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Digital applications in mathematics learning for secondary school students: A systematic literature review

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Abstract

Technological advancements have progressively integrated digital applications into mathematics learning at the secondary level, providing students with interactive tools to support learning and feedback. However, the existing literature presents heterogeneous pedagogical approaches and dispersed results, making it difficult to understand under which conditions these tools generate educational benefits. This systematic literature review aims to analyze recent scientific literature on the use of digital applications in mathematics learning among secondary school students. Using the preferred reporting items for systematic reviews and meta-analyses methodology, 49 studies published between 2020 and 2024 were identified and analyzed across three databases: Web of Science, Scopus, and Springer. The analysis enabled the identification of five major analytical dimensions: (1) types of digital applications employed, (2) teaching methodologies adopted, (3) reported impacts on learning outcomes, (4) implementation challenges, and (5) theoretical models underpinning technological integration. The findings show that active learning methodologies, collaborative work, and problem-based learning are the most effective when combined with interactive simulations, gamification, and augmented/virtual reality tools, enhancing students' understanding of abstract mathematical concepts and generating greater cognitive benefits. In the absence of such pedagogical intentionality, their use tends to be superficial. As the main contribution, this review proposes an integrated analytical framework that classifies current practices, identifies critical gaps, and offers concrete guidance for the pedagogical selection and implementation of digital applications in secondary mathematics education.

Keywords: digital applications, learning, mathematics, students, secondary school

INTRODUCTION

Secondary education has consistently faced various challenges in recent decades, with the most significant being the COVID-19 lockdown in 2020. This phenomenon accelerated the transition toward hybrid learning environments and increased the use of digital technologies and virtual settings in teaching and learning processes (Malpartida Gutiérrez et al., 2021). In this new reality, digital applications ceased to be merely supplementary resources and became central components of pedagogical design, particularly in mathematics. Mathematics is an essential component of secondary education, and its learning contributes to the integral development of students by strengthening logical reasoning, fostering critical thinking, and developing problem-solving skills (Pulla Vásquez et al., 2023). These ideas reinforce the need to understand how digital applications are integrated into mathematics learning among secondary school students, where the goal is the consolidation of advanced cognitive competencies.

Mathematics, an essential component of secondary education, is perceived by students as an abstract subject sometimes even difficult, detached from reality, or disconnected from their everyday experience which

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Contribution to the literature

- This research proposes an original integrated analytical framework that multidimensionally articulates the types of applications, teaching methodologies, cognitive impacts, implementation challenges, and theoretical foundations in secondary mathematics education.
- Unlike previous reviews, this study offers a comprehensive systematization of post-pandemic literature (2020-2024), analyzing how digital tools act as cognitive mediators that transform the representation and visualization of abstract concepts.
- The article identifies critical gaps in current research, such as the lack of pedagogical validation for artificial intelligence and immersive technologies, offering strategic guidelines for informed decision-making in teaching practice and educational policies.

affects their motivation and engagement in the area (Guerrero Farinango et al., 2024). In the current context, Latin American countries that have integrated information and communication technologies (ICT) have demonstrated improvements in educational quality and equity (Aguerrondo et al., 2007). Digital applications provide opportunities for abstract mathematical concepts to become more visual, manipulable, and meaningful through simulations, dynamic modeling, problem solving, and the promotion of critical thinking (Vélez Vera & Rivadeneira Loor, 2023). Likewise, digital applications aim for greater alignment between pedagogical practices and the cognitive characteristics of today's students, who have developed an innate familiarity with digital technologies (Alsina & Salgado, 2022; García Paredes et al., 2023).

After the pandemic, educational technologies remained in place and became more prominent, reshaping the way students construct, model, and represent mathematical knowledge. In current secondary education, it can be observed that students have limited exposure to manipulating concrete or physical environments; instead, cognitive activity is now centered on visualization, modeling, simulation, and digital exploration processes. To understand this new reality, it is necessary to draw upon theoretical frameworks that help explain how students connect, activate, and organize their conceptual networks within environments where cognitive information processing occurs and technology is present. In this regard, the fuzzy cognitive maps (FCMs) approach proposed by Lepore (2024) offers a holistic perspective for modeling cognitive dynamics in mathematics teaching within digital environments. This framework enables a deeper understanding of learning processes and is connected to digital applications, highlighting digital games, collaborative learning tools, and formative assessment.

However, the integration of technology into mathematics education does not guarantee meaningful learning. Achieving this requires alignment with pedagogical foundations. Constructivism considers digital applications as environments in which students actively construct their knowledge through teacher guidance and active participation (Bueno et al., 2021). The technological pedagogical content knowledge (TPACK) model integrates technological, pedagogical, and disciplinary knowledge (Krieglstein et al., 2022). Similarly, cognitive load theory (CLT) suggests that certain digital designs may increase extraneous load and hinder the construction of meaningful schemas; therefore, it requires the careful planning of activities and tasks, and it enables a deeper understanding of learning processes (Hillmayr et al., 2020; Krieglstein et al., 2022). These perspectives establish the analytical foundations that guide the present review.

The integration of digital applications in the learning process has become a fundamental tool for improving mathematical understanding (Bacca et al., 2014). However, despite the growing interest in digital applications, the available evidence shows significant limitations, including persistent questions about the teaching models and methods employed by teachers when incorporating these tools, as well as their effectiveness in educational content (Marín-Campos, 2023). Some studies have analyzed specific applications, such as GeoGebra (Hidayat et al., 2023), virtual reality (VR) resources (Andrade, 2024), gamification strategies (Vergara Rodríguez et al., 2024), or the Ariadne tool, which supports mathematics learning (Sümmermann et al., 2021). Nevertheless, there is no systematization that integrally articulates the type of application, the didactic methodology, the theoretical framework to which it belongs, and the impacts on mathematical learning in secondary education. Some reviewed studies cover partial dimensions: Bano et al. (2018) focused on mobile learning without delimiting the educational level; Hillmayr et al. (2020) conducted a broad meta-analysis on educational technologies without addressing emerging practices or recent cognitive perspectives; Sunzuma (2023) centered the analysis on geometry without encompassing curricular diversity or the post-pandemic context; Memari and Ruggles (2025) examined artificial intelligence (AI) in primary education; Vidak et al. (2023) explored the use of augmented reality (AR); and Hernández-Martínez et al. (2025) analyzed the impact of ICTs on mathematical competencies.

The limitations presented reveal the absence of research offering an updated synthesis that considers the new pedagogical configuration developed after 2020 and that integrates, in a multidimensional manner, the technological, pedagogical, and cognitive aspects involved in the integration of digital applications in mathematics. This gap justifies the need for a new systematic review focused on secondary education and guided by contemporary conceptual frameworks capable of capturing the complexity of mathematical learning in current digital environments.

In response to this existing gap, the present study proposes an original contribution through the development of an integrated analytical framework. We examine existing literature primarily from the Americas and Europe, relating five key dimensions identified in the literature: types of digital applications, pedagogical methodologies employed, cognitive and affective impacts, implementation challenges, and theoretical foundations used. Unlike existing reviews, this approach enables an understanding not only of which applications are used, but how and under what conditions they contribute to mathematics learning in secondary education, providing a conceptual framework that can guide future research and support informed pedagogical decision-making.

