis according to Braun et al. (2019). After familiarizing ourselves with the data, we performed multiple iterations of the analysis in an attempt to generate and draw links between codes and traced common trends across single sentences to capture the interrelations in TPACK research.

#### 2.4.5. Chronological pattern analysis

Following the notion that the "healthy growth" of a research field depends on ongoing studies being informed by and responding to points outlined by their predecessors as either established aspects or ongoing issues, the codings of records were considered chronologically. This approach was chosen to assess the evolution of TPACK research over time and to identify patterns of presence, progression, stagnation, and recurrence across categories, subcategories, and themes in relation to whether these aspects have been sufficiently addressed in the literature (i.e., established) or require future research.

#### 2.4.6. Methodological quality assessment

A key element of a review of reviews is the assessment of methodological quality (Polanin et al., 2017). This assessment of methodological quality consisted of two tasks: assessing the methodological quality of the primary studies included in the reviews and assessing the methodological quality of the reviews.

#### 2.4.7. Methodological quality assessment of reported primary studies in the systematic reviews and meta-analyses

Regarding the assessment of the methodological quality of reported primary studies with qualitative designs within the reviews and meta-analyses, different tools that might be eligible to assess the methodological quality of studies were screened (e.g., Hong et al., 2018; Popay et al., 1998). However, the study quality criteria of quantitative and qualitative studies were not comparable because qualitative research used methodological procedures that were not standardized in comparison to quantitative procedures; thus, the methodological quality assessment of the qualitative studies was omitted (Giacomini, 2001; Popay et al., 1998). The focus was on evaluating the methodological quality of the reported quantitative primary studies (Polanin et al., 2017). A descriptive overview of the number of included study design types (qualitative, quantitative, and mixed design) in each review, which provided a basis for comparing the methodological approaches across the reviews, is provided in Appendix A. The reviews and meta-analyses would have reported the type of quantitative and qualitative study design for each primary study in a table or clearly indicated the number at the beginning of the method section to be considered in our analysis.

#### 2.4.8. Criteria for methodological quality assessment of systematic reviews and meta-analyses

There are different measurement tools for assessing the methodological quality of procedures used in systematic reviews and meta-analyses, such as AMSTAR 2 (Shea et al., 2007; 2009), but most of these tools strongly focus on the quality of systematic reviews and meta-analyses that included only randomized or non-randomized controlled studies. This implies an experimental design for the primary studies (Protogerou & Hagger, 2019). As most quantitative TPACK studies have focused on correlational studies of one cohort, some AMSTAR 2 criteria are not suitable. Consequently, a more suitable tool was needed. The quality assessment tool developed by the "Effective Public Health Practice Project" (EPHPP; see Evans et al., 2015) can be used to assess the quality of correlational studies, as well as reviews and meta-analyses based on correlational studies. EPHPP has eight rating criteria: selection bias, study design, confounders, blinding, data collection methods, withdrawals and drop-outs, intervention integrity, and analyses. In summary, not all AMSTAR 2 and EPHPP criteria work perfectly for correlational studies and (quasi-) experimental studies. Therefore, we combined and partially adapted applicable criteria from both tools to measure the overall methodological quality of systematic reviews and meta-analyses in the TPACK research context. Our newly curated criteria were then used to assess the quality of the reviews.

#### 2.4.9. Coding and intercoder-reliability

The 15 methodological quality assessment criteria were rated for three studies by two authors. For 12 of the 15 criteria, the agreement (in percentage) between coders was perfect. Two criteria regarding the reliability and validity of the included correlational studies revealed one or more disagreements. Consequently, for these two criteria, two authors double-coded approximately 50% of all primary studies, while one author coded the remaining primary studies (50%). All other criteria were rated by one of the authors.

## 3. Results

Systematic searches and screening of the systematic reviews and meta-analyses on TPACK published between 2006 and 2022 resulted in 23 records meeting the eligibility criteria of this study. Among these, only two consisted of meta-analyses (Ning et al., 2022; Young et al., 2013), whereas the remaining 21 were systematic literature reviews. Records varied greatly in their perspectives on TPACK, with some being very general, while others focused on a specific teacher population (e.g., pre-service teachers, as in Wang et al., 2018) or on a specific subject/group of subjects (e.g., STEM, as in Iswadi et al., 2020) (for a detailed overview of the final sample characteristics, see Appendix A). In the following two sections, we present the results of the content and thematic analyses for capturing the current stand of TPACK research (RQ1) and quality assessment (RQ2).

### 3.1. Content and thematic trend analysis: established findings and future issues (RQ1)

We began by extracting the main messages of each individual paragraph, which resulted in a total of 193 single sentences (*Step 1*), of which 136 presented TPACK research as established (*RQ1a*), whereas 63 called for future research (*RQ1b*). Table 4 depicts the frequency of single sentences relating to the five categories in our coding scheme and their relations to established points or calls for future research. Applying content analysis to these single sentences by category (*Step 2*) revealed 27 subcategories: 5 conceptual, 10 methodological, 3 practical, 5 developmental, and 4 generic. Table 4 presents the total frequencies for each category of references to established points or future needs based on the subcategory codings. The generic category focused on general characteristics of the research field (e.g., number of publications over time) rather than aspects of the TPACK construct. Thus, it was not included in subsequent analyses (i.e., coding descriptives and thematic analysis).

