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Collaborative Learning Supported by Digital Technologies in Mathematics Education at the Secondary Level: A Systematic Literature Review

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Abstract. The growing integration of digital technologies in educational systems has heightened research interest in understanding how technology-mediated collaborative learning impacts mathematics instruction in secondary education. However, the scientific literature remains fragmented and lacks updated syntheses that systematically integrate the available evidence. This article presents a systematic literature review aimed at analyzing and synthesizing empirical evidence on collaborative learning supported by digital technologies in secondary mathematics education. Following the PRISMA 2020 guidelines, Scopus, Web of Science, and ERIC were consulted for the period 2020–2026. After a four-phase screening process, including methodological quality assessment, nine peer-reviewed empirical articles were selected. The results reveal a scientific production concentrated in Europe, North America, and Oceania, but limited representation from Latin America. Quantitative and quasi-experimental approaches predominate, alongside a growing presence of mixed methods designs. Socio-constructivism and the computer-supported collaborative learning framework underpin the majority of studies. Reported effects on mathematical performance and conceptual understanding are predominantly positive, although their magnitude depends on the degree of pedagogical structuring of collaboration, rather than technological sophistication. This study found that digital technology enhances collaborative learning in mathematics when pedagogical design explicitly structures interaction, shifting the research focus from technological efficacy to the pedagogical conditions of implementation.

Keywords: Collaborative learning; computer-supported collaborative learning; mathematics education; Secondary education; Digital technologies

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1. Introduction

In the digital era, technology has become a central component of educational systems, transforming traditional pedagogical practices, and redefining teaching and learning processes across all educational levels. In secondary education, this transformation has acquired particular significance in mathematics instruction, an area characterized by high levels of abstraction, persistent difficulties in conceptual understanding, and sustained gaps in academic performance. Research objects in mathematics education must be modeled, compared, redesigned, and critically examined, as they constitute crucial variables for determining student learning outcomes (Hochmuth et al., 2024). Several studies suggest that the integration of digital technologies can contribute to enhancing mathematics learning when combined with active, student-centered methodologies oriented toward meaningful social interaction (Burke et al., 2021).

Within this context, collaborative learning emerges as a key pedagogical strategy to maximize the educational use of technology. Collaborative learning is broadly understood as an instructional approach in which students work together to achieve shared learning goals, engaging in dialogue, negotiation, and co-construction of knowledge. Its pedagogical value lies in promoting social interaction, shared responsibility, and the development of higher-order thinking skills. In digital environments, collaborative learning is further enhanced by technological tools that support communication, shared representations, and both synchronous and asynchronous interaction, thereby extending learning beyond traditional classroom boundaries.

Recent evidence suggests that structured collaboration promotes the construction of shared meanings, the comparison of strategies, and the development of higher-order cognitive skills, particularly when digital tools facilitate the visualization and manipulation of mathematical objects (Aksu & Zengin, 2022; Mohammed & Bello, 2024). Furthermore, research on technology-supported mathematics learning suggests that peer interaction fosters deeper conceptual understanding and stronger mathematical reasoning compared to individualistic approaches (Demir & Zengin, 2023).

From a didactic perspective, the use of specific digital tools, such as virtual manipulatives and dynamic mathematics software, has demonstrated positive effects in teaching geometry and other mathematics content in secondary education. Empirical research shows that these resources allow abstract concepts to be represented visually and interactively, facilitating exploration, argumentation, and collective validation of solutions in collaborative settings (Aksu & Zengin, 2022; Mahmuti & Arifi, 2025). Correspondingly, collaborative work mediated by technology contributes to greater cognitive engagement and deeper learning when tasks are carefully designed and pedagogically structured.

Additionally, studies analyzing video-based learning environments and flipped learning approaches indicate that combining audiovisual resources with collaborative activities, whether in face-to-face or virtual settings, significantly improves mathematics achievement. Notably, students participating in collaborative flipped learning modalities achieve better outcomes than those working individually, provided that collaboration is guided and oriented toward clear mathematical learning objectives (Bakar et al., 2023; Demir & Zengin, 2023).

The rise of mobile learning (m-learning) has further expanded possibilities for collaboration and personalized mathematics learning in school contexts. Recent research indicates that mobile devices facilitate communication, idea exchange, and collaborative work, promoting more flexible and contextualized learning experiences (Burke et al., 2021; Gurmu et al., 2024). However, these studies also highlight that the impact of mobile learning depends on the pedagogical integration of technology and its alignment with specific curricular objectives in mathematics (Bakar et al., 2023).

