Artificial intelligence in technical pedagogical content knowledge (TPACK) contexts: A literature review

La inteligencia artificial en contextos del conocimiento técnico pedagógico del contenido (TPACK): Una revisión bibliográfica

A inteligência artificial em contextos de conhecimento técnico pedagógico do conteúdo (TPACK): uma revisão da literatura

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Abstract

The aim of this research was to examine the scientific production of the technical pedagogical content knowledge model (TPACK) in the context of artificial intelligence (AI). Nineteen articles were selected from the following databases and/or repositories: DIALNET, DIMENSIONS, ERIC, Jstor, OpenAlex, PsycINFO, Redalyc, SCIELO, Scilit, SCOPUS and WoS, from the beginning of the TPACK model in 2006 until July 2024. The inclusion criteria were open access, articles only, full text, social sciences and artificial intelligence contexts. It can be concluded that the scientific production is low, reaching 1.91% of the total number of records analysed, mainly concentrated between the years 2023 and 2024. The countries of the Asian continent show the greatest development, with China accounting for more than a third of the total production. The studies focus mainly on university teachers, specifically on the self-reporting of knowledge, for which instruments related to TPACK and AI are created, adapted, applied and validated. The results show that CK, PK and TK-IA knowledge have little influence on TPACK-IA. Finally, ethical aspects need to be considered when using AI.

Keywords

Teachers' Competence, technological pedagogical content knowledge (TPACK); educational technology, artificial intelligence.

Resumen

El objetivo de la presente investigación fue examinar la producción científica del modelo de conocimiento técnico pedagógico del contenido (TPACK) en contextos de inteligencia artificial (IA). Se seleccionaron 19 artículos incluidos en las siguientes bases de datos y/o repositorios: DIALNET, DIMENSIONS, ERIC, Jstor, OpenAlex, PsycINFO, Redalyc, SCIELO, Scilit, SCOPUS y WoS, desde el inicio del modelo TPACK año 2006 hasta julio 2024. Los criterios de inclusión fueron: acceso abierto, solo artículos, texto completo, ciencias sociales y contextos de inteligencia artificial. Se permite concluir que la producción científica es escasa, llegando al 1,91 % del total de los registros analizados, concentrados principalmente entre los años 2023 y 2024. Los países del continente asiático presentan un mayor desarrollo, siendo China el que obtiene más de un tercio de la producción total. Los estudios mayoritariamente se centran en los docentes del nivel universitario, específicamente en el autoinforme de conocimientos, para ellos se crean, adaptan, aplican y validan instrumentos relacionados con TPACK e IA. Los resultados permiten afirmar que los conocimientos CK, PK y TK-IA presentan poca influencia en TPACK-IA. Por último, se requiere de la incorporación de aspectos éticos al momento de utilizar las IA.

Palabras clave

Competencias del docente, conocimiento técnico pedagógico del contenido (TPACK), tecnología educativa, inteligencia artificial.

Resumo

O objetivo desta investigação foi analisar a produção científica do modelo de conhecimento técnico pedagógico do conteúdo (TPACK) em

contextos de inteligência artificial (IA). Foram selecionados dezanove artigos incluídos nas seguintes bases de dados e/ou repositórios: DIALNET, DIMENSIONS, ERIC, Jstor, OpenAlex, PsycINFO, Redalyc, SCIELO, Scilit, SCOPUS e WoS, desde o início do modelo TPACK em 2006 até julho de 2024. Os critérios de inclusão foram: acesso aberto, apenas artigos, texto completo, contextos de ciências sociais e inteligência artificial. Conclui-se que a produção científica é baixa, atingindo 1,91% do total de registos analisados, concentrando-se principalmente entre os anos de 2023 e 2024. Os países do continente asiático são os que apresentam maior desenvolvimento, sendo a China responsável por mais de um terço da produção total. Os estudos centram-se sobretudo nos professores universitários, especificamente no auto-relato do conhecimento, para o qual são criados, adaptados, aplicados e validados instrumentos relacionados com o TPACK e a IA. Os resultados mostram que os conhecimentos CK, PK e TK-IA têm pouca influência no TPACK-IA. Finalmente, a incorporação de aspectos éticos é necessária aquando da utilização de IA.

Palavras-chave

Competências dos professores, conhecimento técnico pedagógico do conteúdo (TPACK), tecnologia educativa, inteligência artificial.

Introduction

The integration of technologies has become a priority in developing societies due to the rapid growth associated with the Fourth Industrial Revolution (IR 4.0) and the increasing use of the Internet of Things (IoT). In education, the challenges revolve around the knowledge, skills, and competencies that teachers must possess to effectively manage teaching and learning processes. This includes fostering teacher reflection to promote better practices and inclusive environments (Brookfield, 2017; Muhazir and Renawati, 2020; Paidicán, 2018; Van Leendert et al., 2021).

In response to these and other needs, various pedagogical models have emerged. In the realm of Information and Communication Technologies (ICT), the Technological Pedagogical Content Knowledge (TPACK) model has gained significant recognition. This is evidenced by the more than 19.000 citations of the original work by Mishra and Koehler (2006), *Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge*, as recorded in Google Scholar using Harzing's Publish or Perish software.

The basic approach establishes that TPACK is based on three fundamental skills related to technological, disciplinary, and pedagogical knowledge, emerging from the combination of four other skills, described below:

Technological knowledge (TK): Refers to the skills and knowledge related to the use of technological tools and resources (Angeli and Valanides, 2009; Koehler et al., 2014; Mishra and Koehler, 2006).

