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A Review of Studies on Technological Pedagogical Content Knowledge in Mathematics Education

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ABSTRACT
The purpose of this study is to review the studies conducted on Technological Pedagogical Content Knowledge (TPACK) in mathematics education between 2020 and 2024. The research employed a systematic literature review method. The databases ScienceDirect, Wiley Online Library, Taylor & Francis, Springer Link, and Web of Science were examined; a total of 68 studies were identified and included in the scope of this research. The studies obtained were analyzed in terms of cognitive and affective domain themes and subfields of mathematics. According to the results of the research, cognitive domain themes were found to be examined more frequently than affective domains. Within the cognitive domain, the focus was mainly on knowledge levels, whereas within the affective domain, attitude themes were emphasized. In terms of mathematical content, it was determined that the studies were primarily concentrated in the geometry subfield. This study is expected to significantly contribute to the literature by revealing trends in international databases on TPACK in mathematics education and identifying existing research gaps. Furthermore, it is anticipated to serve as a guiding resource for researchers planning to conduct studies on similar topics by offering a comprehensive and holistic evaluation.

Keywords: Technological pedagogical content knowledge, mathematics education, descriptive content analysis

Matematik Eğitimi Alanındaki Teknolojik Pedagojik Alan Bilgisi Çalışmalarının İncelenmesi

Araştırma Makalesi
Bilgi
**Sorumlu yazar*

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ÖZ
Bu çalışmanın amacı, 2020-2024 yılları arasında matematik eğitiminde Teknolojik Pedagojik İçerik Bilgisi (TPAB) konusunda yapılan çalışmaları incelemektir. Araştırmada sistematik literatür tarama yöntemi kullanılmıştır. ScienceDirect, Wiley Online Library, Taylor & Francis, Springer Link ve Web of Science veri tabanları incelenmiş; toplam 68 çalışma tespit edilerek araştırma kapsamına alınmıştır. Elde edilen çalışmalar matematiğin bilişsel ve duyuşsal alan temaları ve alt alanları açısından analiz edilmiştir. Araştırma sonuçlarına göre bilişsel alan temalarının duyuşsal alanlardan daha sık incelendiği bulunmuştur. Bilişsel alanda ağırlıklı olarak bilgi düzeylerine odaklanılırken, duyuşsal alanda ise tutum temalarına ağırlık verilmiştir. Matematiksel içerik açısından çalışmaların ağırlıklı olarak geometri alt alanında yoğunlaştığı belirlenmiştir. Bu çalışmanın matematik eğitiminde TPAB ile ilgili uluslararası veri tabanlarındaki eğilimleri ortaya koyarak ve mevcut araştırma boşluklarını belirleyerek literatüre önemli katkı sağlaması beklenmektedir. Ayrıca, benzer konularda çalışma yapmayı planlayan araştırmacılara kapsamlı ve bütüncül bir değerlendirme sunarak yol gösterici bir kaynak olması öngörülmektedir.

Anahtar Kelimeler: Teknolojik pedagojik içerik bilgisi, matematik eğitimi, betimsel içerik analizi

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Introduction

In the past, the teaching profession was primarily regarded as a role limited to transmitting knowledge to students, whereas today the expected roles of teachers have significantly shifted; tasks such as preparing students for the future, helping them reveal their individual skills, and guiding their learning processes have come to the fore (Tan & Lee, 2018). This change indicates that it is no longer sufficient for teachers to be mere transmitters of knowledge; they need to serve as role models and remain open to professional growth (AbdulRab, 2023). Accordingly, teachers are expected not only to master mathematical content but also to integrate pedagogical strategies and technology effectively.

In this context, the content and scope of teacher knowledge have been the subject of many studies (Ball & Cohen, 1999; Demiray & Zeybek, 2023). Shulman (1987) emphasized that it is inadequate for teachers to approach pedagogical knowledge and content knowledge separately, highlighting the importance of integrating these two dimensions and introducing the concept of "pedagogical content knowledge" (PCK) into the literature. This framework was later expanded with the technological dimension, especially with the impact of digitalization on education. Mishra and Koehler (2006) conceptualized this integration as Technological Pedagogical Content Knowledge (TPACK), which requires teachers to consider pedagogical, technological, and content knowledge in an integrated structure and to incorporate it into teaching processes.