Research focusing on cognitive and multimodal processes involved in mathematical collaboration also emphasizes the importance of shared visual attention, gestures, and social interactions during joint problem solving. Available evidence suggests that visual and gestural coordination among students, mediated by digital resources, enhances shared understanding and collective progress in complex mathematical tasks (Haataja et al., 2025; Walkington et al., 2026). These findings reinforce the notion that technology functions not only as a supportive tool but also as a mediator of collaborative processes essential for mathematics learning.

Despite the growing number of empirical studies, scientific literature presents significant limitations. Several investigations focus on specific tools or methodologies without systematically integrating findings on collaboration, technology, and mathematics learning, resulting in fragmented knowledge (Mahmuti & Arifi, 2025; Mohammed & Bello, 2024). Furthermore, studies examining digital collaboration in recent educational contexts, such as online learning, often emphasize general perceptions without sufficiently addressing the impact on mathematics learning in secondary education (Burke et al., 2021; Gurmu et al., 2024).

From a theoretical perspective, explanatory models in mathematics education provide essential frameworks for interpreting educational phenomena and supporting rigorous research, as they strengthen the link between theory and instructional practice. Pedagogical models, understood as structures that operationalize learning theories into practice, integrate methods, content, strategies, and pedagogical intentions. In the context of technology-mediated learning, these frameworks offer a basis for understanding how teaching and learning processes are designed and implemented in mathematics education.

A review of widely recognized international academic databases revealed the absence of systematic reviews published in the last five years that specifically synthesize evidence on collaborative learning supported by digital technologies in secondary mathematics education. A preliminary exploration of major academic databases (e.g., Scopus, Web of Science, and ERIC) suggested a limited number of recent systematic reviews specifically addressing collaborative learning supported by digital technologies in secondary mathematics education. Existing studies tend to focus either on technology integration or on mathematics learning independently, without systematically examining their intersection. This indicates the need for a more focused and updated synthesis of the available evidence. Accordingly, the present article adopted a systematic literature review (SLR) design following preferred reporting items for systematic reviews and meta-analyses (PRISMA) 2020 guidelines, aiming to provide a rigorous, transparent, and replicable synthesis of the available evidence.

Consequently, this study aimed to analyze and synthesize existing scientific evidence on collaborative learning supported by digital technologies in secondary mathematics education. Specifically, it sought to identify the studied educational populations, employed technologies, implemented collaborative strategies, and the main reported outcomes related to mathematics learning, participation, and interaction. To this end, the following research questions were posed:

- How has scientific production on collaborative learning supported by digital technologies in secondary mathematics education evolved over time and across geographical regions?
- What methodological approaches, research designs, and data collection instruments predominate in studies on collaborative learning supported by digital technologies in mathematics?
- Which theoretical frameworks and instructional strategies underpin the implementation of collaborative learning supported by digital technologies in mathematics education?
- What effects are reported on mathematics learning and associated variables, such as participation, interaction, motivation, and critical thinking, when collaborative learning mediated by digital technologies is implemented in secondary education?
- What methodological limitations and research gaps are reported in studies on collaborative learning supported by digital technologies in secondary mathematics education?

2. Literature Review

2.1 Collaborative Learning in Mathematics Education

Collaborative learning and cooperative learning are often used interchangeably in educational research; however, they represent distinct pedagogical approaches with different structures, objectives, and roles for teachers and students. Cooperative learning is typically defined as a highly structured instructional strategy in which students work in small, heterogeneous groups under clearly assigned roles and guided procedures, emphasizing positive interdependence and individual accountability (Chilan Bravo & Cedeño Loor, 2023).

In contrast, collaborative learning refers to a more flexible and student-centered approach, in which learners engage jointly in the co-construction of knowledge through dialogue, negotiation, and shared problem solving, with less rigidly defined roles and greater autonomy in the learning process. In the context of mathematics education, collaborative learning is particularly relevant as it promotes conceptual discussion, argumentation, and collective reasoning, which are essential for the meaningful construction of mathematical knowledge. For the purposes of this study, collaborative learning is understood as the broader framework within which different forms of group-based interaction, including structured cooperation, may occur.