The objective of this systematic review is to rigorously analyze recent scientific literature produced between 2020 and 2024 on the use of digital applications in mathematics learning among secondary school students, identifying trends, gaps, and relevant conceptual relationships in the field. It combines a selection process guided by PRISMA with qualitative coding and a structured data matrix (ATLAS.ti), producing a replicable taxonomy of digital applications, teaching methodologies, reported impacts, and limitations in secondary mathematics education.

Based on the above, the following research questions (RQs) are proposed:

RQ1. What types of digital applications have been used in mathematics learning in secondary education?

RQ2. What teaching methodologies accompany the use of digital applications in the reviewed studies?

RQ3. What results or impacts do the studies report regarding mathematics learning when digital applications are used?

RQ4. What limitations or challenges are identified in the implementation of digital applications in the classroom?

RQ5. What theoretical or pedagogical models support the use of digital applications in mathematics teaching in secondary education?

LITERATURE REVIEW

Conceptualization of Digital Applications in Mathematics Education

Digital applications, software systems designed to optimize educational processes through interactive, visual, and feedback-oriented functions, are capable of adapting to different pedagogical purposes thanks to their modular architecture (Filippi et al., 2016). In the educational field, these tools act as strategic mediators of learning by facilitating interaction with content and promoting student engagement (Asqui Lema, 2024). Likewise, they provide visual and interactive environments that support the understanding of complex mathematical concepts (Schneider & Battestin Nunes, 2020).

In mathematics, digital applications allow the exploration of dynamic representations, experimentation with algebraic or geometric objects, and the reception of immediate feedback, which fosters the construction of meanings or abstract concepts, as well as the development of problem solving skills (Moliner et al., 2022). From this perspective, digital applications constitute a cognitive environment rather than merely an instrumental resource by reorganizing the ways in which students interact with mathematical knowledge.

Pedagogical Dimensions of Digitally Mediated Mathematical Learning

Mathematical learning involves processes of conceptual understanding, skill development, strategy application, and continuous feedback (Patil & Chandankhede, 2022). The consolidation of these processes requires experiences of meaningful interaction with mathematical ideas. Social participation among students strengthens understanding by allowing them to discuss methods and compare procedures (Brodie, 2022).

Digital applications enhance these processes by facilitating active learning in environments of exploration, visualization, and experimentation, where students manipulate mathematical representations, models, and observe their transformations (Moliner et al., 2022). However, the effectiveness of these tools depends on pedagogical planning, clarity of objectives, and teacher mediation, given that technology alone does not guarantee the construction of deep or meaningful learning (Martínez Perea, 2022). Teacher guidance is essential to direct digital interaction toward meaningful understanding (Pulla Vásquez et al., 2023).

Theoretical Frameworks Explaining Digital Integration in Mathematics

Constructivism and interactive learning

Constructivism posits that students construct knowledge through the interaction between prior

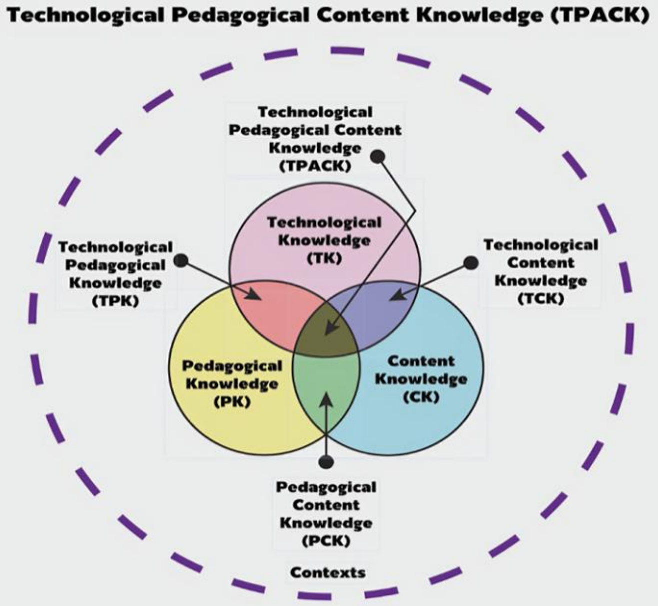

Figure 1. TPACK model (Adapted from Bueno et al., 2021).

experiences and new representations (Wilkie, 2011). In digital environments, this theory explains how applications facilitate knowledge construction by enabling the exploration of concepts, the formulation of hypotheses, and the modeling of mathematical relationships (Bueno et al., 2021). Digital tools that support direct manipulation, such as dynamic environments, strengthen conceptual understanding and representational reasoning (Moliner et al., 2022). However, teacher mediation is necessary to ensure that exploration leads to meaningful learning (Carrillo, 2021).

TPACK model and the pedagogical-technological integration of mathematical content

The TPACK model describes how teachers articulate technological, pedagogical, and disciplinary knowledge (see **Figure 1**) to effectively integrate digital applications into instruction (Bueno et al., 2021). In mathematics, this model helps explain how teachers connect mathematical concepts with digital functions, structuring tasks and activities that promote mathematical thinking (Li et al., 2023). Teacher mastery of TPACK facilitates the design of innovative strategies that enhance conceptual understanding and promote the meaningful use of applications and virtual environments (Patahuddin et al., 2016). Its implementation fosters the development of mathematical and critical thinking among students (Zhang et al., 2024). When this integration is weak, pedagogical impact is reduced, demonstrating the importance of coherent planning aligned with student needs (Del Cerro Velázquez & Méndez, 2021).

CLT and the design of digital environments

CLT posits that learning depends on the efficient management of working memory, particularly in contexts where multiple stimuli are presented simultaneously (Krieglstein et al., 2022). In digital environments, well-designed applications reduce extraneous cognitive load through clear interfaces, structured tasks or activities, and meaningful visual representations (Skulmowski & Rey, 2020). This allows students to allocate cognitive resources to more demanding processes such as problem-solving and mathematical modeling. Conversely, applications with distracting elements may hinder learning, highlighting the need for careful planning of digital interactions (Bagossi et al., 2022). This perspective underscores the importance of instructional design to prevent cognitive overload that may limit comprehension (Hernández Sánchez et al., 2023).

FCMs and the dynamics of mathematical learning

Lepore (2024) proposes a holistic framework based on FCMs to model cognitive dynamics in mathematics education. This approach acknowledges that digital mathematical learning involves dynamic, nonlinear, and highly interconnected changes among concepts. FCMs make it possible to understand how digital applications influence the activation, modification, and consolidation of mathematical ideas, particularly in contexts where simulation, visualization, and exploration reshape students' information-processing patterns. Digital applications present accessible concepts, worked examples, and abstract ideas through interactive media in order to optimize working-memory use and enhance learning (Krieglstein et al., 2022; Skulmowski & Rey, 2020).

Theoretical Articulation: Toward an Integrated Analytical Approach

Understanding mathematical learning mediated by digital applications requires the integration of the theoretical perspectives previously discussed as follows:

1. Constructivism explains how students construct meaning through interaction with digital applications.
2. The TPACK model provides a lens to analyze how technological integration is planned and managed according to mathematical learning goals.
3. CLT allows for assessing the design of digital interfaces and tasks and their impact on cognitive processing.
4. The FCM approach offers an explanatory view of the cognitive dynamics that emerge when students interact with digital environments.