TPACK enables teachers to combine technology, pedagogy, and content effectively in ways that enhance student learning. Research has shown that strengthening teachers' content and pedagogical knowledge positively influences student outcomes (Ward, Kim, Ko & Li, 2014), and with the acceleration of technological advancements, integrating technology has become indispensable in mathematics education (Kirkwood & Price, 2013). In this regard, teachers are expected not only to be experts in their field but also to convey knowledge effectively by supporting it with technology (Angeli & Valanides, 2009; Erdoğan & Şahin, 2010; Polly & Rock, 2016).

The TPACK structure also contributes to student motivation and engagement. It is defined as the knowledge of technology use that enables students to connect their prior knowledge with new knowledge (Mishra & Koehler, 2006). For this reason, examining the studies conducted in the cognitive and affective domains on this topic has become increasingly important. Studies emphasize that TPACK increases students' interest in mathematics and supports their participation in more active learning environments (Öğüt, 2019). Figure 1 presents the TPACK framework.

When examining the cognitive domain, we see that it encompasses mental processes such as acquiring, understanding, analyzing, synthesizing, and evaluating information (Bloom et al., 1956). This domain is closely related to students' intellectual development and plays a central role in structuring knowledge and skills in mathematics education (Hui & Mahmud, 2023). The themes analyzed in this study, such as "concept teaching," "problem solving," "reasoning," and "application," overlap with the comprehension, application, analysis, and evaluation levels of Bloom's taxonomy of the cognitive domain (Bloom et al., 1956). Achievements in the cognitive domain can also be used as an objective measure of students' abilities and academic performance (Kim & Hong, 2018). Furthermore, cognitive achievement enhances students' access to knowledge, application of problem-solving strategies, and logical reasoning skills. Teachers' TPACK competencies enable them to select effective technological and pedagogical strategies that support students' cognitive learning. The TPACK approach facilitates quality learning in mathematics education by promoting technology-supported practices aligned with students' cognitive processes (Yllana Prieto et al., 2023). The subthemes emphasized within the cognitive domain themes in studies on TPACK in mathematics education are particularly important.

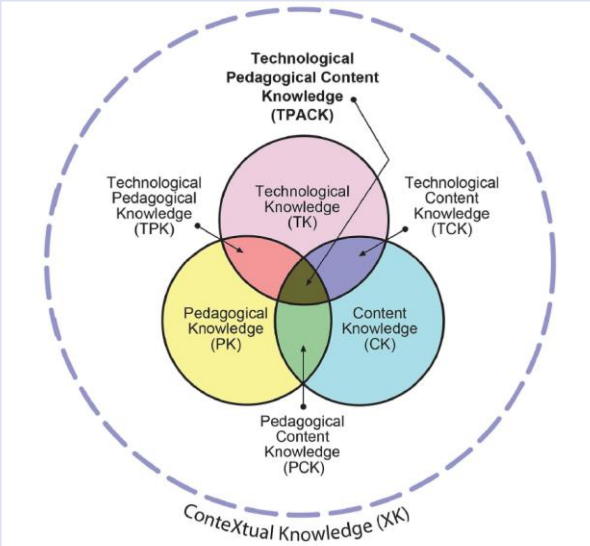

Figure 1. TPACK framework. (Mishra & Koehler, 2006)

When examining the affective domain, we see that it encompasses students' feelings, attitudes, values, interests, and motivations toward learning (Bloom et al., 1956). It determines students' participation in the learning process, willingness to engage, and emotional connection (Hui & Mahmud, 2023). The themes emphasized in this study—such as "attitude development," "interest," "self-confidence," and "motivation"—overlap with the receiving, responding, valuing, and characterizing levels defined in Krathwohl's taxonomy of the affective domain (Krathwohl et al., 1964). Motivation and self-efficacy, in particular, are critically important for shaping students' long-term academic success (Kim & Hong, 2018). Developing the affective domain in learning also enhances performance and cognitive achievement (Yllana Prieto et al., 2023). In mathematics education, TPACK is significant for educators considering students' affective needs and conducting student-centered teaching. Therefore, the subthemes emphasized in affective domain studies hold an important place.

As a result, mathematics teachers need to master students' cognitive and affective processes and equip them with content knowledge, pedagogical competencies, and technological skills. This study aims to conduct a comprehensive review and classification of the research carried out on TPACK in the context of mathematics education. Thus, by revealing the existing literature on TPACK trends, the study seeks to guide researchers planning to conduct studies in this field and identify areas where further research is needed.