Content knowledge (CK): Related to the understanding of discipline-specific knowledge, including aspects such as classroom management, planning, and evaluation of educational processes (Munyengabe et al., 2017; Schmidt et al., 2009).

Pedagogical knowledge (PK): Comprises knowledge and skills associated with teaching and learning methods, approaches, and processes (Mishra and Koehler, 2006).

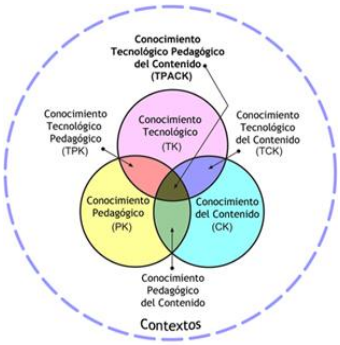
Pedagogical content knowledge (PCK): Related to the interrelationship between CK and PK, focused on student-centered teaching of content (Koehler et al., 2014; Mishra and Koehler, 2006; Shulman, 1986).

Technological content knowledge (TCK): Related to the interrelationship between TK and CK, with a focus on learning specific content through technology (Koehler et al., 2014; Mishra and Koehler, 2006; Schmidt et al., 2009).

Technological pedagogical knowledge (TPK): This refers to the interrelationship between TK and PK, focusing on the potentials and limitations of the pedagogical use of technologies (Mishra and Koehler, 2006; Schmidt et al., 2009; Terpstra, 2015).

Technological pedagogical content knowledge (TPACK): Related to the integration of CK, PK, and TK knowledge, referring to the knowledge that teachers possess when integrating technologies, considering their prior knowledge and students' difficulties (Koehler et al., 2014; Mishra and Koehler, 2006; Schmidt et al., 2009)

Figure 1. *TPACK Model*



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Research related to TPACK has explored aspects related to teacher training, teaching experiences, ICT integration in future classrooms, including the specific aspects of the contexts and particularities of teachers, students, and educational communities (Akyuz, 2023; Byrne-Cohen, 2020; Foulger et al., 2022; Irwanto, 2021; Paidicán et al., 2024; Redmond and Peled, 2019; Schmid et al., 2021; Ortiz et al., 2023).

Over the past few years, new lines of research related to the TPACK model have emerged, such as special education, rural education, and emerging technologies including virtual reality, IoT, and Generative Artificial Intelligence (GenAI) in aspects such as planning, evaluation, and feedback (Cyril et al., 2023; Goldman et al., 2024; Kim and Kwon, 2023; Paidicán and Arredondo, 2024; Sun et al., 2023).

The field of Artificial Intelligence (AI) originated in the United States in 1956 (Hirsch-Kreinsen, 2023; Sánchez, 2024). The advent of AI has had a profound impact on society, particularly following the introduction of ChatGPT in November 2022. This development has been notable for its ability to generate coherent, informative, and remarkably human-like responses (Eysenbach, 2023; Lo, 2023).

From an educational perspective, GenAI presents the starting point for improvement and innovation in teaching and learning processes with an almost unimaginable scope (Hsu and Ching, 2023; UNESCO, 2021). It should be noted that GenAI represents a controversial topic in the educational field and academic community; while some institutions prohibit its use, others accept its use productively (Fayed et al., 2023; Tlili et al., 2023). This has sparked a strong debate on recognizing the usefulness of GenAI. From a future perspective, it requires that teachers and students use GenAI effectively, ethically, and transparently (Russell Group, 2023). For example, ChatGPT allows the creation of a personalized, easy-to-use virtual learning environment oriented to the needs of each student and the development of interactive activities (Annamalai et al., 2023; Rose, 2023; Yilmaz & Yilmaz, 2023). Other uses relate to recommending relevant resources for lesson planning, including articles, videos, and quizzes, and language learning resources, making it an essential component of modern education (Kohnke et al., 2023; Wang et al., 2023). Lastly, according to Goldman et al. (2024), AI can improve classroom practices, learning, and interaction, while enabling educators to address the diverse and unique learning needs of all students more effectively.

A preliminary search for the availability of systematic literature review (SLR), as well as scientometric and bibliometric studies, using Harzing's Publish or Perish program in Google Scholar, reveals the existence of two investigations related to TPACK and AI. However, they have limitations since they only address some databases and focus solely on higher education.

The existing background supports the idea that the present SLR acts as a complement to the development of TPACK by addressing AI from a broader perspective. According to Schmid et al. (2024), TPACK constitutes an extensive and continuously growing area of research, which demands literature reviews and meta-analyses that allow for a systematic description, synthesis, and analysis of the studies carried out in this field.

This study aims to examine the scientific production of the TPACK model in the context of artificial intelligence, addressing the following questions:

1. What types of studies are obtained from the scientific literature on the TPACK model in contexts with AI?
2. What are the methodological orientations of research on the TPACK model in contexts with AI?
3. What results are obtained from research on the TPACK model in contexts with AI?
4. What recommendations are suggested by research on the TPACK model in contexts with AI?

Method

The development of this SLR follows the guidelines proposed by Kitchenham (2004), which are widely used in the social sciences. See Table 1.