In a subsequent step (*Step 3,* thematic trend analysis), we thematically analyzed the 23 subcategories of the respective first four categories, probing for common themes along which subcategories could be grouped across categories. Our analyses revealed three overarching thematic trends, which mirrored the conceptual nature of TPACK as initially described by Mishra and Koehler (2006) as well as by the subsequent research: (1) TPACK as a *complex* construct (see Archambault & Barnett, 2010; Eichelberger & Leong, 2019; Graham, 2011; Petko, 2020); (2) TPACK as a construct situated within its *context* (see Brianza et al., 2022; Porras-Hernandez & Salinas-Amescua, 2013; Rosenberg & Koehler, 2015b; Swallow & Olofson, 2017); and (3) the view of TPACK as a *dynamic construct* (i.e., a process; see Koh et al., 2015; Pamuk, 2012; Zhang & Tang, 2021). As depicted in Tables 5–8, the thematic trends related to subcategories across categories, highlighting the multilevel implications of these three trends across conceptual, methodological, practical, and developmental aspects of TPACK research.

The final analysis approached the codings chronologically (*Step 4*) to identify temporal patterns of the presence and evolution of categories, subcategories, and thematic trends. In Tables 5–8 subthemes are displayed chronologically for visualizing trends in research on these points over time. To this end, Tables 5–8 display established evidence for a subtheme by solid green dots (i.e., RQ1), whereas red circles indicate calls for future research (i.e., RQ2). In addition, cases of consecutive records consistently reporting a subtheme as either established or requiring future research are emphasized by a connecting line, to better visualize the different research trends over time: 1) Consistency of evidence for a subtheme (i.e., green line); 2) ongoing and unaddressed calls for future research (i.e., red line); or 3) recurring patterns of evidence and calls for future research (i.e., disconnected points).

With regard to the categories of TPACK research, Table 9 displays the year ranges of the oldest and most recent mentions of related subcategories, thus indicating the actuality of a category in research. As shown, conceptual, methodological, practical, and developmental aspects of TPACK are present across all years represented in the final sample, from 2011 to 2022. Generic characteristics of TPACK research emerged later in 2015. Whereas for most categories, the patterns of subcategory mentions appear to indicate growth (i.e., recency of "oldest mention" indicating emergence of new aspect) and actuality (i.e., recency of "most recent mention") of research, for the conceptual category, a somewhat distinctive pattern emerged. The findings show that no new conceptual subcategories have emerged since 2015, implying that ongoing conceptual discussions on TPACK continue to revolve around "older" points raised between 2011 and 2015. Furthermore, one conceptual subcategory (i.e., conceptual clarity of TPACK) ceased to be mentioned after 2013, despite this final mention being a call for more research on this point.

An assessment of individual subcategory trends revealed that, of the 23 subcategories describing the TPACK construct (i.e., excluding the generic category), 16 subcategories were last mentioned in relation to calls for future research. Of these, four were of a conceptual, eight of a methodological, two of a practical, and two of a developmental nature. The average number of years between the first and last mention was 8 years (range: 0–11; median = 8; mode = 11), indicating a high rate of persistence and recurrence of topics over time.

Upon closer scrutiny, the following six calls for future research were distinguished for their universal persistence (see continuous red line in Tables 5–8), with no single mention of established evidence across all records: conceptual clarity (oldest and most recent call: 2011–2013), context-sensitivity and instrument quality (oldest and most recent call: 2011–2022), comparative studies (oldest and most recent call: 2016–2022), methods for investigating the progression of TPACK (oldest and most recent call: 2011–2021), longitudinal studies (oldest and most recent call: 2018–2022), and context within teacher education (oldest and most recent call: 2022–2022) (for details, see Tables 5–8).

Focusing on the presence of TPACK thematic trends over time, as shown in Tables 5–8, all three thematic trends characterized TPACK research from 2011 to 2022. Considering the evolution of theme-related research, TPACK's complexity (Thematic Trend 1) was related to five subcategories that emerged between 2011 and 2013, reflecting stagnation in the growth and recurrence of researched

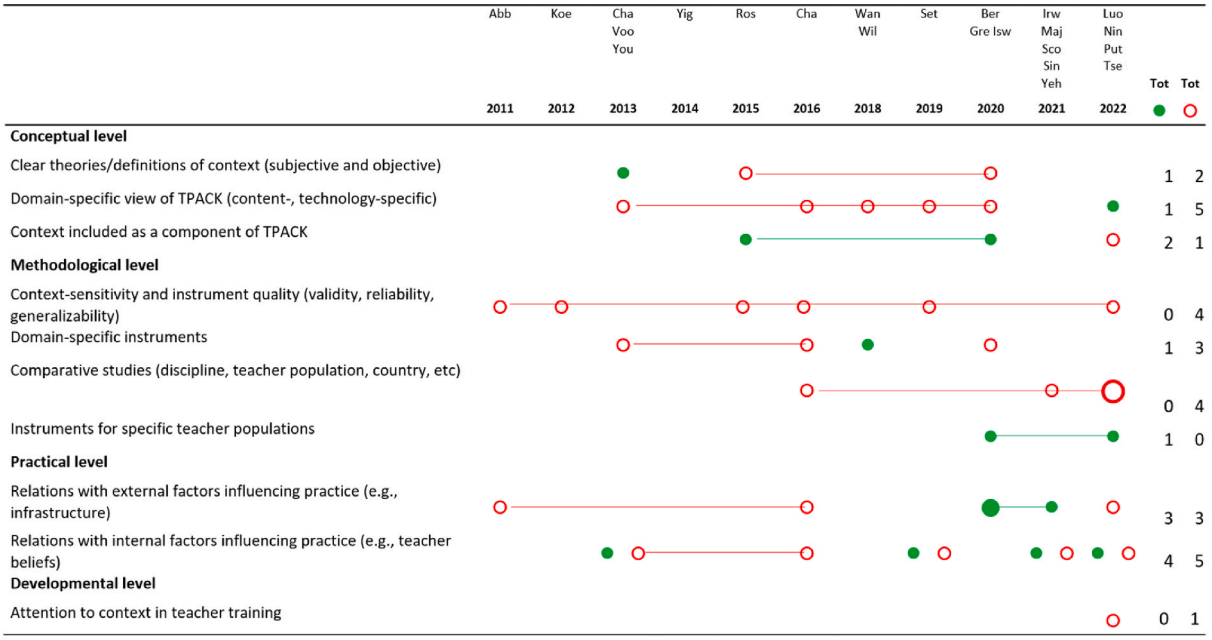
**Table 4**
Frequencies of Mentions Related to Established Points or Future Needs across Categories.