This research aims to systematically examine the studies on Technological Pedagogical Content Knowledge (TPACK) conducted in mathematics education. By screening databases that meet international academic standards, such as ScienceDirect, Wiley Online Library, Taylor & Francis, Springer Link, and Web of Science, the research identifies in which subfields of mathematics the studies have been concentrated, and which cognitive and affective domain themes have been predominantly addressed. Accordingly, analyzing and classifying these aspects of the studies will reveal trends in the field through a systematic approach. The research problem and sub-problems examined in this study are presented below:

Research Question:

What is the distribution of studies on TPACK in mathematics education according to their content characteristics?

Sub-questions:

1. What is the distribution of studies on TPACK and mathematics education according to cognitive domain themes?
2. What is the distribution of studies on TPACK and mathematics education according to affective domain themes?
3. What is the distribution of studies on TPACK according to subfields of mathematics?

Method

In this research, a systematic literature review method was employed, and the PRISMA model was used as the research design to examine studies conducted on TPACK in mathematics education. A systematic literature review aims to examine existing studies in a structured way according to predetermined criteria (Harris et al., 2014) and contributes to revealing not only the body of knowledge in the literature but also existing research gaps (Barn et al., 2017).

Study Group

The sample of this study consists of research focusing on TPACK in mathematics education. The data were obtained through an extensive search across six databases using the main themes "mathematics education" and "technological pedagogical content knowledge." The databases used are:

- Springer Link
- Wiley Online Library
- ScienceDirect
- Taylor & Francis
- Web of Science

The databases selected for this study were chosen in accordance with the criteria of comprehensiveness and validity required for rigorous research. The Web of Science (WoS) database was designated as the primary reference source because it is among the most comprehensive international indexes, maintains high academic quality standards, and supports systematic literature searches through its citation-based structure (Mongeon & Paul-Hus, 2016). The interdisciplinary nature of WoS and its inclusion of high-impact journals enable the reliable identification of studies relevant to the research topic.

However, relying solely on WoS may lead to omissions in the dataset; therefore, additional databases were incorporated. ScienceDirect, Taylor & Francis, Wiley Online Library, and SpringerLink were included to ensure coverage of studies published across different publishers and indexing platforms. This strategy was adopted to enhance the reliability and representativeness of the literature, consistent with the “comprehensive search” principle recommended for systematic reviews.

Based on the examination of records in the selected databases in which the abstract included any of the terms “TPACK,” “TPCK,” or “technological pedagogical content knowledge,” together with the term “mathematics,” a total of 68 studies that met the inclusion criteria were identified and constituted the research sample.

Data Collection Process

The data were collected through the systematic literature review method. This method makes it possible to identify where research written by experts in the field is concentrated and to access structured and comprehensive syntheses of studies using similar methods (Juandi, 2021). The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; Moher et al., 2009) was used to ensure the reliability of the systematic review and the applicability of the results obtained. The PRISMA model was employed in reporting the process so that systematic reviews conducted by different researchers could yield the same results or update existing knowledge (Page et al., 2021). This model, which ensures transparency, completeness, updatability, and replicability of studies, also ensures validity and reliability in the present research (Page et al., 2021).

The PRISMA model consists of four stages, which are listed below:

- Identification
- Screening
- Eligibility
- Included

In the Identification stage, searches are conducted using predetermined keywords in appropriate sections of the databases to identify potential studies. For this research, studies were included if the title, abstract, or keywords contained at least one of the terms "TPACK," "TPCK," or "technological pedagogical content knowledge" and the term "mathematics." At this stage, a total of 153 studies were identified. The details of the data obtained from the databases are presented in Figure 2.

In the Screening stage, duplicate and irrelevant studies are excluded from the pool of potential studies. In the third stage, eligibility, the titles, abstracts, and content of the studies are examined, and those that do not meet the criteria are excluded. The inclusion criteria established for evaluating the eligibility of studies are as follows:

- Written in English
- Conducted between 2020 and 2024 in the field of mathematics education and on TPACK
- Open access and full-text availability
- Published in article or conference paper format

The data on the number of studies reached through the PRISMA model are presented in Figure 2.

The primary rationale for selecting the 2020–2024 period for this study is the existence of several compilations and analyses in the field of TPACK and mathematics education that focus on the period prior to 2020. For instance, the study by Baydar Işık (2020) provides a comprehensive overview of pre-2020 research and offers an important framework for the existing literature. However, this study and similar works naturally do not reflect the significant transformations of recent years, including the rapidly evolving digital learning environments following the COVID-19 pandemic, the widespread adoption of online teaching practices, and the expanding diversity of technological tools.