Together, these perspectives underpin the integrated analytical framework guiding this systematic review, enabling a comprehensive understanding of the relationships among application types, teaching methodology, learning impact, and theoretical grounding.

Table 1. Descriptors

Descriptor	Synonym/keywords in Spanish	Keywords in English
Descriptor 1: Digital applications	Aplicaciones digitales, aplicaciones, aplicaciones educativas, herramientas digitales	Digital applications, applications, educational apps, digital tools
Descriptor 2: Mathematics learning	Aprendizaje de la matemática, matemática, educación matemática	Mathematics learning, math/mathematics, mathematics education
Descriptor 3: Secondary education	Educación secundaria, escuela secundaria	Secondary education, high school

State of the Art and Theoretical Gaps in Previous Reviews

Previous reviews have examined specific areas related to the use of technology in mathematics, such as mobile learning (Bano et al., 2018), the impact of digital tools on performance (Hillmayr et al., 2020), technological integration in specific content areas such as geometry (Sunzuma, 2023), AI in primary education (Memari & Ruggles, 2025), AR (Vidak et al., 2023), and the impact of ICTs on mathematical competencies (Hernández-Martínez et al., 2025).

However, these reviews present important limitations as follows:

1. They do not focus exclusively on secondary education students.
2. They do not address the post-pandemic period (2020-2024), characterized by accelerated expansion of digital application use.
3. They do not simultaneously integrate application type, methodology, impact, and theoretical grounding.
4. They do not incorporate emerging cognitive perspectives such as the FCMs proposed by (Lepore, 2024).

These gaps justify the need for a focused, updated, and multidimensional systematic review on the use of digital applications in mathematical learning in secondary education. Collectively, the theoretical framework establishes the conceptual, pedagogical, and cognitive foundations required to understand the role of digital applications in mathematics learning. It also identifies relevant gaps in previous reviews and supports the development of an integrated analytical approach that guides the RQs and interpretation of findings.

METHODOLOGY

This study was conducted through a systematic literature review, understood as a rigorous and structured method for identifying, evaluating, and synthesizing previous research on an educational phenomenon (Crisol-Moya et al., 2020). The review followed the preferred reporting items for systematic reviews and meta-analyses (PRISMA) methodology, which organizes the process into the phases of identification, screening, eligibility, and inclusion, ensuring transparency and traceability (Moher et al., 2009; Urrútia & Bonfill, 2010).

The review was carried out between November 11 and 20, 2024, and covered publications from 2020 to 2024. This period was selected due to the substantial increase in the use of educational technologies following the pandemic, based on systematic review protocols and using high-impact databases such as Web of Science (WoS), Scopus, and Springer. Two researchers independently participated in the study selection and coding process, resolving discrepancies through consensus, which increases the reliability of the procedure, as suggested by (Sánchez-Meca & Estrada Lorenzo, 2010).

Planning Stage

In this initial stage, the research problem and topic were defined using thesauri to ensure semantic precision. A preliminary search was conducted to verify the existence of a systematic literature review using the search equation: "revisión sistemática" AND "aplicaciones digitales" AND "matemática," and none were found. Subsequently, a search protocol was developed, considering the descriptors (see **Table 1**). Descriptors were used in both Spanish and English and were associated with three central constructs: digital applications, mathematics learning, and secondary education.

To ensure the quality of the review, validity was assessed through internal controls (protocol compliance) and external controls (selection of peer reviewed articles). To minimize selection bias, inclusion and exclusion criteria were defined as a priori (see **Table 2**), prior to beginning the search, and were applied systematically during the screening process. The criteria considered included:

1. Including studies that examine the use of digital applications in the teaching and learning of mathematics at the secondary level.
2. Excluding articles that were not peer-reviewed or that did not focus on the teaching and learning context.

Peer-reviewed empirical studies examining the use of digital applications in mathematics learning among secondary school students were included. Documents not indexed as scientific articles and studies focused on other educational levels or disciplines were excluded.

Table 2. Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Document type	Articles	Proceedings, theses, conferences, instruments
Access	Open	Paywalled or without author permission
Period	2020-2024	Out of range
Population	Secondary school students	Students with special educational needs and students from other educational levels
Area	Mathematics	Physics, chemistry, biology, and other areas
Results	Research focused on secondary students in relation to learning mathematics using digital applications	Exclude studies that do not directly address the use of digital applications or similar approaches to research

Table 3. Search equations used

Database	Search equation
WoS	((“Applications” OR “digital applications” OR “educational apps” OR “digital tools”) AND (“math” OR “mathematics learning” OR “mathematics education”) AND (“secondary education” OR “high school”))
Scopus	TITLE-ABS-KEY ((“Applications” OR “digital applications” OR “educational apps” OR “digital tools”) AND (“math” OR “mathematics learning” OR “mathematics education”) AND (“secondary education” OR “high school”))
Springer	TITLE-ABS-KEY ((“Applications” OR “digital applications” OR “educational apps” OR “digital tools”) AND (“math” OR “mathematics learning” OR “mathematics education”) AND (“secondary education” OR “high school”))

Open access was not used as a selection criterion; no article for which full text was available to the authors was included, regardless of its access modality.

Search Stage

The bibliographic search was conducted in WoS, Scopus, and Springer. These databases were selected due to their relevance in indexing studies in education, educational technology, and mathematics, as well as their inclusion of high-impact journals in these areas. However, we acknowledge that excluding databases such as ERIC or IEEE Xplore may limit the identification of studies related to our research.

To ensure the reproducibility of the study, as required by systematic review standards, the search strings (equations) and the specific filters applied in each database were documented (see **Table 3**). The search utilized specific thematic fields: TITLE-ABS-KEY in Scopus and TS (Topic Search: title, abstract, keywords) in WoS. In Springer, the advanced search tool was used with the same operators, recognizing that this platform does not always support identical structures to those used in Scopus. Searches were performed applying filters for language (English and Spanish), document type (peer-reviewed scientific articles), and time range (2020-2024).

Documentation Stage

The study selection process was carried out in three phases. First, duplicates were removed using Mendeley. Then, two reviewers independently screened the records identified (n = 727) by title and abstract. A broad inclusion criterion was applied to avoid discarding potentially relevant studies. Discrepancies were resolved through consensus. In the third phase, a full-text review was conducted, in which the preselected articles were examined in their entirety. Final inclusion decisions were made independently following the PRISMA 2020 flow. In cases where uncertainty persisted, a third researcher intervened to make the final decision.

A total of 727 records were initially identified. After removing 38 duplicates, 689 remained. During the initial screening, 550 were excluded for not aligning with the topic or educational level. Full-text review was conducted for 139 articles, of which 90 were excluded for not meeting the specific criteria. Ultimately, 49 studies were included for analysis. The entire process is summarized in the PRISMA diagram (see **Figure 2**).