| Unit of analysis | Step 1: Content reduction | | Step 2: Content analysis | |
|---|---|---|---|---|
| | Single sentences | | Subcategories | |
| | RQ1a | RQ1b | RQ1a | RQ1b |
| *Conceptual* | 18 | 10 | 6 | 12 |
| *Methodological* | 56 | 31 | 20 | 36 |
| *Practical* | 16 | 12 | 11 | 11 |
| *Developmental* | 24 | 7 | 17 | 4 |
| *Generic* | 28 | 5 | Total generic mentions: 22 | |

**Table 5**
Thematic trend 1: TPACK as a Complex Construct.

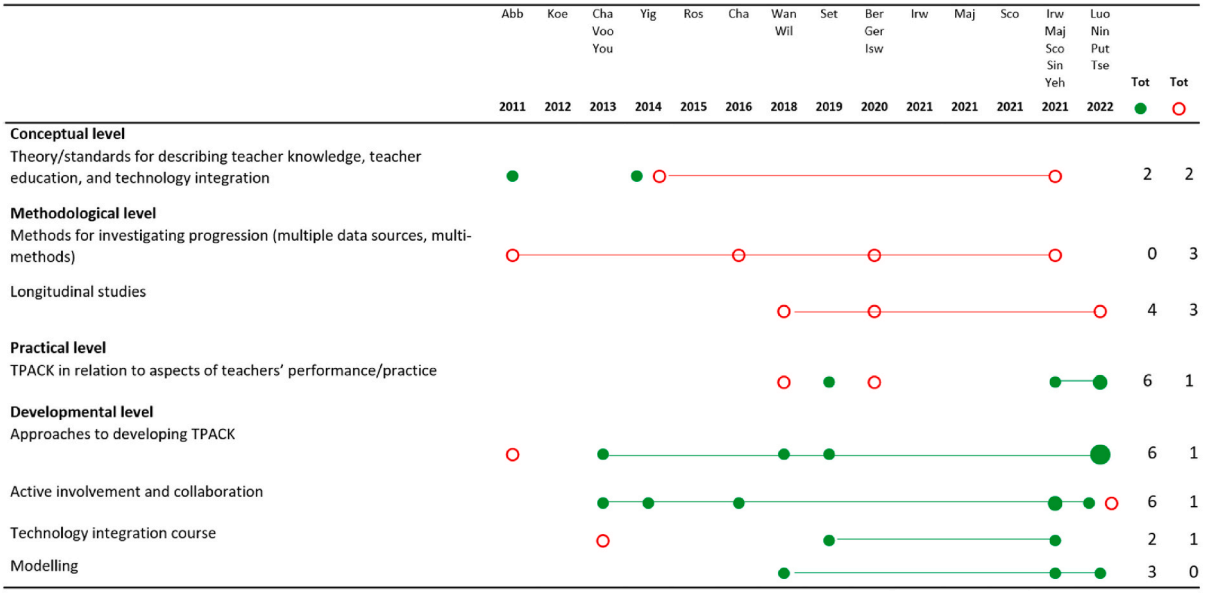

*Note*. ● established aspect (RQ1a); ○ aspect requiring future research (RQ1b). Circle size represents the number of mentions: ● = 1; ● = 2; ● = 3 or more. A continuous line connecting points emphasizes uninterrupted agreement regarding an aspect being regarded as either established or requiring future research over time.