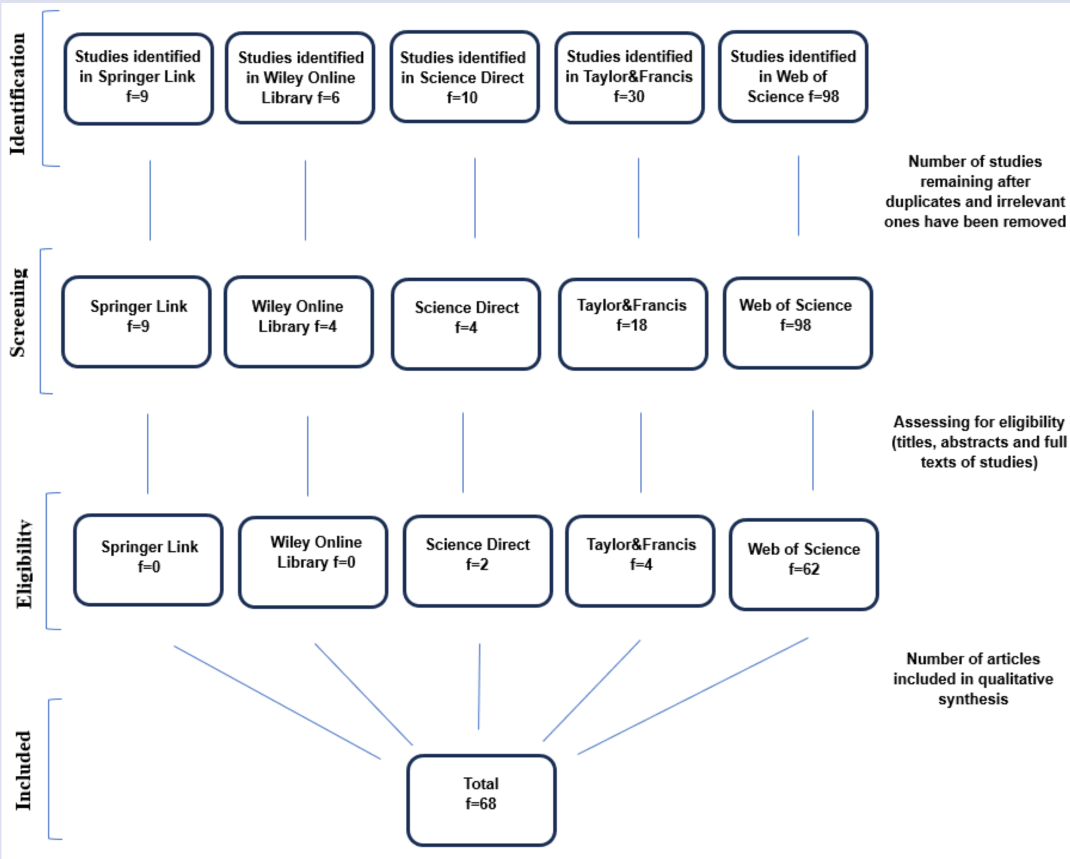

Figure 2. The selection process for the studies included in the analysis. (Adapted from Moher et al. (2009), PRISMA statement; see also Page et al. (2021))

Therefore, the present study was confined to the years 2020–2024 to address the current gap in the literature and to examine the emerging trends of the post-2020 period more thoroughly. This approach aimed to deliver a more robust analysis of contemporary approaches, trends, and shifts in technology integration related to TPACK within the context of mathematics education.

In the final PRISMA stage ("included"), the final step in the PRISMA, zero studies from Springer Link and Wiley Online Library databases, two from ScienceDirect, four from Taylor & Francis, and 62 from Web of Science were included in the research. In total, 68 studies were analyzed within the scope of the research. While analyzing the 68 studies obtained according to the research questions, some categorizations were made. This categorization was intended to facilitate the review of the studies.