Table 1. *Stages described in this SLR*

Stage	Activity
Stage 1: Planning the SLR	Activity 1.1: Identifying the rationale of the SLR Activity 1.2: Developing a protocol for the SLR
Stage 2: Conducting the SLR	Stage 2: Conducting the SLR Activity 2.1: Identifying the purpose of the SLR Activity 2.2: Selecting primary study sources Activity 2.3: Evaluating the quality of study sources Activity 2.4: Data collection and monitoring Activity 2.5: Data synthesis
Stage 3: Reporting the SLR	Activity 3.1: Communicating results of the SLR

Planning and Conducting the SLR

As a preliminary phase, an exploration was carried out using a Scoping Search, including the five stages proposed by Arksey and O'Malley (2005) and Pham et al. (2014) to identify the existence of literature reviews, bibliometrics, or scientometrics related to the TPACK model and artificial intelligence, including scientific production from 2019 to 2024. To do this, the first 200 Google Scholar records obtained through Harzing's Publish or Perish program, version 8.12.4612, and the ERIC, SCOPUS, and WoS databases or repositories were reviewed. The search equations were built and adapted according to the general terms “technological AND pedagogical AND content AND knowledge OR TPACK” AND “Artificial intelligence.”.

Table 2. Summary of RS, bibliometrics and scientometrics of the TPACK model and artificial intelligence

Author	Period of years	N° of articles	Databases	Research focus
Memarian and Doleck. (2024).	Start of model until April 2023	23 articles	SCOPUS y WoS	Characterise the quality of technological and pedagogical knowledge for teaching information and communication technology in higher education.
O'Dea and O'Dea. (2023).	2015-2023	Articles, conference proceedings and book chapters in English	WoS, Scopus, la biblioteca digital ACM y el IEEE	To investigate the current development of AI in higher education, including the TPACK and Unified theory of acceptance and use of technology (UTAUT) frameworks.

In Table 2, the existence of two literature reviews related to the TPACK and AI model can be observed. However, their orientations only address higher education, including five databases, two of which are repeated in the studies. Finally, only the review of 23 articles is declared, while the number of documents reviewed in the second study is unknown. The background information set out above confirms the need and usefulness of this SR, addressing unpublished aspects of the TPACK model and AI.

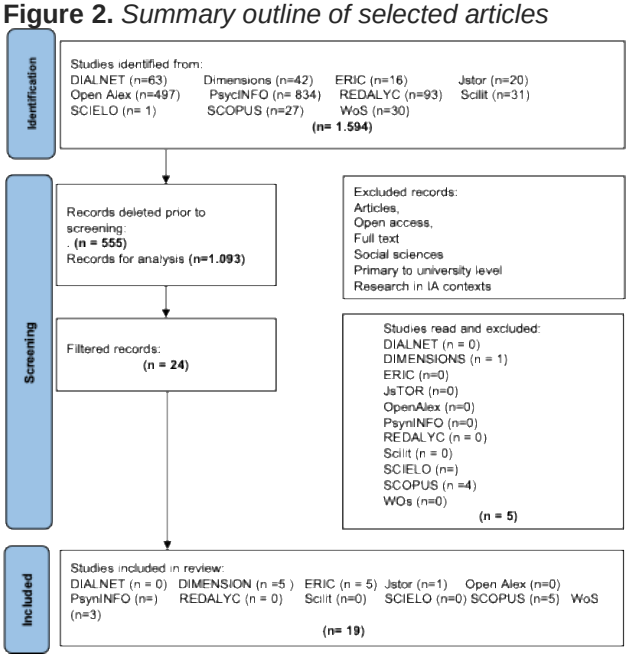
Secondly, an SR was developed to analyze TPACK and AI documents from the inception of the TPACK model until July 2024. The search equations were built by following the suggestions of Mishra and Koehler (2006) and De Rossi and Trevisan (2018), including the term TPACK to favor the inclusion of two or more types of knowledge. In addition, the terms were verified in the ERIC and Unesco thesaurus.

Table 3. Specific protocol of keywords in each database

Database	Protocol
DIALNET	MODELO TPACK AND STEAM AND Artificial intelligence
DIMENSIONS	technological pedagogical content knowledge OR tpack AND Artificial intelligence
ERIC	technological pedagogical content knowledge OR tpack AND Artificial intelligence
Jstor	technological pedagogical content knowledge AND tpack AND Artificial intelligence
OpenAlex	technological pedagogical content knowledge OR tpack AND Artificial intelligence
PsycINFO	technological pedagogical content knowledge OR tpack AND Artificial intelligence
Redalyc	MODELO TPACK AND EDUCATION STEM AND Artificial intelligence
SCIELO	technological pedagogical content knowledge OR tpack AND Artificial intelligence
Scilit	technological pedagogical content knowledge OR tpack AND Artificial intelligence
SCOPUS	technological pedagogical content knowledge OR tpack AND Artificial intelligence
WoS	(((TS=(technological pedagogical content knowledge)) OR TS=(TPACK)) AND TS=(Artificial intelligence)

The inclusion criteria were: open access, full text, social sciences, educational levels from pre-school to university, and research developed in AI contexts. The following were excluded: abstracts, editorials, press releases, conference documents, master's and doctoral dissertations and theses, areas other than social sciences, pre-school and non-university adult education levels, and non-AI studies.