**Table 6**
Thematic trend 2: TPACK as a Situated Construct.



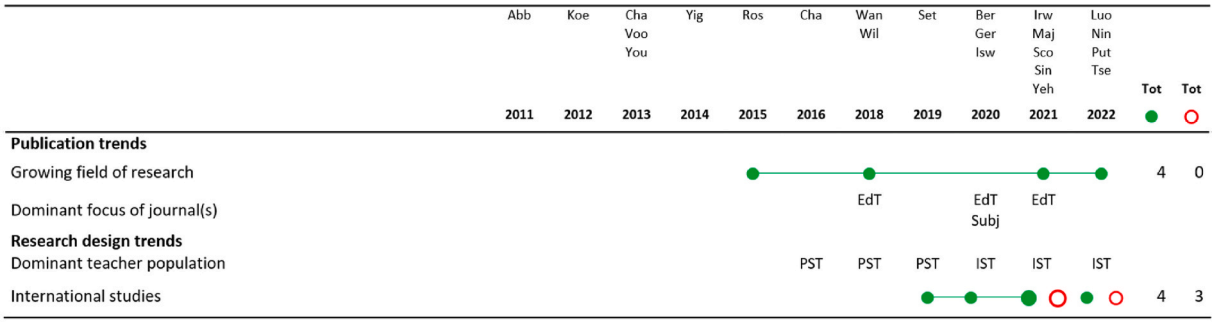

*Note*. ● established aspect (RQ1a); ○ aspect requiring future research (RQ1b). Circle size represents the number of mentions: ● = 1; ● = 2; ● = 3 or more. A continuous line connecting points emphasizes uninterrupted agreement regarding an aspect being regarded as either established or requiring future research over time.

**Table 7**
Thematic trend 3: TPACK as a Dynamic Process.




*Note*. ● established aspect (RQ1a); ○ aspect requiring future research (RQ1b). Circle size represents the number of mentions: ● = 1; ● = 2; ● = 3 or more. A continuous line connecting points emphasizes uninterrupted agreement regarding an aspect being regarded as either established or requiring future research over time.

**Table 8**
Generic Aspects of TPACK Research.




*Note*. ● established aspect (RQ1a); ○ aspect requiring future research (RQ1b). Circle size represents the number of mentions: ● = 1; ● = 2; ● = 3 or more. EdT = educational technology; Subj = subject-specific. PST = pre-service teachers; IST = in-service teachers. A continuous line connecting points emphasizes uninterrupted agreement for aspects over time.

aspects between 2013 and 2022. The situated nature of TPACK (Thematic Trend 2) was related to 11 subcategories, the most recent of which emerged in 2022, indicating the ongoing expansion of this trend in research at the time of the present study. Similarly, views on TPACK as a process (Thematic Trend 3) consisted of eight subcategories emerging between 2011 and 2018, illustrating growth followed by a plateau in the past four years.

**Table 9**
Overview of Subcategory Descriptives by Category.

| | # subcategories | Oldest mention (range) | Most recent mention (range) | RQ1a mentions (range) | RQ1b mentions (range) |
|---|---|---|---|---|---|
| Conceptual | 5 | 2011–2015 | 2013–2022 | 0–2 | 1–5 |
| Methodological | 10 | 2011–2020 | 2020–2022 | 0–9 | 0–5 |
| Practical | 3 | 2011–2018 | 2022–2022 | 3–4 | 3–5 |
| Developmental | 5 | 2011–2022 | 2021–2022 | 0–6 | 0–1 |
| Generic | 4 | 2015–2019 | 2021–2022 | 4–4 | 0–3 |

**Table 10**
Methodological Quality Assessment of the Included Reviews and Meta-analyses.

| Authors (Year) | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 | A9 | A10 | A11_M | A12_M | A13_M | A14a | A14b |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ,(Abbitt, 2011b) | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 99 | 99 | 99 | 1 | 1 |
| Koehler et al. (2012) | 0 | 0 | 1 | 2 | 1 | 0 | 0 | 2 | 0 | 0 | 99 | 99 | 99 | 1 | 1 |
| Chai et al. (2013) | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 2 | 0 | 0 | 99 | 99 | 99 | 1 | 1 |
| Voogt et al. (2013) | 0 | 0 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 99 | 99 | 99 | 1 | 1 |
| Young et al. (2013) | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Yigit (2014) | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 99 | 99 | 99 | 99 | 99 |
| Rosenberg and Koehler (2015b) | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 99 | 99 | 99 | 1 | 1 |
| Chai et al. (2016) | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 2 | 0 | 0 | 99 | 99 | 99 | 1 | 1 |
| Willermark (2018) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 99 | 99 | 99 | 99 | 99 |
| Wang et al. (2018) | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 2 | 0 | 0 | 99 | 99 | 99 | 1 | 1 |
| Setiawan et al. (2019) | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 99 | 99 | 99 | 1 | 1 |
| Bernardes and de Andrade Neto (2020) | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 99 | 99 | 99 | 0 | 0 |
| Greene and Jones (2020) | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 99 | 99 | 99 | 0 | 0 |
| Iswadi et al. (2020) | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 1 | 0 | 0 | 99 | 99 | 99 | 0 | 0 |
| Irwanto (2021) | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 99 | 99 | 99 | 0 | 0 |
| Major and McDonald (2021) | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 99 | 99 | 99 | 0 | 1 |
| Scott (2021) | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 99 | 99 | 99 | 1 | 1 |
| Sing et al. (2021) | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 99 | 99 | 99 | 1 | 1 |
| Yeh et al. (2021) | 1 | 0 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 99 | 99 | 99 | 1 | 99 |
| Luo and Zou (2022) | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 0 | 0 | 0 | 99 | 99 | 99 | 0 | 1 |
| Ning et al. (2022) | 1 | 0 | 0 | 2 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 99 | 99 |
| Putri et al. (2022) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 99 | 99 | 99 | 0 | 0 |
| Tseng et al. (2022) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 99 | 99 | 99 | 1 | 1 |