While cognitive domain categories are classified, each category within the cognitive domain was grouped based on its sub-thematic structures. The subcategories obtained were specified under their respective categories to facilitate the analyses and reviews. Cognitive data related to knowledge, understanding/comprehension, learning, and thinking, considered the fundamental building blocks of the learning process, were grouped under the category "Knowledge and Thinking," which appears first in the table. This category covers individuals' mental processes, their access to knowledge through these processes, and their interpretation through thinking. As a result of the analyses, the domains of competence, skill, proficiency, and ability were identified and grouped under the category "Skills and Competencies," listed second in the table. The subthemes in this category highlight the capacity of individuals to perform tasks based on their knowledge and skills. The analysis of cognitive domain themes in the studies revealed the inclusion of performance, usage, behavior, effort, application, practice, and habit. These themes represent the behavioral outcomes of acquired cognitive processes, their practice, and reflection in real life, and were grouped under the category "Application and Performance." This was followed by the category "Creativity and Development," which includes the development, experience, and creation/production subcategories. These subthemes reflect the innovation and productivity steps within cognitive processes and were named with a title representing these aspects. This classification into four main categories aimed to facilitate the examination of cognitive domain themes addressed in the studies.

While cognitive domain categories are classified, for systematic and analyzable results, the affective domains also obtained were grouped under appropriate categories: Motivation and Interest, Value and Belief, Adaptation, Thought and Opinion, and Social and Emotional Factors. Each main category was grouped according to its sub-thematic structures. Motivation, willingness, and interest reflecting individuals' intrinsic drive toward learning were grouped under "Motivation and Interest." Attitude, self-efficacy, belief, intention, utility value, self-assessment, and self-belief—obtained from the analyses of the themes—were grouped under the category "Value and Belief." Acceptance and adjustment were determined as the subthemes of the "Adaptation" category, as they relate to individuals' ability to adapt to environmental conditions. Perception, insight, and imagination were identified through the analyses and grouped under the category "Thought and Opinion," as they reflect individuals' mental perception and interpretation of events. Expectation, trust, social influence, comfort, and anxiety—representing affective data related to individuals' emotional states derived from their social environment—were grouped under the "Social and Emotional Factors." This classification aimed to facilitate the examination of findings and to clarify how many studies fell under each affective domain category.

While mathematical domains and subdomains are classified, an attempt was made to classify the reviewed studies according to mathematics subdomains within grade levels: primary, secondary, and undergraduate mathematics curricula. However, it was observed that many of the 68 studies referenced mathematics domains within different curricula across various countries, often specifying grade levels inconsistently. The mathematics subdomain was sometimes stated, but the grade level was not. No interpretation of grade level was made for such studies, and only whether a grade level was specified was noted. Due to these inconsistencies and the variability of international curricula, a strict classification by grade level (primary, secondary, undergraduate) could not be applied. Consequently, the data were grouped under common mathematics domain categories derived from the subdomains found in the studies. During categorization, it was observed that some studies explicitly specified mathematics subdomains, while others referred to mathematics, analysis, algebra, or geometry without further specification. Such cases were classified under "general" subcategories, such as analysis (general), algebra (general), and geometry (general), as shown in Table 3.

In conducting the analyses, a coding software was utilized. To establish the codes and ensure the validity and reliability of the study, the opinion of an additional expert was consulted. Based on the evaluations carried out with the expert, the codes specifying the categories into which the studies would be classified were finalized, and the studies were incorporated into the research accordingly.

Results

This section presents the findings and comments regarding the research problems and sub-problems.

Distribution of Studies According to Content Characteristics

1. Findings Regarding the Distribution of Studies by Cognitive Domain Themes

The question "What is the distribution of studies on TPACK and mathematics education in terms of cognitive domain themes?" includes information obtained from a detailed analysis of the terms related to cognitive domain themes found in the abstracts and contents of 68 studies. It was determined that some studies included more than one cognitive domain theme, while others did not include any cognitive domain themes. For each cognitive domain theme identified in the studies, frequency values within the table were incremented by one unit. Findings related to this research question are presented in Table 1.

When Table 1 is examined, it is seen that the cognitive domain themes used in the studies were classified under appropriate headings. The analysis of these categories reveals which cognitive domains were more frequently emphasized in the studies.

In terms of cognitive domains, studies on TPACK and mathematics education most frequently focused on the "Knowledge" subdomain (f=21) within the "Knowledge and Thinking" category (f=28). Other areas within this category included comprehension/understanding in 3 studies, learning in 2 studies, and thinking in 2 studies.

Table 1. Distributions of cognitive domains

Cognitive Domain Categories	Cognitive Domain Subcategories	f	Total
Knowledge and Thinking	Knowledge	21	28
	Understanding/Comprehension	3	
	Learning	2	
	Thinking	2	
Skills and Competencies	Competence	5	13
	Skill	3	
	Proficiency	3	
	Ability	2	
Application and Performance	Performance	3	16
	Usage	3	
	Behavior	3	
	Effort	3	
	Application	2	
	Practice	1	
	Habit	1	
Creativity and Development	Development	9	17
	Experience	7	
	Creation/Production	1	

Beyond the "Knowledge and Thinking" category, the other categories showed relatively similar numbers of studies. Specifically, 13 studies were found in the "Skills and Competencies" category, 16 in "Application and Performance," and 17 in "Creativity and Development."