Data Extraction and Coding

Data extraction was carried out using an Excel matrix that recorded: author, year, country, type of digital application, methodological approach, educational level, variables studied, results, challenges, and theoretical frameworks used. Subsequently, the data were coded in ATLAS.ti following a combined strategy: a deductive approach based on the five RQs and an inductive approach that allowed the identification of emerging subcategories not initially anticipated. Double coding by both researchers enabled the comparison of criteria, the unification of categories, and ensured consistency in the analysis, following good practices in qualitative thematic coding (Díaz-Iso et al., 2020).

Synthesis and Analysis

The synthesis of results was conducted at two complementary levels. First, a quantitative descriptive analysis was applied to identify general patterns in the frequency of applications, methodologies, countries, designs, and educational theories. Second, a qualitative

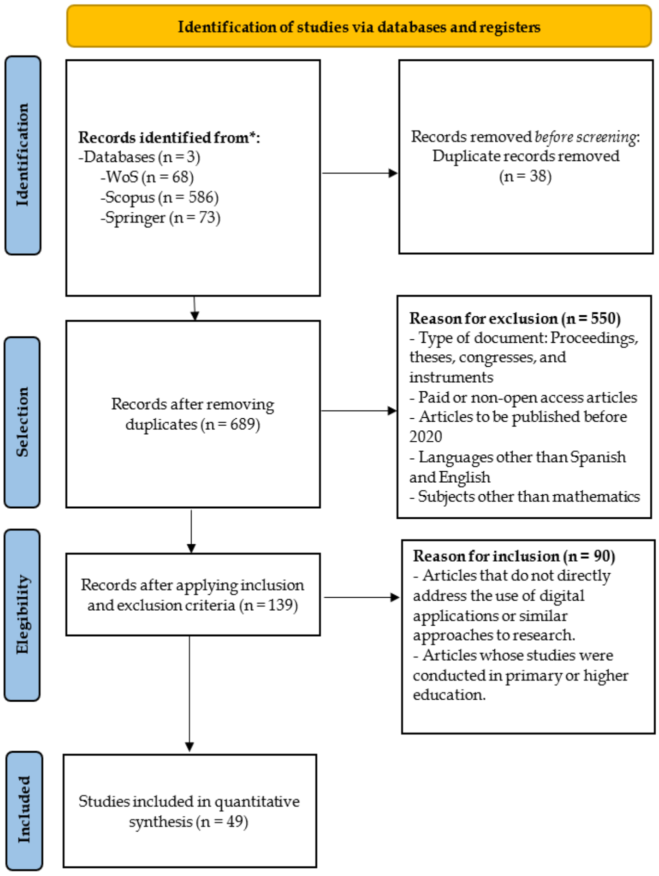

Figure 2. PRISMA flow diagram (Source: Authors' own elaboration)

thematic analysis was developed, based on the RQs with an inductive approach, allowing us to identify patterns, recognize pedagogical trends, cognitive and affective impacts, implementation challenges, and underlying theoretical frameworks. This process led to the development of an integrated analytical framework that articulates the dimensions identified in the recent literature on digital applications in secondary mathematics education.

To ensure methodological rigor, decisions regarding inclusion, exclusion, and coding were documented, and potential limitations were acknowledged, such as the absence of gray literature or the restriction to three databases. However, the structured selection process, the double independent review, and the combined use of descriptive and thematic analysis strengthen the validity and reliability of the review.

RESULTS

Considering the methodology outlined above, the following section presents the results obtained after analyzing the existing literature.

Geographic Distribution of the Studies

This systematic literature review on the use of digital applications in mathematics shows a diverse geographic distribution (see **Figure 3**). The highest frequency of studies is observed in Spain (4 studies), followed by Germany, the USA, and Italy (with 3 studies each). The next group includes Vietnam, Wales, Malaysia, Israel, France, Turkey, Sweden, Austria, and Indonesia, with 2 studies each. Finally, countries such as Argentina, Chile, Mexico, the Netherlands, Portugal, Colombia, England, Palestine, Norway, and Greece contributed 1 study each. This distribution reflects a broad global interest in integrating technological tools into secondary education, with a concentration in a few leading countries in the field.

Analysis of Publication Years

According to the analysis of the publication years, the highest number of studies was recorded in 2024, with a total of 16 publications, indicating a growing trend. In 2023, 11 studies were reported, while 2022 and 2021 registered 9 and 8 studies, respectively. The year 2020 showed the lowest number, with only 5 publications. This progression demonstrates a sustained increase in frequency over the past few years, which could be related to a rising need or interest in the research area under study (see **Figure 4**).

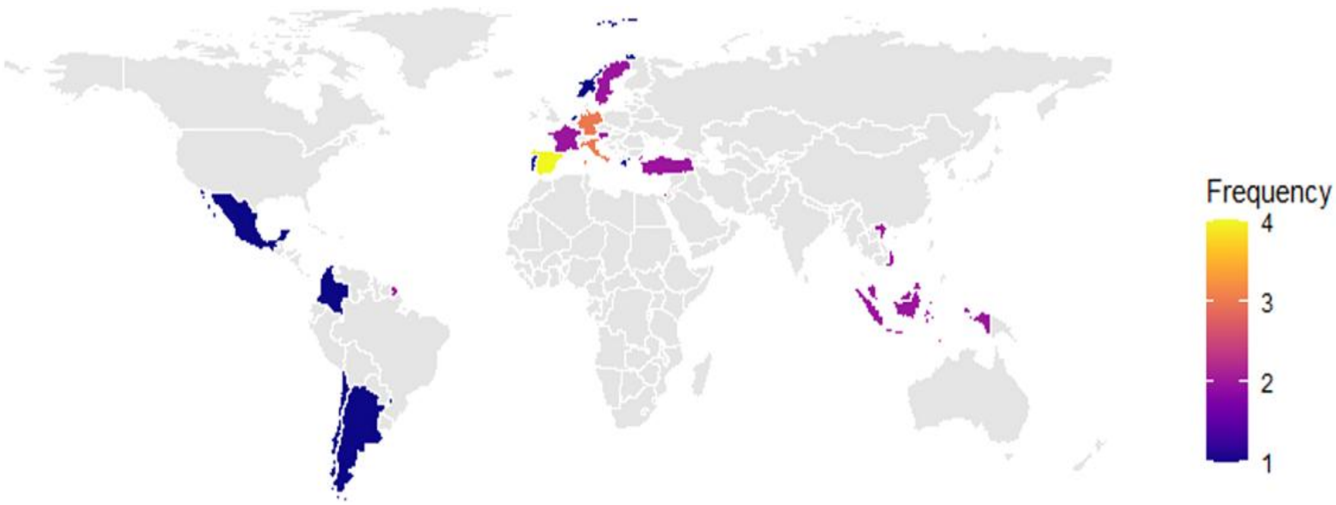

Figure 3. Geographic distribution of studies (Source: Authors' own elaboration)

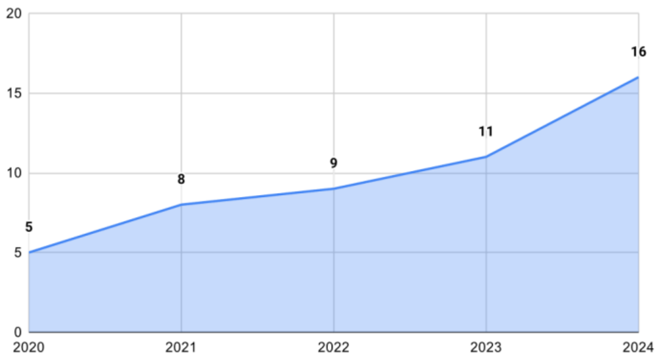

Figure 4. Years of publication (Source: Authors' own elaboration, using RStudio)

Overall, the data reflect a positive and consistent evolution over the last five years. We present the results derived from the analysis of the existing literature:

RQ1. What types of digital applications have been used in secondary mathematics learning?