Figure 2. *Summary outline of selected articles*



In the identification stage, 1.594 records were obtained, with PsycINFO providing the largest number (52,32%), followed by OpenAlex (31,17%). The articles were reviewed according to titles, keywords, and abstracts, considering the inclusion criteria. It should be noted that in some cases, it was necessary to access the full text. Finally, 19 articles were included: five in ERIC, DIMENSIONS, and SCOPUS with 26,31% respectively, followed by WoS (15,78%) and JSTOR (5,26%). A systematic reading of the articles was carried out to obtain answers to the questions raised in the research, see Annex A.

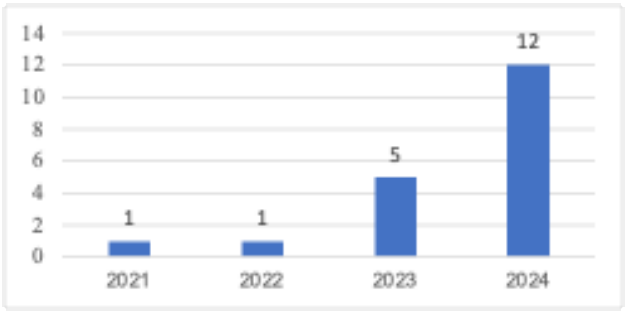
Results

In the first part of the results, a quantitative analysis was developed, including the following: years of publication, geographical distribution, type of research, educational level, geographical location, and samples.

Quantitative data indices of the TPACK model in artificial intelligence contexts

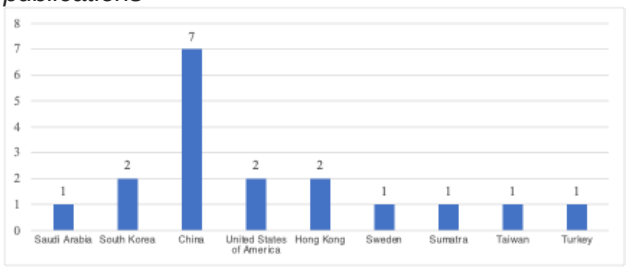
In response to the first question, it is observed that scientific production took place between the years 2021 and 2024, with the latter representing 63,15% of the total, see Figure 3.

Figure 3. *TPACK Articles in Artificial Intelligence Context by Year of Publication*



In terms of geographical distribution, China accounts for 36,84% of scientific production, followed by South Korea with 10,52%, the United States, and Hong Kong. In terms of distribution by continent, Asia accounts for 68,42%, followed by America and Europe, see Figure 4.

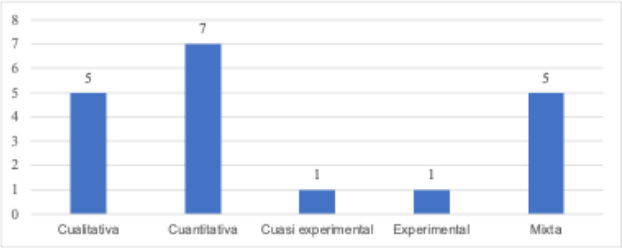
Figure 4. *Geographical distribution of selected publications*



Regarding the type of study, 36,84% used quantitative methodologies, followed by qualitative and mixed methodologies, with 26,31% each; see Figure 5.

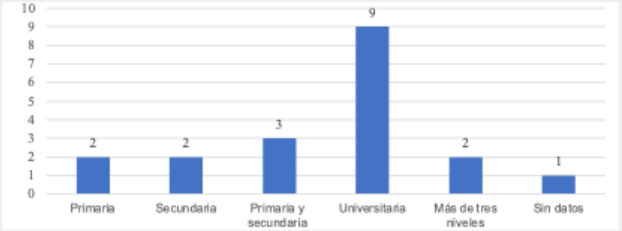
The most representative sample is from Yue et al. (2024), with 1.664 teachers at the primary, secondary, and university levels in China, while the smallest is from Yingling (2023), with five instructors of graduate students at the postgraduate university level in the United States. Notably, the study by Chiu et al. (2024) presents a varied sample, including teachers, principals, vice-principals, and department heads.

Figure 5. *Types of research found in this SLR*



In terms of educational levels, 47,36% of the studies were conducted at the university level, including undergraduate and graduate studies. Additionally, research incorporating more than one level represents 26,31%; see Figure 6.

Figure 6. *Educational levels of SLR research*



Regarding the instruments, 10 different instruments were used: focus groups, discussion groups, pre- and post-tests, planning, reflections, tests, screenshots, interviews, and questionnaires, the latter being used in 68,42% of the studies. It should be noted that the TPACK questionnaires related to AI mainly use the work of Celik (2023) as a reference for the creation, adaptation, validation, and application of new instruments.

The TPACK model in artificial intelligence contexts

The second part of the analysis includes questions two, three, and four. The guidelines refer to previous work by Paidicán and Arredondo (2022), which classifies research into: self-reporting of knowledge, teacher training and experiences, and TK and its relationship with TPACK.

Table 4. *Teacher-centered approaches to TPACK research and artificial intelligence*

TPACK approach	Authors	Quantity/ percentage
Self-reporting of teachers'	An et al. (2022), Celik (2023), Chen (2023), Chiu et al. (2024), Ning et la. (2024), Saz et al. (2024), Velander et al. (2024), Wang et al. (2024); Yue et al. (2024)	9 56,25%
Teacher training	Kim (2024a), Sun et al. (2023),	2 12,5%
Teaching experiences	Kim y Kwon (2023), Kim (2024), Kohnke et al. (2024), Majed et al. (2024), Yingling (2023)	5 31,25%
TK development & its relationship with TPACK		0

Table 4 shows that more than half of the studies relate to self-reporting of knowledge, followed by teaching experiences, and together they account for 87,5% of all teacher-related studies. The research has mainly been carried out in the last two years, mostly in China, although there are also studies in European and American countries.