In the "Skills and Competencies" category, among the 13 subthemes identified, five were in competence, 3 in skill, 3 in proficiency, and 2 in ability.

Within the "Application and Performance" category, 16 cognitive domain themes were identified across studies. The subcategories included 3 in performance, 3 in usage, 3 in behavior, 3 in effort, 2 in application, 1 in practice, and 1 in habit.

In the "Creativity and Development" category, the subthemes were distributed as follows: 9 in development, 7 in experience, and 1 in creation/production.

When the distribution by cognitive domain categories is considered overall, it is evident that the "Knowledge" theme accounted for the largest number of studies. Of the 74 cognitive domain themes identified, 21 were in this area. From this, cognitive domain studies emphasized knowledge more than other areas. The closest numbers of studies were found in development (9), experience (7), and competence (5). Studies in other cognitive domains were comparatively fewer.

2. Findings Regarding the Distribution of Studies by Affective Domain Themes

The question "What is the distribution of studies on TPACK and mathematics education in terms of affective domains?" includes findings obtained from the detailed analysis of affective domain themes identified in the abstracts and contents of the studies. It was determined that some studies included more than one affective domain, while others included none. Frequency values for each affective domain identified in the studies were incremented by one unit. Findings related to this question are presented in Table 2.

Table 2 presents data on the affective domain categories obtained from the analyses of the studies and the number of subcategories within each. The affective domain is a significant dimension that addresses individuals' emotions, values, and attitudes. The data reveal which affective domains were more frequently emphasized in the studies.

When examining the 68 studies included in this research on TPACK and mathematics education, it was found that the largest number of affective domain data fell under the "Value and Belief" category (f=24). Within its subcategories, attitude (f=8) was most frequently addressed, followed by self-efficacy (f=7). The theme of intention appeared in 3 studies, while utility value and belief were each found in 2 studies. Self-assessment and self-belief were each mentioned in 1 study.

The next most frequently represented category was "Social and Emotional Factors" (f=14). Expectation was the most studied subtheme (f=6) within this category, followed by trust and social influence, each in 3 studies. Comfort and anxiety were each addressed in 1 study.

The "Thought and Opinion" category, represented in 7 studies, also held a notable place in the affective domain. Within this category, perception was the most frequently examined theme (f=5), followed by insight (f=1) and imagination (f=1).

When all categories and themes are considered, the "Adaptation" and "Motivation and Interest" categories were the least frequently studied, each represented in 3 studies. In the "Adaptation" category, acceptance (f=2) and adjustment (f=1) were the subthemes identified. In the "Motivation and Interest" category, motivation appeared in 2 studies and interest in 1.

Overall, when the affective subcategories are evaluated, priority was given to studies focusing on attitudes. Of the 51 affective data points identified, eight were related to attitude. This was followed by self-efficacy (f=7), expectation (f=6), and perception (f=5). Studies in the other themes were comparatively fewer.

Table 2. Distributions of affective domains

Affective Domain Categories	Affective Domain Subcategories	f	Total
Motivation and Interest	Motivation	2	3
	Interest	1	
Values and Beliefs	Attitude	8	24
	Self-efficacy	7	
	Belief	2	
	Intention	3	
	Perceived Usefulness	2	
	Self-assessment	1	
	Self-belief	1	
Adaptation	Acceptance	2	3
	Adjustment	1	
Thoughts and Opinions	Perception	5	7
	Insight	1	
	Imagination	1	
Social and Emotional Factors	Expectation	6	14
	Confidence	3	
	Social Influence	3	
	Comfort	1	
	Anxiety	1	

3. Findings Regarding the Distribution of Studies by Mathematics Domains

To answer the question "What is the distribution of studies on TPACK in mathematics education by mathematics domains?", the 68 studies were examined in detail. The mathematics domains emphasized in the abstracts and content sections were identified and are presented in Table 3 under the heading "Mathematics Subdomains." The "Mathematics Categories" were grouped based on these subdomains for analytical clarity.

Among the 68 studies, 37 referred only to "mathematics" in general, without specifying subdomains. These were not assigned to any category in the table, nor were their frequencies increased.