***Notes.*** For many code categories, a dummy-coded was used (0 = was not done, 1 = was done). The other codes had three categories, ranging from "0" was not done, "1" was done, and "2" was partially done. If the code is not applicable, "99" was assigned. A detailed description of the coding of the categories used for methodological quality assessment can be found in Appendix A. The list below shows the abbreviations of the categories.
A1: Research question and inclusion criteria considered "PICO" components.
A2: Written study protocol.
A3: Explanations for including the selected study designs.
A4: Comprehensive literature search.
A5: Selection and agreement of included studies by two raters.
A6: Interrater agreement on the extraction of data.
A7: Justifications of excluded studies and listing of excluded studies.
A8: Detailed description of the included studies.
A9: Assessing the risk of bias (RoB).
A10: Declaration of funding source.
A11_M: For meta-analyses: use of appropriate methods for statistical combination of results.
A12_M: For meta-analyses: assessment of the potential impact of RoB in individual studies on the results of the meta-analysis.
A13_M: For meta-analyses: accounting for the RoB in individual studies on the results of the meta-analysis.
A14a: Reliability of data collection tools.
A14b: Validity of data collection tools.

### *3.2. Methodological quality assessment*

The results and code categories of the methodological quality assessment are displayed in Table 10. Nearly all the included reviews or meta-analyses provided a comprehensible and appropriate description of their literature search strategy (Code A4). With regard to the quality of the coding process, only a few reviews or meta-analyses (a) coded the eligibility of studies for inclusion in the further analysis ($k = 4$, Code A5) and/or (b) involved a second independent coder to assess their study characteristics and allow for calculating interrater reliability ($k = 8$, Code A6). According to the recently published PRISMA guidelines (Page et al., 2021a,b), interrater reliability between coders is a key quality assessment criterion for systematic reviews and meta-analyses. For reviews and meta-analyses, including correlational data, scholars recommend assessing the reliability and validity of primary studies and reviews and meta-analyses to report the methodological quality of the included correlational studies (Polanin et al., 2017). Most of our reviews

and meta-analyses considered the reliability ($k = 13$, Code 14a) and validity ($k = 13$, Code A14b) of their included correlational studies. None of the two meta-analyses included methods to prevent risk of bias, such as an outlier analysis or sensitivity analysis (see Code A13_M; cf. Page et al., 2021a, b).

## 4. Discussion

TPACK is a popular framework that describes teachers' knowledge of teaching with technology. It has sparked a large number of research projects and scientific publications that have been summarized in a growing number of reviews on TPACK. As we have shown in this paper, few of these past reviews adhere to the strict standards for systematic reviews that have been described in frameworks such as PRISMA. Further, there are hardly any meta-analyses available. This might be an indicator of the limited number of experimental or quasi-experimental studies investigating the effects of TPACK (e.g., relations with student learning or teacher collaboration). Instead, most of the existing reviews have tended to remain confined within the framework, focusing on important theoretical or methodological aspects of TPACK but somewhat "missing" the reality of the strong interrelatedness of TPACK's theory, methods, practice, and development.

### 4.1. The complexity of TPACK

Our review of reviews has shown that research on TPACK has stagnated in some respects and flourished in others. With regard to the theoretical and methodological progress of research on TPACK, researchers have literally been "running in circles." According to the reviews analyzed in this paper, research has constantly struggled with the complexity of the construct, which has led to repeated criticisms regarding the "fuzziness" of TPACK (Archambault & Barnett, 2010; Eichelberger & Leong, 2019; Graham, 2011; Petko, 2020). Although the Venn diagram of TPACK seems to be simple at first glance, it becomes more complicated when researchers need to define what is meant by "knowledge," "knowledge domains," and "combinations of knowledge domains". For example, there has been an extended discussion on whether the combined knowledge domains of TPACK are integrative or transformative—that is, whether these hybrid domains are constructed from their core domains or whether they constitute knowledge domains in their own right (Angeli et al., 2016; Graham, 2011; Schmid et al., 2020). What is additionally crucial to note from this example, is how this apparent conceptual complexity has ramifications with direct methodological implications (e.g., different operationalizations across instruments resulting in variable instrument validity and reliability, as well as heterogeneous and not easily comparable findings; Setiawan et al., 2019; Voogt et al., 2013). These implications give rise to empirical complexity, which in turn contributes to increasing conceptual heterogeneity and in this way, risks developing into a dangerous vicious cycle (i.e., instruments assessing different conceptualisations of TPACK lead to diverse empirical findings, which, at times, suggest contrasting conceptual notions of TPACK). To answer these unresolved conceptual questions, it would be necessary for research on TPACK to align with general research on PCK and teacher professional knowledge in general, where very similar questions are considered (Chan & Hume, 2019; Gess-Newsome, 2015).

Much of the confusion related to TPACK's complexity also seems to stem from the lack of an overarching model of how knowledge is represented in the minds of teachers and how this becomes relevant in practical situations (Phillips et al., 2017). Not only is knowledge a latent construct (i.e., only indirectly observable) but cognitive psychology has distinguished many different kinds of knowledge, for example, declarative, procedural, conceptual, episodic, semantic, iconic, cognitive, metacognitive, as well as embodied and emotional knowledge. In addition, knowledge has been combined with other traits, such as dispositions, attitudes, and beliefs, to constitute more complex forms of competence or expertise (Kunter et al., 2013; Raduan & Na, 2020). To date, there is no consensus in psychology or in educational sciences on what constitutes good professional knowledge. As it is rather unlikely that there will be a comprehensive overarching model in cognitive psychology in the near future, studies on TPACK need to specify what they mean by "K" in the TPACK model.