Across the literature reviewed specifically the 49 articles included in our analysis–it was found that the digital applications used in secondary mathematics learning can be grouped into seven main categories: dynamic and symbolic mathematics software; virtual learning environments (VLEs); AI tools; AR and VR resources; gamification applications; video platforms and digital reinforcement environments; and programming and computational thinking tools. Dynamic and symbolic applications constitute the predominant category, aligning with studies that highlight their capacity to support interactive visualization, modeling, and the representation of algebraic and geometric relationships (Hidayat et al., 2023; Viberg et al., 2023). In contrast, tools related to computational thinking show lower representation despite their increasing curricular relevance (Laina, 2024).

The review reveals a clear tendency toward technologies that incorporate dynamic and symbolic applications (Viberg et al., 2023), as they enable improved representation, direct manipulation, and consequently, enhanced understanding of abstract concepts. These features align with constructivist approaches that encourage exploratory student activity (Zulfiani et al., 2023). However, there is a substantial gap between the use of dynamic applications and the adoption of AR or VR tools, largely due to infrastructural needs and constraints. We also highlight the case of AI based applications: despite their recent surge, students do not show clear preferences or consistent use of any particular tool in their learning process, given the abundance of options and the still limited body of knowledge regarding their role in mathematics education. This pattern reflects an uneven adoption of emerging technologies and underscores the need for research that examines their pedagogical feasibility. **Table 4** summarizes these functional categories and their frequency in the literature.

RQ2. What teaching methodologies accompany the use of these digital applications in the reviewed studies?

The reviewed studies show a clear predominance of active and collaborative learning as the methodology most frequently associated with the use of digital applications, which aligns with constructivist

Table 4. Functional category of digital applications

Reference	f (%)	Functional category	Description	Action form
Artigue and Trouche (2021), Chytas et al. (2024), Dorner and Ableitinger (2022), Hidayat et al. (2023), Moliner et al. (2022), Mollakuqe et al. (2021), Nurjanah et al. (2020), & Viberg et al. (2023)	8 (30.8)	Dynamic and symbolic mathematics application	Applications where expressions, graphs, geometry, and algebra are manipulated in dynamic or symbolic environments.	GeoGebra, Symbolab, Cabri, Géometre, Aplusix, Cabri 3D, & Mathaid
Indrapangastuti et al. (2021) & Segal and Biton (2024)	2 (7.6)	VLEs	Platforms to manage and organize learning processes	WhatsApp & Moodle
Soesanto et al. (2022)	1 (3.8)	AI	Personalization of learning and individual learning generation	Generative AI (ChatGPT)
Angraini et al. (2024), Canbaz and Yalçin (2024), Del Cerro Velázquez and Méndez (2021), & Walkington et al. (2025)	4 (15.3)	AR and VR	Immersive experiences, spatial visualization of abstract concepts	GeoGebra AR, Microsoft HoloLens 2, Assemblr Edu, & Unity 3D + Vuforia SDK
Balda et al. (2024), Christopoulos et al. (2024), Fuentes-Cabrera et al. (2020), & Zulfiani et al. (2023)	4 (15.3)	Gamification and game-based learning	Game applications that motivate and challenge students in mathematical contexts.	Virtual 3D minigames, Mathigon, Escape Room, & MathSci 21st app
Jiménez et al. (2021) & Piedra and Reascos (2024)	2 (7.6)	Video platforms and digital educational content	Applications with audiovisual media for reinforcement	Educational videos & EdPuzzle

Table 4 (Continued). Functional category of digital applications

Reference	f (%)	Functional category	Description	Action form
Arroyo et al. (2022), Jablonski et al. (2023), Muliyana et al. (2024), & Weinhandl et al. (2023)	4 (15.3)	Technology-enhanced learning environments (TELEs)	Didactic environments with digital resources for contextualized mathematics teaching.	Wearable earning platform, TELEs, MathCityMap, & Molge
Laina (2024)	1 (3.8)	Programming and computational thinking applications	Solving computational mathematical problems and algorithmic reasoning.	Scratch

Table 5. Didactic methodologies using digital applications

Reference	f (%)	Category	Description
Arroyo et al. (2022), Christopoulos et al. (2024), Jablonski et al. (2023), Jiménez et al. (2021), Muliyana et al. (2024), Soesanto et al. (2022), Vergara Rodríguez et al. (2024), &Yung et al. (2020)	8 (13.5)	Gamification and game-based learning	Game elements to motivate learning & learning abstract concepts through gamification
Angraini et al. (2024), Arroyo et al. (2022), Jiménez et al. (2021), Kaufmann and Stenseth (2021), Nga et al. (2023), Nurjanah et al. (2020), Walkington et al. (2025), & Zulfiani et al. (2023)	8 (13.5)	PBL	Solving mathematical problems, exercises, and contextualized problems
Jablonski et al. (2023), Muliyana et al. (2024), & Tang et al. (2023)	3 (5)	Mobile learning	Use of mobile devices as a means of learning
Jiménez et al. (2021) & Soesanto et al. (2022)	2 (3.3)	Flipped classroom	Reviewing content before the in-person class
Arroyo et al. (2022), Artigue and Trouche (2021), Bagossi et al. (2022), Balda et al. (2024), Canbaz and Yalçin (2024), Fuentes-Cabrera et al. (2020), Indrapangastuti et al. (2021), Iqbal et al. (2022), Jablonski et al. (2023), Kaufmann and Stenseth (2021), Kefalis et al. (2024), Lyakhova and Neate (2024), Nga et al. (2023), Nurjanah et al. (2020), Walkington et al. (2025), Weigand et al. (2024), Zhong and Xia (2020), & Zulfiani et al. (2023)	18 (32.2)	Active and collaborative learning	Active participation of the student, individually or in groups
Biehler et al. (2024), Mollakuqe et al. (2021), & Zhong and Xia (2020)	3 (5.0)	PBL	Creating products or solving problems through integrated projects
Bagossi et al. (2022), Canbaz and Yalçin (2024), Hidayat et al. (2023), Iqbal et al. (2022), Jablonski et al. (2023), Nga et al. (2023), Nurjanah et al. (2020), Vélez and Rivadeneira (2023), Walkington et al. (2025), & Weigand et al. (2024)	10 (16.9)	Simulation	Interactive representation of various mathematical phenomena
Cevikbas and Kaiser (2021), Moliner et al. (2022), Mustafa et al. (2024), & Soesanto et al. (2022)	4 (6.7)	Intelligent tutoring	Adaptive learning based on the student's needs
Awang et al. (2024) & Barlovits et al. (2022)	2 (3.4)	Personalized learning	Adapting content to the rhythm and style of learning based on the student's needs

approaches that emphasize student engagement in the exploration and resolution of mathematical tasks (Canbaz & Yalçin, 2024; Zulfiani et al., 2023). This trend contrasts with the more limited presence of problem-based learning (PBL), which remains relevant but is less frequently linked to advanced digital applications, particularly in studies focused on traditional procedural tasks (Muliyana et al., 2024).