The categories in Table 3 show that topics such as arithmetic operations, fractions, number patterns, exponents, and ratio-proportion were grouped under "Numbers and Operations." In algebra, studies addressed equations, inequalities, and matrices, in addition to those mentioning algebra in general. Frequencies for these were included under "Algebra (general)." Studies on probability and statistics were grouped under "Probability and Statistics." In the geometry category, subdomains included trigonometry, analytic geometry, Pythagorean theorem, polygons, and solid geometry. Studies that only referred to geometry were placed under "Geometry (general)." Similarly, some studies in the analysis category addressed specific subdomains such as functions, parabolas, limits, continuity, slopes, sequences, and series, while others referred only to "analysis." These were included under "Analysis (general)." The "Other" category included studies on topics outside the main mathematics categories, such as STEM, problems, philosophy of mathematics, and mathematical modelling.

In evaluating the studies, it was acknowledged that a single study could include multiple mathematics subdomains. In such cases, each subdomain was counted separately, with the frequency increased by one unit for each. Thus, the total frequency presented in Table 3 (f=74), together with those classified as mathematics (general) (f=37), does not match the total number of studies examined (f=68). Findings related to the question "What is the distribution of studies on TPACK in mathematics education by mathematics domains?" are presented in Table 3.

As seen in Table 3, the largest number of studies was conducted in the domain of "Geometry" (f=24). Within the 68 studies, 14 referred only to "geometry" without specifying subdomains, and these were categorized under geometry (general). The subcategories of geometry included trigonometry (f=4), analytic geometry (f=2), Pythagorean theorem (f=2), polygons (f=1), and solid geometry (f=1). The study in solid geometry focused specifically on pyramids.

The "Numbers and Operations" and "Analysis" categories had a frequency of 13. Within "Numbers and Operations," there were four studies on arithmetic operations, three on fractions, three on number patterns, two on exponents, and one on ratio-proportion. The four studies on arithmetic operations included one on numbers one on addition-subtraction, one on multiplication-division, and one on division only. In the "Analysis" category, subthemes included functions, parabola, analysis (general), limits, sequences and series, continuity, and slope. Functions (f=3) and parabola (f=3) were the most studied, with all three studies on functions focusing on linear functions. Two studies referred to analysis in general, and two focused on limits. Sequences and series, continuity, and slope were each addressed in 1 study.

In algebra, the frequency was 12, close to that of Numbers and Operations and Analysis. Of these, eight studies referred to algebra in general, 3 to equations and inequalities, and 1 to matrices. Among the three studies on equations and inequalities, two focused on linear equations and one on equations more generally.

Table 3. Distributions of mathematics domains

Mathematics Domain Categories	Mathematics Domain Subcategories	f	Total
Numbers and Operations	Operations with Numbers	4	13
	Fractions	3	
	Number Patterns	3	
	Exponential Expressions	2	
	Ratio-Proportion	1	
Algebra	Algebra(general)	8	12
	Equations and Inequalities	3	
	Matrix	1	
Probability and Statistics	Probability	5	7
	Statistics	2	
Geometry	Geometry (general)	14	24
	Trigonometry	4	
	Analytic Geometry	2	
	Pythagorean Theorem	2	
	Polygons	1	
	Solid Geometry	1	
Analysis	Functions	3	13
	Parabola	3	
	Analysis (general)	2	
	Limit	2	
	Sequences and Series	1	
	Continuity	1	
	Slope	1	
Other	STEM	2	5
	Problems	1	
	Philosophy of Mathematics	1	
	Mathematical Modelling	1	

The least studied domain was "Probability and Statistics," with seven studies, of which five were on probability and two on statistics.

Finally, the "Other" category included two studies on STEM, one on problems, one on philosophy of mathematics, and one on mathematical modelling. The study on mathematical modelling was conducted with high school students.

Overall, Table 3 shows that 74 studies addressed mathematics subdomains. The table did not include the 37 studies that referred only to mathematics in general without specifying subdomains. Aside from these, the highest frequency was found in the "Geometry" category, followed by "Numbers and Operations" and "Analysis" (f=13 each). These were followed by "Algebra" (f=12) and "Probability and Statistics" (f=7).

Discussion

This section presents discussion based on the findings obtained from the analysis of 68 studies on TPACK in mathematics education published between 2020 and 2024, identified through ScienceDirect, Wiley Online Library, Taylor & Francis, Springer Link, and Web of Science. Discussions are provided in order of the findings regarding cognitive and affective domain themes and the mathematics domains addressed in the studies.