Here too, the derived methodological implications cannot be overlooked. In fact, we found that multiple authors repeatedly emphasized the need to carefully consider the alignment between conceptual operationalization of TPACK and the characteristics of methods adopted for its assessment (e.g., Abbitt, 2011b; Sing et al., 2021; Voogt et al., 2013; Willermark, 2018). Reflecting on and accounting for this point may be key, especially since, to date, self-report approaches have dominated TPACK research (Greene & Jones, 2020; Putri et al., 2022; Willermark, 2018). For example, items such as "I can choose technologies that enhance students' learning for my lesson" (TPK item by Schmidt et al., 2009) are frequently used to assess TPACK domains. Although such items are indisputably appropriate for investigating teachers' effective use of technology in their teaching, it may be essential to place greater consideration to the nature of the construct such formulations and methods capture (e.g., do they assess knowledge, self-efficacy, or competence?). Since there are currently many different terms, conceptualizations, and measurements of TPACK (e.g., knowledge, self-efficacy, beliefs, and competence), hardly any cumulative knowledge building is possible. The complexity of knowledge constructs and their latent processes (i.e., frequently only indirectly observable) might render reaching a uniform understanding hard to achieve (and perhaps even of questionable value). Nevertheless, a clear and coherent organization of these various understandings is necessary for consolidating TPACK research and advancing the field.

### 4.2. The situatedness of TPACK

The lack of an overarching organization of TPACK's complexity becomes even more visible when TPACK is considered a situated and dynamic construct. As a situated construct, research on TPACK struggles to determine how context needs to be considered (Porras-Hernandez & Salinas-Amescua, 2013; Rosenberg & Koehler, 2015b; Swallow & Olofson, 2017). Knowledge can be understood

either as knowledge of context or as contextualized knowledge (Rosenberg & Koehler, 2015a). In addition, how context shapes the development of individual teachers' TPACK and what role context plays in the application of TPACK to specific situations need to be clarified. In other words, TPACK needs to be clearly defined and operationalized in a context-specific manner (e.g., content field, external setting, and teacher experience level). Most reviews analyzed in our study repeatedly state that more contextualized research is needed to clarify these issues. On a methodological level, this calls for context-sensitive approaches, including assessment of context (Rosenberg & Koehler, 2015b), comparative studies (Ning et al., 2022; Scott, 2021; Tseng et al., 2022), and domain- and population-specific assessment instruments (Chai et al., 2016; Voogt et al., 2013).

A more systematic conceptual and methodological approach to context would also enable to bring TPACK closer to the daily realities of teaching and learning. From this perspective, greater attention to context might be a key approach for bridging the gap between decontextualized theory and situated practice (e.g., Baildon & Ong, 2022; Hirschkorn & Geelan, 2008). Addressing this gap emerges as crucial for the development of teachers' knowledge and the design teacher education particularly in light of reports of student teachers struggling to see the relevance of pedagogical theory for practice (e.g., Puustinen et al., 2018) as well as beginning teachers feeling insufficiently prepared for school life given a lack of attention to contextual aspects in their training programs (e.g., Calvo de Mora, 2014; Fuentes-Abeledo et al., 2020; Grudnoff, 2011). Recently, a few authors have reported teacher education programs aiming to increase contextualization of teachers' knowledge development through enhancing cohesion between experience of formal theory and situated practice (e.g., Ribaeus et al., 2022) or by broadening the limited focus of practicum "beyond the four walls of the classroom" to more extensive involvement in school organization and community matters (e.g., Koubek et al., 2021; Resch et al., 2022).

However, as described in the introduction, increasing TPACK's contextualization might lead to the fragmentation within its body of research, which is already visible in more recent reviews focusing on TPACK in one particular subject or regarding one particular technology. Whereas some reviews stated that progress has been made in this regard, subsequent reviews detected new problems. Consequently, the evolution of TPACK research is complex and spiral rather than linear, requiring adequate contextualization of studies to shed light on cycles of aspects being viewed as established or requiring future research.

### 4.3. The dynamic nature of TPACK

Considering TPACK as a procedural form of knowledge that constantly evolves and that might take its practical shape in applied situations reveals an emphasis on the importance of investigating the construct over time. In fact, methodologically, there is a strong call for longitudinal research across long and short time intervals (Koh et al., 2015; Pamuk, 2012; Zhang & Tang, 2021). The fact that within the context of teacher education, TPACK has emerged as a rather successful concept for designing teacher professional development activities and courses, supports the importance of addressing this construct as a dynamic process. Nevertheless, the findings from TPACK development studies are usually limited to investigating the relations between an activity, short intervention, or a single course on pre-service teachers' TPACK. Future research should extend these findings by further investigating the effectiveness of teacher activities and training within (i.e., over longer time periods) and beyond (i.e., teachers' entrance into the field) teacher education contexts.