The comparative analysis reveals a gradual shift toward emerging methodologies such as simulation and gamification, which demonstrate motivational effects and support the contextualization of learning for students (Vergara Rodríguez et al., 2024). However, the adoption of personalized learning remains limited, despite the increasing use of applications incorporating AI. This gap indicates that technological availability does not always translate into pedagogical innovation, and that tensions persist between traditional approaches and methodologies centered on student autonomy. **Table 5** presents a detailed distribution of these methodologies.

RQ3. What outcomes or impacts do the studies report regarding mathematics learning when using digital applications?

The studies conclude that the use of digital applications enhances mathematical performance and conceptual understanding, particularly in geometry and algebra. This effect is consistent in research employing

Table 6. Results and impacts reported in mathematical learning with digital applications

Reference	f (%)	Category	Common results/impacts
Bagossi et al. (2022), Canbaz and Yalçin (2024), Cevikbas and Kaiser (2021), Christopoulos et al. (2024), Dorner and Ableitinger (2022), Fuentes-Cabrera et al. (2020), Hidayat et al. (2023), Indrapangastuti et al. (2021), Jablonski et al. (2023), Kaufmann and Stenseth (2021), Moliner et al. (2022), Mollakuqe et al. (2021), Muliyana et al. (2024), Nga et al. (2023), Rojas-Garcia et al. (2022), Viberg et al. (2023), Yung et al. (2020), & Zhong and Xia (2020)	18 (36.7)	Improvement in mathematical skills and academic performance	Significant increase in academic performance in areas such as geometry, algebra, and functions. Better conceptual understanding and spatial ability. Improvement in the use of mathematical software to solve problems.
Balda et al. (2024), Jiménez et al. (2021), Lyakhova et al. (2021), Lyakhova and Neate (2024), Muliyana et al. (2024), Piedra and Reascos (2024), Rojas-Garcia et al. (2022), Romano et al. (2023), Segal and Biton (2024), Vergara Rodríguez et al. (2024), & Weinhandl et al. (2023)	11 (22.4)	Motivation, interest, participation, and positive attitudes	Increase in motivation, interest, and enjoyment. Increase in active participation and engagement with learning. Positive attitudes towards mathematics enhanced by audiovisual content and gamification.
Angraini et al. (2024), Arroyo et al. (2022), Biehler et al. (2024), Chytas et al. (2024), Kaufmann and Stenseth (2021), Laina (2024), & Nyman et al. (2024)	7 (14.3)	Computational thinking, programming, and digital skills	Improvement in algorithmic reasoning and programming skills. Increase in digital skills for solving mathematical problems.
Barlovits et al. (2022), Piedra and Reascos (2024), Segal and Biton (2024), Soesanto et al. (2022), Viberg et al. (2023), & Weinhandl et al. (2022)	6 (12.2)	Reduction of anxiety and emotional and collaborative support	Decrease in anxiety and fear towards mathematics. Greater confidence and security. Strengthening of collaborative work and social skills in learning.
Fuentes-Cabrera et al. (2020), Jiménez et al. (2021), Laina (2024), Lyakhova and Neate (2024), Moliner et al. (2022), & Nurjanah et al. (2020)	6 (12.2)	Autonomous learning, self-regulation, and metacognition	Increase in autonomy and ability to manage learning. Development of metacognitive skills and self-assessment.
Angraini et al. (2024), Canbaz and Yalçin (2024), Del Cerro Velázquez and Méndez (2021), Hidajat (2023), Iqbal et al. (2022), Lyakhova et al. (2021), Romano et al. (2023), & Walkington et al. (2025)	8 (16.3)	Immersive learning through AR/VR	Improvement in academic performance, spatial understanding, and motivation. Increased enjoyment and attention thanks to immersive experiences and spatial visualization.
Awang et al. (2024), Mustafa et al. (2024), Soesanto et al. (2022), & Weinhandl et al. (2022)	4 (9.2)	Effectiveness of adaptive systems and AI	Personalization of learning, improvement in adaptive performance and critical thinking. Reduction of anxiety through intelligent support.

dynamic software and simulations, where visual manipulation and representation support the comprehension of abstract ideas (Christopoulos et al., 2024). However, the results are not homogeneous. Some studies report significant improvements only when there is continuous teacher support, which challenges the notion that technology alone guarantees meaningful learning.

Regarding student motivation, gamification and audiovisual resources produce systematic increases in interest and active participation (Balda Álvarez et al., 2024) although some authors caution that these effects may be temporary and do not always lead to deep learning. Similarly, evidence on reducing math anxiety is mixed: while some investigations report decreased fear of errors and increased confidence, other findings suggest that the introduction of complex digital applications may generate additional stress in students with low digital literacy.

The development of computational thinking and digital skills emerges as a growing benefit, but one that is still underdeveloped in specific contexts, particularly those incorporating programming or AI. This issue reveals an important gap between the theoretical potential of these tools and their actual implementation in the classroom. **Table 6** summarizes these trends and variations across studies.

RQ4. What limitations or challenges are identified in the implementation of these tools in the classroom?

Based on the 49 articles reviewed regarding the use of digital applications in mathematics learning, it was

Figure 5. Main limitations and challenges in implementing digital applications in the classroom (Source: Authors' own elaboration through qualitative analysis with ATLAS.ti on the review of 49 articles on digital applications in mathematics education)

observed that integrating these tools into the classroom represents a considerable challenge in various situations, as it involves multiple considerations detailed below (see **Figure 5**).

The studies agree that the main limitations for implementing digital applications in the classroom stem from technical and pedagogical barriers. The difficulty in handling the tools and the absence of clear guidelines affect both teachers and students, leading to superficial use or dependence on the instructor (Balda Álvarez et al., 2024). The lack of teacher training is also reported as a recurring obstacle, especially when technological competencies beyond basic literacy are required (Benavides Piedra & Reascos, 2024).

Limited infrastructure constitutes another critical pattern. Unstable connectivity, scarcity of devices, and incompatibility across platforms reduce the continuity of digital activities and generate frustration in the learning process (Kefalis et al., 2024). Studies on AR and VR mention the usability difficulties that prevent fully leveraging the immersive potential of these technologies (Hidajat, 2023).

At the methodological level, several studies point to a gap between pedagogical design and the actual integration of applications. In many cases, digital resources are used as decorative complements rather than as a structural part of the teaching-learning process, which limits their formative impact (Chytas et al., 2024). This highlights that technology does not guarantee innovation by itself but depends on instructional decisions and continuous teacher support.

The reviewed studies show important empirical limitations. Several works rely on small samples, which hinders the generalization of findings to a broader level (Hidayat et al., 2023). Others warn that emerging applications, such as educational AI, still lack pedagogical validation and present ethical risks that must be investigated in greater depth (Mustafa et al., 2024).