The review of mathematics education research focusing on TPACK reveals that relatively greater emphasis has been placed on cognitive domain themes than affective ones. Within the cognitive domain, studies were heavily concentrated on the "Knowledge and Thinking" category, especially the "Knowledge" theme (f=21). This suggests that TPACK research in mathematics education has prioritized students' ability to acquire, process, and recall mathematical knowledge. Although other cognitive aspects such as skills, performance, and creativity were addressed, the lower frequency of studies in these areas indicates that higher-order processes like analysis, synthesis, and creativity remain underexplored. Therefore, future research should examine how TPACK can effectively support critical thinking, problem-solving, and application-based learning in mathematics.

Although fewer in number, studies focusing on affective domain themes nonetheless make an important contribution to the TPACK literature. Among the affective categories, "Value and Belief" was the most emphasized, with the subtheme of attitude (f=8) being the most frequently coded, followed by self-efficacy (f=7). In contrast, "Motivation and Interest" and "Adaptation" were the least represented. This indicates that TPACK-related mathematics education research has not sufficiently addressed these themes. Moreover, the findings confirm that affective components such as expectation and perception are essential for technology-integrated mathematics instruction.

In general, frequency distributions strongly emphasize the cognitive domain, though affective factors such as attitude and self-efficacy also hold significant importance. These findings align with Saharuddin and Kamsin (2023), who demonstrated that the TPACK approach influences students' cognitive knowledge and affective motivation. It is evident that while cognitive themes dominate, more attention should be given to affective factors in future TPACK research.

Regarding mathematics domains, the largest number of studies focused on "Geometry." This can be attributed to the suitability of geometry teaching for technology integration through visual and interactive tools. Widely available dynamic geometry software, such as GeoGebra, Desmos, Cabri Geometry, and Sketchpad, facilitates technology-supported instruction and encourages teachers to adopt such approaches. Cantürk Günhan and Açan (2016) also noted the effectiveness of dynamic geometry software in improving geometry achievement.

Similarly, Erdem's (2024) review of TPACK-themed theses revealed that most were concentrated in mathematics education, with calculus—particularly the topic of derivatives—being the focus of many studies. These findings indicate that the TPACK framework is effectively applied in general mathematics education and in teaching specific mathematical topics. Moreover, the scope of research on mathematics subdomains continues to diversify.

These findings also reveal the original contribution of the present research when compared with previous studies in the literature. Although the study by Baydar Işık (2021), which examined TPACK studies in mathematics education between 2009 and 2020, provided a comprehensive analysis of methodological trends for that period, it did not classify the studies according to cognitive and affective domain themes nor evaluate their trends based on sub-disciplines of mathematics. Moreover, the absence of any recent national or international research that holistically addresses these dimensions in the post-2020 period indicates a gap in the literature. Therefore, by examining TPACK studies conducted between 2020 and 2024 within the context of both cognitive/affective domain themes and mathematical subfields, the present study fills this gap and offers a current and comprehensive perspective to the literature.

Pedagogical Implications

- The review shows that few studies have focused on cognitive and affective subdomains in TPACK-related mathematics education research. More studies addressing these areas are recommended to fill this gap in the literature.
- Cognitive domain studies have been more prevalent than affective ones. Research that explores affective dimensions and studies integrating both would contribute more comprehensively to the literature.
- Within the mathematics domains, probability and statistics were relatively underrepresented. Greater focus on these areas in future studies would further enrich the field.

Ethical Statement of the Study

It has been undertaken by the authors of this study that the scientific, ethical and citation rules have been followed in the writing process of the study titled "A Review of Studies on Technological Pedagogical Content Knowledge In Mathematics Education"; no falsification has been made on the collected data, "Academia Journal of Educational Research and Editor" has no responsibility for any ethical violations to be encountered, all responsibility belongs to the author (s) and the study has not been sent to any other academic publication environment for evaluation

Conflict of Interests

There is no potential conflict of interest between the authors in the publication of the study.

Author Contribution

The corresponding author of this study contributed 60% of the research, and the second author contributed 40%.

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Data Availability

Data are available upon reasonable request from the corresponding author.

Ethical Approval

Since the research is not a case study or a study conducted on any participant group, and since it is a study in which researches that are open to the access of all researchers and readers are used and examined as documents, ethics committee permission was not required.

Consent for Publication

The publication of this study has been approved by all authors.

Artificial Intelligence Statement

No artificial intelligence tools were used during the writing of this study.

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