Viewing TPACK as a process might be complicated by the fact that, after more than 15 years of research, we still lack conceptual clarity on the relations between the framework's domains (e.g., the transformative vs. integrative debate; Mouza et al., 2014; Schmid et al., 2020; Thyssen et al., 2023), which would inform the development of TPACK (e.g., will increases in TK lead to growth in other T-related domains? Or, is it necessary for teacher education to target domains individually?) Nevertheless, all recent reviews also mentioned that TPACK is a growing field of research that seems to be inspiring for both pre-service and in-service teacher education across a wide range of educational systems worldwide. This suggests that, despite this lack of clarity, most reviews also seemed to agree that scientific progress has been made. Therefore, it is plausible to ask whether the scientific fuzziness of the TPACK framework might even be beneficial for its practical applicability, ensuring we remember to approach technology integration in teaching and learning as wicked problems, rather than one for which single solutions can be provided based on a theory (Kimmons, 2015; Tondeur et al., 2021). According to this view, TPACK might be an inspiring model for practice but a less fruitful model for research.

### 4.4. Future research

To move TPACK forward as a framework for research, to address TPACK's complexity studies need to be more precise about what they mean by "knowledge" (or as understood as an associated construct), consider how this is measured, and use these conceptual and methodological anchors to systematically organize TPACK research. That being said, research on TPACK should seek tobroaden its approaches to include more experimental and longitudinal studies for capturing it's situated and dynamic nature, with clearly operationalized and standardized measures that go beyond self-reports.

Across all reviews analyzed in our study, there was an apparent call for more data triangulation, inclusion of more neighboring constructs, and development of better TPACK measures. Yet, in addition to echoing these suggestions, we would like to urge future studies to not break off investigations at the point of treating TPACK as the main outcome variable of professional development activities, but rather aim to supplement these studies with measures of student learning. In other words, as reflected from this review of reviews, future research calls for studies aiming to investigate TPACK in practice and adopt methods aligned with this goal, namely using designs and instruments able to account for context as well as capture dynamic processes. This would allow for proper meta-analytic comparisons in which process and context factors could serve as covariates if sufficiently specified in the original research reports.

### 4.5. Limitations

The present study has some limitations that need to be considered in future research. The limitations are mainly related to the general methodological approach of reviews of reviews and specifically to the design of the present study. A pertinent problem with reviews of reviews is that individual primary studies are sometimes analyzed several times, which gives these studies a disproportionately high significance (see Polanin et al., 2017). In our study, we could not sufficiently consider this overlap. This was because not all reviews showed exactly which contributions they integrated into the review. This overlap is not considered problematic in the present systematic review of reviews, since individual reviews may have looked at the same primary studies but each with a different focus. Such an overlap is particularly problematic in meta-analyses due to the overestimation of effects by multiple uses of the same studies. Another problem with reviews of reviews and meta-analyses is that old results are reproduced. However, since TPACK research is still very young, this risk hardly exists in this review of reviews. Furthermore, in the overview table (see Appendix A) of the reviews and meta-analyses considered, we have indicated the period during which the primary studies originated in each case. Third, it must be taken into account that the methodology for reviews and meta-analyses has developed rapidly in recent years (e.g., PRISMA was published in 2009). Thus, older articles naturally tend to score lower in methodological quality assessments. Therefore, the year of publication of the given study must be considered when interpreting such assessments, as the article may have been state of the art at the time of publication but not necessarily so today.

Regarding possible limitations due to the specific design of the present review of reviews, one involves the literature search, as the search terms (e.g., TPACK, review) were only probed within the title domain and because we limited ourselves to five electronic search databases. Therefore, it is possible that we missed some reviews or meta-analyses. However, the PRISMA procedure enabled us to consider additional sources, which we did. Another limitation lies in the basis of the various codings. For RQ1, we considered the "Discussion" and "Conclusion" sections because we assumed that the most important thematic trends must be found within these sections, and for RQ2, we included only the "Methods" section of the studies. The "Findings" section, by contrast, often refers heavily to primary studies, which were not of interest for our study. However, this choice might have led to the neglect of less important topics.

As reviews of reviews summarize older reviews that summarize even older research papers, there is always a delay in processing that needs to be taken into account. Possibly, newer studies have already started to close the research gaps highlighted in this paper.

### 4.6. Conclusion

Almost two decades since its proposal in 2006, TPACK has engendered an abundant number of studies that consistently present it as a highly relevant and useful framework for informing educational research and practice. With this second-order review, we essentially described the conceptual, methodological, practical, and developmental aspects of TPACK that are considered established or unaddressed calls for future research. Much has been learned, and the framework has been fruitful for all these areas. Nevertheless, both old and new gaps were found, and the evidence suggests that many of these recurring issues are not isolated conceptual, methodological, practical, or developmental challenges. Rather, these issues appear to be interrelated, stemming from the complex, situated, and dynamic nature of TPACK itself. These points imply that having set a good groundwork, advancing research, and practice requires more holistic considerations and organization of explorations of the qualities of TPACK in relation to contexts and over time.

## CRediT authorship contribution statement

**Mirjam Schmid:** Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Formal analysis, Conceptualization. **Eliana Brianza:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis, Conceptualization. **Sog Yee Mok:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis. **Dominik Petko:** Writing – review & editing, Writing – original draft, Conceptualization.

## Data availability

Data will be made available on request.