Finally, student diversity introduces additional challenges. Differences in digital skills, math anxiety, and lack of self-regulation habits affect the effectiveness of digital applications in real contexts (Segal & Biton, 2024). The constant need for technical and pedagogical support reinforces that technological integration requires sustained school policies, active participation, commitment, and not merely isolated or superficial interventions (Muliyana et al., 2024).

RQ5. What theoretical or pedagogical models support the use of digital applications in secondary mathematics education?

The review shows a clear predominance of constructivism and related approaches, which underpin more than half of the studies analyzed. In these works, digital applications are conceived as environments for the active construction of knowledge, where students explore, manipulate, and reflect on mathematical concepts (Fuentes-Cabrera et al., 2020), particularly through dynamic software such as GeoGebra or interactive video resources like EdPuzzle (Jiménez et al., 2021; Moliner et al., 2022; Weinhandl et al., 2022). This pattern confirms the shift from transmission-based approaches toward student-centered models.

Second, the TPACK model appears as a key framework to explain how teachers articulate mathematical content, pedagogy, and technological resources when designing activities (Dorner & Ableitinger, 2022; Mustafa et al., 2024). Its presence is especially evident in studies analyzing the teacher's role and the planning of sequences involving AR/VR or VLEs, although systematic criteria for assessing the actual degree of integration are not always made explicit.

Other frameworks, such as connectivism and experiential or situated learning, are used less frequently, mainly in studies emphasizing networking, online collaboration, or contextualized experiences with mobile technologies and AR/VR (Christopoulos et al., 2024; Soesanto et al., 2022). More specific models, such as those based on gamification, simulation, or technology acceptance theories, tend to appear in isolation, suggesting a certain theoretical dispersion when addressing motivational, affective, or technology adoption aspects (Balda Álvarez et al., 2024; Hernández Sánchez et al., 2023).

Taken together, these findings indicate a field strongly grounded in constructivism, yet with a need for greater articulation among different frameworks to more fully understand the cognitive, emotional, and contextual effects of digital applications in mathematics education, see **Table 7**.

Table 7. Theoretical and pedagogical models supporting the use of digital applications

Reference	f (%)	TPM	Description
Angraini et al. (2024), Artigue and Trouche (2021), Bagossi et al. (2022), Biehler et al. (2024), Cevikbas and Kaiser (2021), Chytas et al. (2024), Del Cerro Velázquez and Méndez (2021), Fuentes-Cabrera et al. (2020), Hidayat et al. (2023), Indrapangastuti et al. (2021), Jiménez et al. (2021), Kaufmann and Stenseth (2021), Lyakhova et al. (2021), Moliner et al. (2022), Mollakuqe et al. (2021), Nga et al. (2023), Nurjanah et al. (2020), Segal and Biton (2024), Sümmermann et al. (2021), Viberg et al. (2023), Walkington et al. (2025), Weinhandl et al. (2022, 2023), Yung et al. (2020), & Zhong and Xia (2020)	24 (51.0)	Constructivism and related approaches	A model based on active learning, constructing knowledge through interaction and reflection. Includes cognitivism, self-directed learning, and phenomenology.
Artigue and Trouche (2021), Awang et al. (2024), Dorner and Ableitinger (2022), Fuentes-Cabrera et al. (2020), Hidajat (2023), Kefalis et al. (2024), Mustafa et al. (2024), Tang et al. (2023), Walkington et al. (2025), & Weigand et al. (2024)	10 (20.4)	TPACK model	A model that integrates pedagogical, technological, and content knowledge to optimize teaching with technology.
Artigue and Trouche, 2021), Bagossi et al. (2022), Canbaz and Yalçin (2024), Iqbal et al. (2022), Lyakhova and Neate (2024), Nyman et al. (2024), & Soesanto et al. (2022)	7 (14.3)	Connectivism	A theory emphasizing learning through networks and connections, especially in digital environments and social interactions.
Canbaz and Yalçin (2024), Jablonski et al. (2023), Rojas-Garcia et al. (2022), Romano et al. (2023), & Sümmermann et al. (2021)	5 (10.2)	Experiential and situated learning	Models that promote learning through direct and contextualized experience.
Christopoulos et al. (2024) & Vergara Rodríguez et al. (2024)	2 (4.1)	Game-based and gamification models	Models that use game mechanics to motivate and structure learning.
Balda et al. (2024) & Hernández Sánchez et al. (2023)	2 (4.1)	Didactic engineering and theory of didactic situations	Models that design and analyze teaching and learning situations in a planned and reflective manner.
Arroyo et al. (2022), Laina (2024), Muliyana et al. (2024), & Piedra and Reascos (2024)	4 (8.2)	Other specific models and methodologies	Models addressing specific aspects of learning, technology acceptance, and particular cognitive skills.

Note. TPM: Theoretical and pedagogical models & some studies apply more than one model, so the total may exceed 100%

A Proposed Integrated Analytical Framework

Based on the systematic analysis of the five central dimensions identified in this review types of digital applications, pedagogical methodologies, learning impacts, implementation challenges, and underlying theoretical models an integrated analytical framework was developed that synthesizes the recurrent patterns across the 49 studies reviewed.

The framework presented here (see **Table 8**) was developed through a process of comparative thematic coding, in which we identified emerging categories and the relationships among them. These categories were then cross-analyzed following a configurative synthesis approach, which allowed us to articulate in a structured manner how digital applications operate in secondary mathematics education and under what conditions they generate significant effects.

A central finding is that constructivism is present in a transversal manner and constitutes the predominant theoretical foundation. Its recurrence is not redundant; rather, it reflects a fundamental principle in technology-mediated mathematics education: the effectiveness of digital applications depends on their capacity to activate processes of active knowledge construction through exploration, manipulation, hypothesis formulation, and problem solving.

However, the framework also reveals the interdependence among theories:

1. Constructivism describes the student's cognitive activity.
2. The TPACK model explains teacher planning and meaningful didactic integration.
3. CLT guides the design of interfaces and digital tasks.

Table 8. Proposed integrated analytical framework for digital applications in secondary mathematics education

Type of application	Examples	Pedagogical methodologies	Learning impacts	Implementation challenges	Theoretical models	Pedagogical recommendations
Dynamic and symbolic mathematics software	GeoGebra, Symbolab, Cabri 3D, Aplusix, & Mathaid	Active and collaborative learning & simulation	Improves conceptual understanding of algebra and geometry, develops problem-solving skills, & strengthens spatial reasoning	Technical complexity, limited teacher training, & curricular misalignment	Constructivism & CLT	Design open-ended tasks that require modeling and conjecture, not only passive visualization
Gamification applications	Mathigon, MathSci 21st, Escape Rooms, & 3D Minigames	Gamification & PBL	Increases motivation and engagement, greater persistence in mathematical tasks, & reduction of math anxiety	Risk of superficial learning & lack of alignment with curricular objectives	Constructivism & connectivism	Align game mechanics with specific mathematical goals; avoid decorative gamification
AR/VR applications	GeoGebra AR, HoloLens, Assemblr Edu, & Unity 3D + Vuforia SDK	Simulation & experiential learning	Improves spatial understanding, increases attention and motivation, & immersive experiences that enrich abstract learning	High hardware costs, limited curricular content, & technical instability	Experiential learning & situated cognition	Use for abstract topics (functions, solids) and combine with structured instructional guides
AI-based tools	ChatGPT, adaptive tutors	Personalized learning & AI-assisted teaching	Adaptive feedback, promotes self-regulation, & emergence of critical thinking	Limited empirical evidence, ethical and privacy concerns, & lack of pedagogical validation	TPACK model & CLT	Use as a complement, not a substitute; integrate with formative assessment and teacher supervision
Video platforms and VLEs	Khan Academy, EdPuzzle, WhatsApp, & Moodle	Flipped classroom & collaborative learning	Student accessibility and autonomy, independent learning, & improved peer communication	Risk of passive consumption, digital distractions, & connectivity inequality	Connectivism & sociocultural theory	Combine with in-person or synchronous activities that promote discussion and application
Programming and computational thinking tools	Scratch & We are able learning	PBL & project-based learning	Development of algorithmic reasoning, strengthening of computational thinking, & digital literacy	High learning curve & few math-specific tasks	Constructivism & TPACK model	Integrate with authentic mathematical problems (modeling, simulation, patterns)