Quantitative methodology is the most widely used, with the main emphasis on the creation, adaptation, validation, and application of self-report instruments. The studies address the subjects of English, science, arts, and computer science.

Regarding the samples, the most representative study is by Yue et al. (2024), including 1.664 Chinese teachers, followed by Wang et al. (2024), including 606 Chinese undergraduate and graduate university teachers. The smallest sample is from Chen (2023), with 6 teachers from the same country. It is worth mentioning the research by Chiu et al. (2024), which diversifies the sample by including teachers, principals, vice-principals, and department heads.

Concerning the instruments, the study by An et al. (2023) stands out for the construction of a new questionnaire, including seven different references, followed by the studies by Celik (2023), Ning et al. (2024), and Saz et al. (2023) with four references each. It should be noted that the instruments referring to the TPACK and AI model are complemented with topics related to ethics, anxiety, expectations, among others. The questionnaires are composed of 23 to 42 items, with a Likert scale of 3 to 5 factors. The reliability indices, according to Cronbach's alpha, range from 0,7 to 0,957, as reported by An et al. (2023) and Ning et al. (2024), respectively. Most of the studies develop exploratory and confirmatory factor analyses and structural equation modeling. The study by Velander et al. (2024) stands out for using the theoretical references of Celik (2023) for the focus group analysis rather than a questionnaire, which is more commonly used.

The results indicate that teachers have confidence in using ICT, where their attitudes and perspectives

are factors that should be taken into account when gaining TPACK knowledge. Additionally, solid and sustained support is required to achieve adequate integration of technologies (An et al., 2023; Chen, 2023; Velander et al., 2024). Furthermore, such integration requires pedagogical strategies that incorporate teachers' experiences, beliefs, and ideas, as well as other aspects such as social influence, anxiety, and expectations of student performance, as they represent an impetus to approach TPACK from AI (Ning et al., 2023; Velander et al., 2024; Wang et al., 2024). On the other hand, the results obtained by Yue et al. (2024) indicate that teachers present a low level of CK and TK knowledge when using AI, but their teaching practices related to TPACK are a crucial factor in developing confidence when using AI.

It should be noted that Celik (2023) study highlights the need to use technologies with appropriate pedagogical and ethical guidelines, in both personal and professional aspects. In turn, Chiu et al. (2024) point out that meeting teachers' basic psychological needs, autonomy, and competence is an indirect predictor of personal-ethical and personal-professional competencies.

The analyses developed in the studies indicate that the instruments are mostly valid and reliable and that CK, PK, and TK-AI knowledge have little influence on TPACK-AI, while TK, TPK, and TCK are important in AI teaching (Ning et al., 2024; Celik, 2023).

It is recommended to diversify research on the TPACK model and AI, in both theoretical and empirical aspects, to explain the reasons for teachers' CK knowledge and its implications for AI literacy teaching (Ning et al., 2023; Velander et al., 2024; Wang et al., 2024). Ethical issues in different educational contexts, multimodal teaching, online platforms, evaluation of computer-based teaching resources, teaching methods, and GenAI-specific strategies should also be addressed (Celik, 2023; Chen, 2023; Chiu et al., 2024). Finally, research by Yue et al. (2024) indicates that teacher training processes should include at least the following: age-appropriate CK selection for teachers, AI-specific innovative pedagogical approaches, strengthening teachers' confidence in AI teaching, and AI teaching-related practices, including experimental methods (Chiu et al., 2024).

Studies related to teacher training processes were carried out in South Korea and China, with the participation of 26 and 40 teachers at primary, secondary, and university levels, who teach history, mathematics, biology, physics, and computer and information science. Mixed and quasi-experimental methodologies were used. Regarding the instruments, the studies coincide in the use of pre- and post-tests, highlighting the study by Sun et al. (2023), which includes individual and group planning and interviews. The duration of the training ranged between 30 and 75 hours, distributed over 15 to 30 days.

The study by Sun et al. (2023) includes the following training topics: first, AI knowledge related to representation and reasoning, interaction, and social impact; second, AI teaching skills of teachers related to AI lesson plans and AI programming skills; and third, AI teaching self-efficacy of teachers related to efficacy beliefs and expectations in AI teaching. Meanwhile, Kim (2024a) focuses his AI convergence training process based on TPACK, such as AI Convergence Teaching Expertise.

The results indicate that the programs developed with TPACK guidelines have a positive impact on teachers' self-efficacy, knowledge, and skills when effectively integrating AI. They highlight aspects of teachers' daily practices, such as the design and implementation of lesson planning. Research recommends exploring the long-term effects of TPACK-based training programs and establishing the actual impact on student learning outcomes in AI-related subjects.