Recent research has confirmed that cooperative learning produces positive effects on mathematics academic performance, especially when tasks require complex reasoning and negotiation of meanings. Structured cooperation enhances not only mathematical performance but also student motivation and cognitive engagement (Talkhan et al., 2025). Furthermore, integrating cooperative learning into hybrid environments strengthens conceptual understanding and active participation, particularly when activities are designed with clearly defined roles and shared goals (Tang et al., 2025).

Within this perspective, cooperative learning is not limited to a group technique; rather, it constitutes a pedagogical approach that transforms the traditional dynamics of mathematics instruction, shifting the teacher's role toward processes of co-construction of knowledge. This reconfiguration of teacher and student roles is particularly relevant in technology-mediated contexts, in which peer interaction acquires new dimensions.

2.2 Digital Applications as Mediators of Mathematics Learning

Digital tools have redefined mathematics learning environments, expanding possibilities for interaction, visualization, and immediate feedback. The strategic use of digital tools contributes to improved understanding of mathematical content when combined with active methodologies (Acosta Marino et al., 2025). From a research perspective, a recent bibliometric study confirms the sustained growth of publications focused on integrating digital technologies in mathematics instruction over the past five years, highlighting its relevance on the international academic agenda (Filiz, 2025). Similarly, the collaborative design of digital materials strengthens both mathematical competencies and pedagogical skills, emphasizing the need for a planned and reflective integration of technology into the curriculum (Lindenbauer et al., 2024).

Consequently, digital applications, such as learning management platforms, interactive mathematics software, simulators, and gamification tools, enable the creation of dynamic environments in which visualization, experimentation, and immediate feedback foster deep cognitive processes. These characteristics make them highly valuable resources for supporting the co-construction of mathematical knowledge in collaborative contexts.

2.3 Convergence of Collaborative Learning and Digital Applications

The integration of cooperative learning and digital applications establishes a hybrid pedagogical model that enhances both social interaction and technological mediation of mathematical knowledge. Digital tools strengthen collaboration by facilitating synchronous and asynchronous communication, monitoring group progress, and supporting the co-construction of academic products (Mulatillo Ruiz, 2024). Moreover, the impact of cooperative learning is intensified when digital technology is integrated, as it enables immediate feedback, interactive visualization, and group performance monitoring (Talkhan et al., 2025). In blended learning contexts, technology acts as a catalyst for positive interdependence, extending interaction spaces beyond the physical classroom (Tang et al., 2025).

3. Methodology

3.1 Study Design

This study was conducted using SLR approach, which is considered a rigorous, transparent, and replicable procedure for identifying, evaluating, and synthesizing empirical evidence on a specific educational phenomenon (Page et al., 2021). The methodological process was structured following the PRISMA 2020 guidelines, which organize the review into the phases of identification, screening, eligibility, and inclusion, ensuring traceability and control of the selection process (Haddaway et al., 2022). The review was guided by five predefined research questions (RQ1–RQ5), which directed the identification of temporal and geographical trends, methodological approaches, theoretical frameworks, reported effects, and limitations in existing research on collaborative learning supported by digital technologies in secondary mathematics education.

The analysis period covered publications from 2020 to 2026, aiming to capture scientific production following the acceleration of educational digitalization in the post-pandemic context. The search, selection, and coding processes were conducted independently by the researchers, resolving discrepancies through consensus with an expert evaluator, thereby enhancing procedural reliability (Sanchez-Meca & Botella Ausina, 2010; Haddaway et al., 2022). Searches were executed between November 2025 and February 2026.

3.2 Search Strategy

The literature search was conducted in three high-impact academic databases in the educational and technological fields: Scopus, Web of Science (WoS), and ERIC. Searches were performed between November 2025 and February 2026. Combinations of English descriptors were used, associated with the following conceptual axes: collaborative learning, digital technology/educational technology, mathematics education, and secondary education. Terms were combined using Boolean operators (AND, OR) and adapted to the specific syntax of each platform. The search strings used in each database are presented in Table 1.

Table 1: Search strings by database

Database	Search String
Scopus	TITLE-ABS-KEY ((“collaborative learning” OR “computer-supported collaborative learning” OR CSCL OR collaboration) AND (mathematics OR MATH OR “mathematics education” OR “STEM education”) AND (technology OR digital OR online OR ICT OR “educational technology”) AND (“secondary education” OR “secondary school” OR “high school”))
ERIC	(“collaborative learning” OR “cooperative learning” OR CSCL) AND (mathematics OR math) AND (technology OR digital OR online OR ICT)
Web of Science	TS=((“collaborative learning” OR “cooperative learning” OR “computer-supported collaborative learning” OR CSCL OR collaboration) AND (mathematics OR math OR “mathematics education”) AND (technology OR digital OR online OR ICT OR “educational technology”))

The Scopus search string included the term “STEM education” alongside “mathematics education” to broaden the initial retrieval of records that, although classified under STEM, specifically addressed mathematics. The thematic relevance of each record was verified in the subsequent screening by reviewing titles, abstracts, and, when necessary, full texts, ensuring that only studies focused on mathematics learning were included.