## Appendix A

Overview of the Basic Data

| Authors (Year) | Focus (i.e., main topic, sample, etc.) | Types of included studies[1] | Databases | Time frame | Final number of studies |
|---|---|---|---|---|---|

(*continued on next page*)

(*continued*)

| Authors (Year) | Focus (i.e., main topic, sample, etc.) | Types of included studies[1] | Databases | Time frame | Final number of studies |
|---|---|---|---|---|---|
| Abbitt (2011b) | Methods and instruments; pre-service teachers | n.a. | EBSCO Academic Search Premier, E11C, EDITLib.org | 2005–2010 | 20 |
| Koehler et al. (2012) | Measures | Qualitative; quantitative | PsycINFO, Education & Information Technology Digital Library (EdITLib), Education Resources Information Center (ERIC), www.tpack.org | 2006–2010 | 66 |
| Chai et al. (2013) | Generic | Qualitative ($n = 31$); mixed ($n = 11$); quantitative (n = 13); theoretical ($n = 9$); other type of publication ($n = 10$) | Web of Science, Scopus, Education Research Complete and ERIC in EBSCOhost | 2003–2011 | 74 |
| Voogt et al. (2013) | Generic | Qualitative ($n = 13$); mixed ($n = 2$); quantitative ($n = 28$); theoretical ($n = 11$), other ($n = 1$) | ERIC, Web of Science, Scopus, PsycINFO | 2005–2011 | 55 |
| Young et al. (2013) | Teacher education; pre-service teachers | Quantitative ($n = 8$) | TPACK.org, EBSCO, ERIC, and ProQuest | 2009–2012 | 8 |
| Yigit (2014) | Pre-service teachers; mathematics | Empirical; theoretical | ERIC, JSTOR, PsycINFO | 2005–2013 | 12 |
| Rosenberg & Koehler (2015b) | Context | N.a. | ERIC, PsycINFO, Mendeley groups, TPACK newsletters | 2005–2013 | 193 |
| Chai et al. (2016) | Quantitative measures | N.a. | Scopus, Education Research Complete, ERIC | 2011–2014 | 45 |
| Wang et al. (2018)[2] | Development; pre-service teachers | Qualitative; mixed; quantitative | ERIC, PsycINFO, Mendeley TPACK.org | 2006–2015 | 88 |
| Willermark (2018) | Empirical studies | Qualitative ($n = 12$); mixed ($n = 45$); quantitative ($n = 50$) | ERIC[4], Scopus[4], SSCI | 2011–2016 | 107 |
| Setiawan et al. (2019) | Science | N.a. | ERIC, Scopus | 2011–2017 | 16 |
| Bernandes & de Andrade Neto (2020) | Chemistry | Quantitative ($n = 10$); theoretical ($n = 13$) | ERIC, Scopus, SciELO, Science Direct, Web of Science | 2006–2019 | 23 |
| Greene & Jones (2020) | English as a second language | Qualitative ($n = 9$); mixed ($n = 7$); quantitative ($n = 8$) | EBSCO, ERIC, JSTOR, Web of Science | 2009–2019 | 24 |
| Iswadi et al. (2020) | TPACK-STEM scale; science/STEM | Qualitative ($n = 2$); mixed ($n = 5$); quantitative ($n = 1$) | Springerlink, Perpusnas | 2015–2019 | 8 |
| Irwanto (2021) | Generic | Qualitative ($n = 37$); mixed ($n = 20$); quantitative ($n = 33$); non-empirical ($n = 16$)[5] | Springer | 2010–2021 | 106 |
| Major & McDonald (2021) | In-service teachers; online teaching | Qualitative ($n = 3$); mixed ($n = 6$); quantitative ($n = 4$) | ERIC, Academic Search Elite, Google Scholar | 2012–2020 | 13 |
| Scott (2021) | Research methods | Quantitative ($n = 168$); mixed ($n = 65$) | ERIC, Web of Science, Scopus, PsycINFO | 2006–2020 | 233 |
| Sing et al. (2021) | English | Qualitative ($n = 4$); mixed ($n = 4$); quantitative ($n = 6$) | Scopus, ProQuest, Universiti Malaysia Sabah | 2017–2021 | 14 |
| Yeh et al. (2021) | Collective TPACK | Qualitative ($n = 9$); mixed ($n = 2$) | Web of Science, Scopus, | Until 2020 | 11 |
| Luo & Zou (2022) | Humanities; online teaching | Qualitative ($n = 10$); mixed ($n = 7$); quantitative ($n = 7$) | Web of Science, Scopus, JSTOR, Wiley Online Library, EBSCOhost | 2012–2022 | 24 |
| Ning et al. (2022) | Teacher education | Quantitative ((quasi-) experimental studies) (n = 59) | Web of Science, Google Scholar, ProQuest, Scopus. | 2006–2022 | 59 |
| Putri et al. (2022) | Science; pre-service teachers | Qualitative (7); mixed (6); quantitative (20) | Scopus and SINTA (Science and Technology Index) | 2012–2022 | 44 |
| Tseng et al. (2022) | Languages | n.a. | Web of Science and Scopus | 2011–2019 | 51 |

*Notes.* [1] Not all publications indicate which type of studies were included or how many studies of the respective method were included. [2] The review by Wang, Schmidt-Crawford, and Jin (2018) is based on Wang et al., (2018) and was therefore considered as one record. [3] Only 25 were used to calculate the results for the seven realms of knowledge of TPACK. [4] These databases were not used for the main search but only for the preliminary search. [5] These numbers are based on Fig. 3 in the original study.

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