Research focusing on teaching experiences is conducted mainly in Asia, including China, Hong Kong, and South Korea, during the years 2023 and 2024. The samples include between five and 293 teachers from primary to university (postgraduate) levels. Kim's study (2024) only includes schools with leading AI in education teachers or schools selected for demonstrating excellence in AI education. Regarding the area of work, research in areas such as English and linguistics is more frequent. However, the study by Kim and Kwon (2023) includes four distinct areas: mathematics, computer science, technology education, and convergent artificial intelligence. Most of the research uses qualitative methodologies, with the TPACK questionnaire focusing on TK, CK, TCK, and AI being the most commonly used instrument (Kim and Kwon, 2023; Majed et al., 2024). It should be noted that Yingling (2023) study includes a wider range of instruments, including questionnaires, interviews, focus groups, screenshots, ChatGPT interactions, and lesson plans. The experiences are developed in contexts of problem-based learning, basic reasoning, and reflection (Kim, 2024). Yingling (2023) uses the tool ChatGPT, while Majed et al. (2024) incorporate ChatGPT, Bard, Quizizz, and Educational Copilot in their experience.

The analyses of the experiences are developed in a descriptive and interpretative manner, although the work proposed by Kim (2024) stands out for its specificity, incorporating the curriculum, interaction between teacher and AI, environment, and evolution over time, based on Kim et al. (2022a).

The results indicate that teachers' levels of confidence in their competence to teach AI are influenced by CK, PK, and TK, provided that opportunities for actual teaching practice and experience are offered (Kim and Kwon, 2023). In addition, teachers play a key role in the instructional process, including design, assessment, and decision-making, while AI was mainly employed as an analyst of students' learning progress, process, and experience using multimodal data, e.g., identifying students' developing competencies and skills, access to resources, feedback, and integration between teachers and students (Kim, 2024). On the other hand, GenAI has great potential in higher education in aspects related to teaching and learning, although it requires effective teacher training programs when integrating AI. Additionally, GenAI has great potential for use in the area of language teaching but requires extensive knowledge of PK and TK to increase student engagement and participation in highly skilled contexts using tools such as ChatGPT (Majed et al., 2024; Yingling, 2023).

The study by Kohnke et al. (2024) found that the rapid advancement of AI contributes to technology overload and uncertainty and that TPACK plays a crucial role in teachers' ability to manage technostress, including comprehensive training, supportive communities, and a balanced approach to technology use.

It is recommended to develop training processes that consider knowledge and skills aligned with AI-driven systems (Kim, 2024). Additionally, there is a need to study GenAI and its connection to equitable education (Majed et al., 2024), as well as to address how teachers' knowledge and learning experiences influence the use of AI technology (Yingling, 2023). Finally, it is important to explore teachers' well-being, effective AI integration, the impact of TPACK, and factors that facilitate the reduction of technostress.

The studies focused on students represent 15,75% of the total analyzed, developed between the years 2021 and 2024, in Asian countries and at the university level. In relation to the methodology used, which includes mixed, qualitative, and experimental approaches, the samples range from 15 to 55 students from the areas of English and design. Regarding the instruments, the use of the TPACK questionnaire based on Celik (2023), planning, and GPT-3.5 as an assistance tool is observed.

The results indicate that the use of AI supports students' personalized learning and practice, meeting their learning needs, although it requires the strengthening of art and technology learning, teamwork, and collaboration between humans and AI in future design education (Tang et al., 2021). Furthermore, the integration of AI tools such as GPT-3.5 improves students' writing quality, efficiency, and critical thinking, although its effectiveness is conditional on its use within a structured and pedagogically sound framework in a more engaging and interactive learning environment (Yu and Hi, 2024).

Prospective teachers of foreign languages such as English must possess the knowledge and skills to employ appropriate AI strategies. This is essential and includes: participating in training programs, collaborating with expert colleagues, keeping informed about AI trends, and improving TK knowledge (Hastomo et al., 2024).

Studies suggest that prospective teachers actively participate in training workshops, including mentoring processes to support their professional development in the field of technologies (Hastomo et al., 2024). In addition, future research needs to use complementary models such as TPACK and instructional designs to facilitate conscious authorship and critical thinking in foreign language writing (Yu and Hi, 2024). Finally, it is suggested to explore the expansion of the platform for learning design in situations similar to the COVID-19 health emergency, from both theoretical and practical points of view (Tang et al., 2021).

Discussion

TPACK model research in AI contexts shows significant development on the Asian continent, which is partially consistent with studies developed in other contexts (Lee et al., 2022; Mahtari et al., 2024; Paidicán and Arredondo, 2023a; Sakaria et al., 2023; Yeh et al., 2021). It should be noted that there is an increase in TPACK and AI model studies between 2023 and 2024, coinciding with the post-pandemic stage of the COVID-19 health emergency. According to Paidicán and Arredondo (2024), findings indicate that teachers required knowledge, skills, and abilities for the use of new technologies. In addition, the emergence of ChatGPT at the end of 2022, as Milmo (2023) notes, the innovative pre-trained generative transformer (PT) technology has achieved a significant milestone by breaking the technology adoption speed record, reaching an impressive 100 million users in just two months.

However, the transformative advances introduced by AI bring with them challenges for users. In the context of ChatGPT-based AI, one such phenomenon called ‘hallucinations’ refers to the generation of incorrect results that, at first glance, may seem logical and coherent but can be misleading, underscoring the need for critical and conscious use of these technologies (Brynjolfsson et al., 2023; Peng et al., 2023; Pinski & Benlian, 2024).