3.3 Inclusion and Exclusion Criteria

To ensure thematic relevance and methodological quality, explicit inclusion and exclusion criteria were defined and systematically applied during the screening and eligibility phases. The criteria are presented in Table 2.

Table 2: Inclusion and exclusion criteria

Type	Criteria
Inclusion	Peer-reviewed empirical articles; studies focused on secondary mathematics education; research explicitly incorporating collaborative learning mediated by digital technologies; publications in indexed journals; studies published between 2020 and 2026.
Exclusion	Grey literature (theses, technical reports, non-peer-reviewed proceedings); exclusively theoretical studies; research focused on other educational levels (primary or higher education); studies in which technology is not integrated into collaborative dynamics.

3.4 Study Selection Process

The selection process followed four phases in accordance with PRISMA 2020 guidelines. In the identification phase, a total of 1,461 records were retrieved: Web of Science (n = 681), Scopus (n = 134), and ERIC (n = 646). After removing 57 duplicates using Zotero and manual verification in Google Sheets, the working corpus consisted of 1,404 records. During the screening phase, titles and abstracts were reviewed against the eligibility criteria, resulting in the exclusion of 1,344 records for the following reasons: not addressing technology-mediated collaborative learning; not pertaining to secondary mathematics education; not integrating technology into collaborative dynamics; being non-empirical or non-peer-reviewed documents; or lacking full-text access (n = 28). Subsequently, 32 records underwent full-text review to verify methodological and thematic relevance. The complete process is summarized in Figure 1.

3.5 Data Extraction and Organization

A structured extraction matrix was designed to systematize relevant information from each selected study, organized in Google Sheets and managed through Zotero for bibliographic control. Analysis categories included: author and year of publication, country or region, methodological design, sample size and characteristics, theoretical framework, pedagogical model, type of technology used, evaluated variables, main findings, and reported limitations.

3.6 Data Analysis

The analysis combined descriptive and analytical procedures. Descriptively, frequencies and distributions were calculated by year of publication, country, methodological approach, and type of technology used to identify trends and patterns in the scientific production analyzed (RQ1 and RQ2).

Analytically, a thematic content analysis was conducted to address RQ3, RQ4, and RQ5. Units of analysis consisted of text segments related to theoretical frameworks, instructional strategies, reported effects, and declared limitations in each article. Through systematic reading, the researchers inductively coded the units into emerging categories, and then later grouped them into stable thematic categories supporting the synthesis tables presented in the results section.

The coding process was performed independently by the researchers and supervised by an expert evaluator in cases of interpretive discrepancies, ensuring intercoder consistency. This procedure allowed for the identification of patterns, trends, and research gaps related to the posed research questions, moving beyond mere description toward an analytical interpretation of the available evidence.

3.7 Methodological Quality Assessment and Risk of Bias

Following the thematic screening and accessibility verification, a methodological quality and risk of bias assessment was conducted to define the final corpus of included articles and strengthen the study's internal validity.

To evaluate the studies, a critical appraisal matrix was adapted from the standards of the Joanna Briggs Institute. The evaluation instrument was structured around two primary dimensions—thematic and methodological—which were divided into six key criteria: (1) alignment of objectives, (2) procedural coherence, (3) appropriateness of the research design, (4) robustness of the empirical evidence, (5) correspondence between research questions and findings, and (6) rigor of the discussion.

Each criterion was rated using an ordinal scoring scale (Yes = 1, Partial = 0.5, No = 0). To ensure a rigorous selection and prioritize research design quality over mere content alignment, a differentiated weighting system was applied, assigning 60% to the methodological dimension and 40% to the thematic dimension. A minimum inclusion threshold of ≥2.5 weighted points was established for a study to be selected.

The assessment was conducted independently by the researchers. Any discrepancies were resolved through deliberation with an expert evaluator to reach consensus, thereby enhancing inter-rater reliability. Based on these rigorous standards, of the 32 eligible studies, 23 were excluded for falling below the required ≥2.5 threshold due to high risk of bias, insufficient rigor, or incomplete data. This procedure yielded a final corpus of nine articles selected for in-depth analysis.