4. Situated cognition and experiential learning support immersive technologies such as AR and VR.

This convergence shapes a pedagogical framework that is essential for understanding how and why certain applications generate deep learning, whereas others produce only superficial engagement.

Likewise, the analysis identifies two structural challenges that affect all categories:

1. Insufficient teacher training in pedagogical integration beyond technical proficiency.
2. Misalignment between applications and national curricula, which limits their integration and sustainability.

Finally, this framework constitutes the main contribution of the review, as it offers an analytical tool applicable to teachers and researchers. In addition, it integrates the five RQs posed: the types of applications (**RQ1**), the associated methodologies (**RQ2**), the reported impacts (**RQ3**), the emerging challenges (**RQ4**), and the underlying conceptual foundations (**RQ5**).

Based on this articulation, we identify critical gaps such as the lack of pedagogical validation in AI tools and the limited longitudinal evidence in AR/VR.

DISCUSSION

The results of this systematic review provide insight into how digital applications have reconfigured the learning of mathematics in secondary education during the period 2020-2024. Overall, the 49 studies analyzed show that digital integration does not function merely as a complementary resource but as a cognitive mediator that transforms the ways students represent, visualize, and apply mathematical concepts in digital environments (Moliner et al., 2022). This shift demonstrates a pedagogical movement toward practices centered on mathematical modeling and decision-making supported by interactive visual environments (Vélez Vera & Rivadeneira Loor, 2023).

A central finding is the strong predominance of dynamic and symbolic mathematics applications such as GeoGebra, Aplusix, and Cabri 3D, which facilitate visual and symbolic manipulation and allow students to explore functions, geometry, and algebra through dynamic representations that strengthen conceptual and spatial reasoning (Hidayat et al., 2023). Their widespread use stems from their availability and coherence with the constructivist approach, which views learning as an active process of meaning construction through the manipulation of representations and guided exploration (Artigue & Trouche, 2021). However, emerging technologies such as AI and AR or VR still lack evidence, as they show uneven adoption due to technical limitations, infrastructure constraints, and weak curricular alignment (Walkington et al., 2024).

The review shows that active and collaborative learning is the most frequent methodology associated with the use of digital applications, aligned with sociocultural perspectives that emphasize interaction and the joint construction of meaning (Bagossi et al., 2022). Methodologies such as PBL, gamification, and simulation also present positive effects on mathematical understanding, as they help connect abstract concepts with meaningful experiences (Vergara Rodríguez et al., 2024). Despite this, differences persist between traditional practices and approaches that promote autonomy and personalization. AI applications show great potential, but their use remains limited in contexts with insufficient teacher training or low digital literacy.

Regarding impacts, the studies report consistent improvements in mathematics learning, concept visualization, and the development of mathematical skills, especially in geometry, algebra, and functions (Christopoulos et al., 2024). The incorporation of audiovisual and technological resources enhances motivation and attitudes toward mathematics (Balda Álvarez et al., 2024). However, these effects do not occur automatically. Several studies highlight that effectiveness depends on teacher support, didactic coherence, and the design of activities that guide digital exploration toward meaningful learning (Griffith et al., 2020). Moreover, complex digital tools may increase extraneous cognitive load and generate anxiety in students with low technological competence (Segal & Biton, 2024), which reinforces the importance of planning activities while considering CLT (Krieglstein et al., 2022; Lepore, 2024).

From a theoretical standpoint, the review confirms that constructivism is the dominant approach due to the exploratory nature of digital applications (Moliner et al., 2022). The TPACK framework is consolidated as a key structure for understanding how teachers articulate mathematical content, pedagogy, and technological resources during planning (Dorner & Ableitinger, 2022). Perspectives such as connectivism and the sociocultural approach support collaborative practices and experiences mediated by technology. A notable contribution of this review is the incorporation of the cognitive dimension of students' learning processes in technological environments proposed by Lepore (2024), which helps explain how digital applications reconfigure students' cognitive dynamics in visualization and simulation settings an aspect absent in previous reviews.

From a practical perspective, the findings show that the potential of digital applications depends on appropriate pedagogical conditions and structures. The literature agrees on the need to strengthen teacher training in the pedagogical integration of technology (Weinhandl et al., 2022), emphasizing that technological proficiency alone does not guarantee learning. In addition, limitations in infrastructure, connectivity, and access to devices are factors that affect the quality of digital experiences (Kefalis et al., 2024). Furthermore, the lack of curricular alignment continues to be an obstacle to the sustained implementation of emerging technologies.

Compared to existing reviews that address specific applications or partial approaches, this review offers an integrated analytical framework that articulates five dimensions: types of applications, methodologies employed, reported impacts, implementation challenges, and theoretical foundations in the current context. It incorporates emerging perspectives such as the cognitive dimension in technological environments, which guides teaching practice to transform mathematics instruction, extending the boundaries of previous studies.

The findings also have implications for educational policy. It is necessary to promote continuous professional development programs based on the TPACK model to strengthen the pedagogical integration of technology. Likewise, it is essential to implement digital equity policies–stable infrastructure, access to devices, and technical support–as these conditions determine the real effectiveness of digital applications in the classroom.

Finally, this review identifies future research directions. Real evidence is needed, including medium- and long-term experimental studies that examine the effects of digital applications on mathematics learning, the understanding of abstract concepts, the impact of AI applications, research in Latin American contexts, and studies that incorporate CLT in students. These ideas reaffirm that digital applications can improve mathematics learning as long as they are integrated into solid theoretical frameworks, appropriate methodologies, and well-planned instructional designs.

CONCLUSIONS

This systematic review demonstrates that digital applications–especially those based on simulation, AR/VR, and dynamic mathematics–have become central resources for enhancing conceptual understanding and mathematical reasoning in secondary education. Their effectiveness increases when integrated into active and collaborative methodologies, such as PBL and gamification, in alignment with constructivist approaches and with the TPACK model as a guide for instructional planning. The proposed integrated analytical framework synthesizes five key dimensions and constitutes the main contribution of this study by offering a conceptual tool to guide the selection and pedagogical use of digital applications. Challenges persist related to teacher training, infrastructure, and curricular alignment, as well as gaps in the literature on AI, immersive technologies, and longitudinal studies–areas that require particular attention in future research.

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