The studies privilege the use of quantitative, qualitative, and mixed methodologies, in agreement with Major and McDonald (2021), Paidicán and Arredondo (2022), and Paidicán and Arredondo (2023a), with a predominance in university education. In addition, teacher-centered studies focus their efforts on the adaptation, creation, and application of new instruments related to teachers' self-knowledge of TPACK and AI. The results cannot be generalized, as the number of studies is very limited and they address different aspects related to AI, such as knowledge, ethics, and others. This is corroborated by previous studies, which state that teachers require PK knowledge to effectively use AI in the process of transforming educational pedagogy in which they are immersed and thus fully exploit the potential of AI tools (Cavalcanti et al., 2021; Luckin et al., 2022; Wang et al., 2021; Xu, 2020.

Teaching experiences related to TPACK and AI, for their adequate development, require minimum elements. Previous studies by Sampaio (2016), Da Silva et al. (2021), and Paidicán and Arredondo (2024) point out that teaching experiences need solid organization and execution, considering adequate infrastructure and resources. The increase in the use of ICT has led teachers to face new situations, one of which is represented by technostress. The research developed by Kohnke et al. (2024) shows that the rapid advancement of AI causes teachers’ anxiety, overload, and technological uncertainty, corroborated by previous studies that indicate that technostress represents for teachers the obligation to use ICT (Dong et al., 2020). The TPACK model could help in reducing technostress, as high levels of PK and TK knowledge allow teachers to feel confident and competent when integrating ICT into teaching and learning processes in schools, colleges, and/or universities (Özgür, 2020; Li et al., 2024; Raja and Nagasubramani, 2018).

With student-based studies, the successful implementation of AI-related practices requires the complementary use of models, such as, for example, TPACK and ADDIE (Analyze, Design, Develop, Implement, and Evaluate), according to Gonzalez and Bravo (2024) and Rodriguez and Cubillas (2024). Both models allow for effectively addressing the challenges of digital education, including dynamic, personalized learning experiences and the needs of teachers in the process of continuous training.

Conclusions

There are two SLR related to TPACK and AI, but their realization has limitations related to the choice of only some databases and a specific focus on university education. This aspect is essential to assess the relevance of this research and its contribution to the development of the TPACK model.

There is little development of the scientific production of the TPACK model in AI contexts, with only 19 articles obtained, equivalent to 1,91% of the identified records, distributed between the years 2021 and 2024, the latter being the most productive, even though the year has not yet ended. Furthermore, the studies preferably take place on the Asian continent, reaching almost 70%, with China being the country with the highest levels of scientific production. 47,36% of research is carried out in higher education, using mostly quantitative methodologies, followed by qualitative and mixed methodologies. Finally, the studies most frequently use the questionnaire, the main reference being the work developed by Celik (2023) for the application, creation, and adaptation of new instrument.

Of the studies focused on teachers, self-reports of knowledge are more recurrent, representing 56,25% of the total research related to teachers. There is a clear prevalence for the creation, adaptation, and validation of instruments related to the TPACK model and AI, including different subjects or areas of work such as science, arts, computer science, and English. The findings suggest that CK, PK, and TK-AI knowledge have little influence on TPACK-AI. Finally, there is agreement on the need to establish guidelines on ethical aspects when using AI.

The studies related to teacher training conclude that the incorporation of AI requires solid knowledge of lesson planning and self-efficacy in teaching, including students' expectations when teaching with AI.

In research related to teaching experiences, the incorporation of AI-powered tools stands out, including ChatGPT, Bard, Quizizz, and Educational Copilot. Although their use is conditioned by the teachers' confidence levels, the levels of CK, PK, and TK knowledge, and the real opportunities and practices of using AI. Teachers play a key role in the design, evaluation, and decision-making, while AI is mainly used as an analyst of the progress, process,

and learning experience of students using multimodal data, prioritizing both group and personal feedback spaces.

In student-based studies, work with AI is prioritized in areas related to foreign languages such as English, for the development of knowledge and skills, especially in aspects such as critical thinking and ethically conscious text production.

Finally, the studies recommend the development of experimental, quasi-experimental, and longitudinal studies to obtain more concrete evidence of the use of AI in TPACK model contexts. Additionally, ethical aspects of the use of AI must be explored in depth, as well as addressing the new situations that teachers face, such as technostress.

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Annex A. *Research articles included in the SLR*

N°	Author	Country	Type of study	Sample	Instruments	Educational level	Subject	Aim of the research
1	An et al. (2022)	China	Quantitative, Instrument validation	470 teachers	Questionnaire of effort expectations, social influence, facilitating conditions, AIL-TK, AI-TPK, AI-TPACK and teachers' behavioural intention.	Secondary	English	To investigate English language teachers' perceptions, knowledge and behavioural intentions when using AI to support teaching and learning.
2	Celik (2023)	Turkey	Quantitative, Instrument validation	439 teachers	TPACK-AI questionnaire and ethical aspects, based on Jang & Tsai, 2013; Sang et al., 2016; Schmid et al., 2020; Valtonen et al., 2017).	Primary and secondary	No data	Explore teachers' knowledge to use AI-based tools pedagogically and ethically.
3	Chen (2023)	China	Qualitative, case study	6 teachers	TPACK interviews based on Niess (2008), classroom observations, lesson plans and didactic reflection diaries.	University	English	Examining the knowledge components and attributes of instructors of English for academic purposes in the age of digital intelligence.
4	Chiu et al. (2024)	Hong Kong	Mixed, explanatory sequential	370 teachers, one director, one deputy director, four heads of department.	TPACK questionnaire based on (Perceived Support for School Learning (Lee et al., 2020), Basic Psychological Needs Scale, revised (Chen et al., 2015), TPACK (Schmidt et al., 2009), Personal and Professional Ethical Competencies (Redecker, 2017),	Secondary	No data	To examine a research model that uses school learning support as a predictor of needs satisfaction and to identify needs support strategies for digital education.