3.8 PRISMA Flow Diagram

Figure 1 presents the PRISMA flow diagram summarizing the complete process of identification, screening, eligibility, methodological quality assessment, and final study selection, in accordance with PRISMA 2020 guidelines (Page et al., 2021) and recent methodological updates in educational systematic reviews (Haddaway et al., 2022). The diagram details count for each phase: records identified by database (WoS = 681; Scopus = 134; ERIC = 646); duplicates removed (n = 57); records after deduplication (n = 1,404); records excluded in screening (n = 1,344); full-text eligibility assessment (n = 32); studies excluded due to methodological quality (n = 23); and studies included in the final synthesis (n = 9).

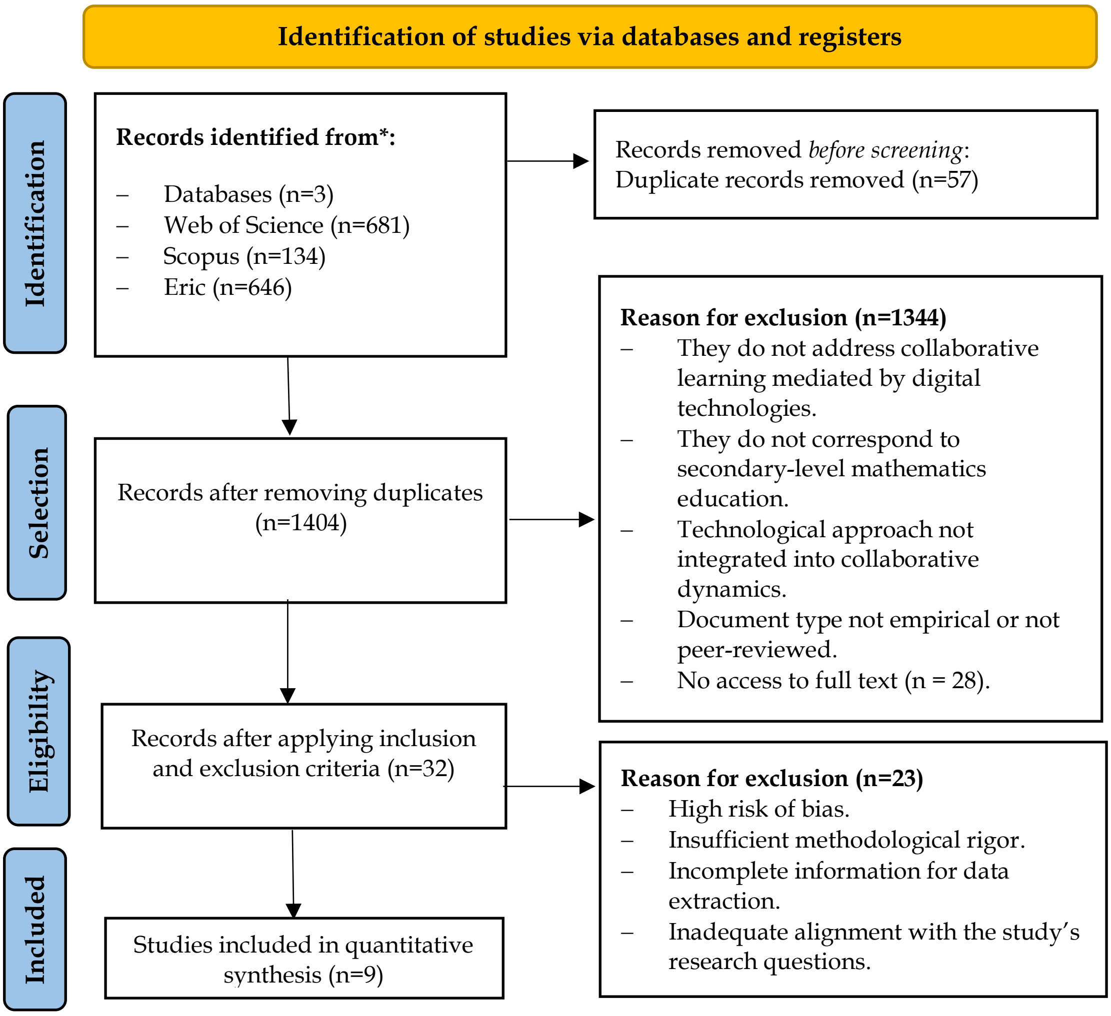

Figure 1: PRISMA flow diagram

4. Results

The results have been presented following the indicators outlined in the methodology.