N°	Author	Country	Type of study	Sample	Instruments	Educational level	Subject	Aim of the research
					interviews and focus groups.			
5	Hastomo et al. (2024)	Sumatra	Mixed	55 Students	TPACK Questionnaire adapted from (Celik, 2023) and interviews	University	English	To explore prospective teachers' technological knowledge of the use of artificial intelligence-driven tools according to the TPACK model.
6	Kim and Kwon (2023)	South Korea	Mixed	67 teachers	TPACK questionnaire, level of confidence in AI education and interviews, based on (Koehler et al., 2014).	Primary	Mathematic, computer science, technological education, and convergent artificial intelligence	Examining the Competencies and Experiences of Primary School Teachers in South Korea in Teaching Artificial Intelligence Curricula and Assessing Their Skills.
7	Kim (2024)	China	Qualitative	20 teachers	Interviews based on Kim et al. (2022a).	Primary and secondary	No data	Examining Perspectives of Leading Educators on Artificial Intelligence in Education and Key Considerations for Collaborative Classroom Instruction Design and Implementation.
8	Kim (2024a)	South Korea	Mixed	26 teachers	TPACK questionnaire and pre- and post-tests	University	History, mathematics, computer science, biology, physics,	Developing an Artificial Intelligence-Based Educational Programme Within the TPACK Framework to Enhance the Competence of Future Educators
9	Kohnke et al. (2024)	Hong Kong	Training	16 english instructors	Interviews	University undergraduate and	English	Exploring English Teachers' Opinions and Perceptions of Technostress Related to

N°	Author	Country	Type of study	Sample	Instruments	Educational level	Subject	Aim of the research
10	Majed et al. (2024)	Saudi Arabia	Qualitative, exploratory	293 teachers	TPACK Questionnaire, focusing on TK, CK and TCK	postgraduate University	Linguistics	Generative AI, Studying How Linguistics Teachers Can Leverage Generative Artificial Intelligence to Enhance Teaching Competence and Student Engagement
11	Ning et al. (2024)	United States	Quantitative	135 Studenty 231 teachers en servicio	TPACK-AI questionnaire	Primary, secondary and university	Science and arts	Building a Framework to Integrate Technological Pedagogical Content Knowledge for Artificial Intelligence Technology
12	Tang et al. (2021)	China	Quantitative	40 Students	Lesson plans	University	Design	Comparing Traditional Design Education and New Design Education Methods Combined with Artificial Intelligence Technology
13	Saz et al. (2024)	No data	Instrument validation	175 people	TPACK-AI Questionnaire Based (Alemán-Saravia et al., 2023; Paidicán and Arredondo, 2023; Ladrón-de-Guevara et al., 2021)	No data	No data	Validating a TPACK Questionnaire for Use with Educators in Relation to the Use of Generative Artificial Intelligence Programs
14	Sun et al. (2023)	China	Experimental study	40 teachers	Pre-test and post-test, individual and group planning and interviews.	Primary and secondary	Computer Science	Designing a Professional Development Programme Based on the Technological Pedagogical Content Knowledge (TPACK) Framework.
15	Velander et al. (2024)	Sweden	Quantitative	37 teachers en servicio y formador de formadores	Focus group based on TPACK-AI (Celik, 2023) and questionnaire based	Primary	No data	Exploring Teachers' and Teacher Trainers' Understanding and

N°	Author	Country	Type of study	Sample	Instruments	Educational level	Subject	Aim of the research
					on Lindner and Berges (2020)			Preconceptions of Artificial Intelligence in Teacher Training and Professional Development
16	Wang et al. (2024)	China	Instrument validation	606 teachers de pre y pos grado	Questionnaire based on technology self-efficacy scale (Dong et al., 2019), AI anxiety scale (Wang and Wang, 2019), TPACK-AI scale (Celik, 2023), UTAUT scale (Morris et al., 2003), GEIA scale (An et al., 2023).	University undergraduate and postgraduate	No data	Investigating Teachers' Views on the Effective Integration of Generative Artificial Intelligence Tools into Their Instructional Practices
17	Yingling (2023)	Taiwan	Quasi-experimental, training,	5 instructores de StudentGraduados (teachers novatos)	Questionnaires, interviews, focus groups, screenshots, ChatGPT interactions and lesson plans'.	University postgraduate	English	Investigating the Exploration and Integration of ChatGPT in Language Teaching by Graduate Student Instructors
18	Yu y Hi (2024)	Taiwan	Mixed	15 Students	Reflections, self-assessments and final examination	University	English	Exploring the Innovative Integration of Open-Access GPT-3.5 in an English Writing Course
19	Yue et al. (2024)	China	Quantitative	1664 teachers	TPACK-AI questionnaire based on (Schmid	Primary, secondary and trainee teachers	English	Determining Teachers' Preparedness in TPACK Knowledge and Attitudes Towards Teaching Artificial Intelligence