4.1 Scientific Production on Collaborative Learning Supported by Digital Technologies in Secondary Mathematics Education

The geographical distribution of the included studies (Figure 2) shows a marked concentration in the Northern Hemisphere and in contexts with high scientific output, such as the United States, Finland, and Turkey (n = 2), as well as in other European and Oceanian contexts (Kosovo and Australia). This concentration does not necessarily indicate an absence of pedagogical implementation in other regions but rather reflects structural limitations in publication and scientific dissemination capacity in the Global South, particularly in Latin America.

Nevertheless, the corpus includes contributions from historically underrepresented regions in indexed literature, such as Africa (Nigeria and Ethiopia) and Southeast Asia (Brunei), suggesting an incipient expansion of the field into peripheral contexts, although still marginal. Turkey is the only country with two contributions (Aksu & Zengin, 2021; Demir & Zengin, 2025), indicating the consolidation of an active research community in this domain within its educational system.

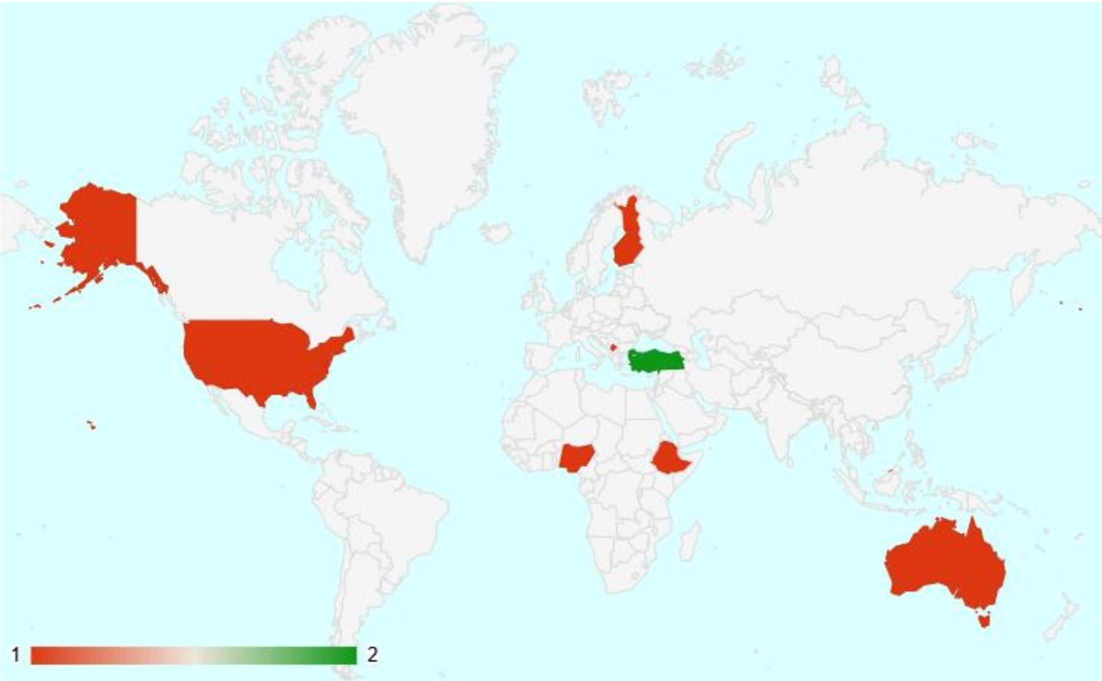

Figure 2: Geographic distribution of included studies by country

Regarding temporal evolution (Figure 3), scientific production is concentrated between 2021 and 2026, peaking in 2024 (n = 3) and showing a secondary maximum in 2023 (n = 2). This pattern aligns with the acceleration of educational digitalization in the post-pandemic period and the sustained growth of research on technology in mathematics education documented bibliometrically by Filiz (2025). The absence of studies in 2022 within the final corpus, despite the search period covering that year, may be attributed to screening factors or a potential publication gap in that specific year. The presence of a study in 2026 (Walkington et al., 2026) demonstrates that the field's research frontier already incorporates emerging technologies, such as augmented reality, in collaborative mathematics contexts.

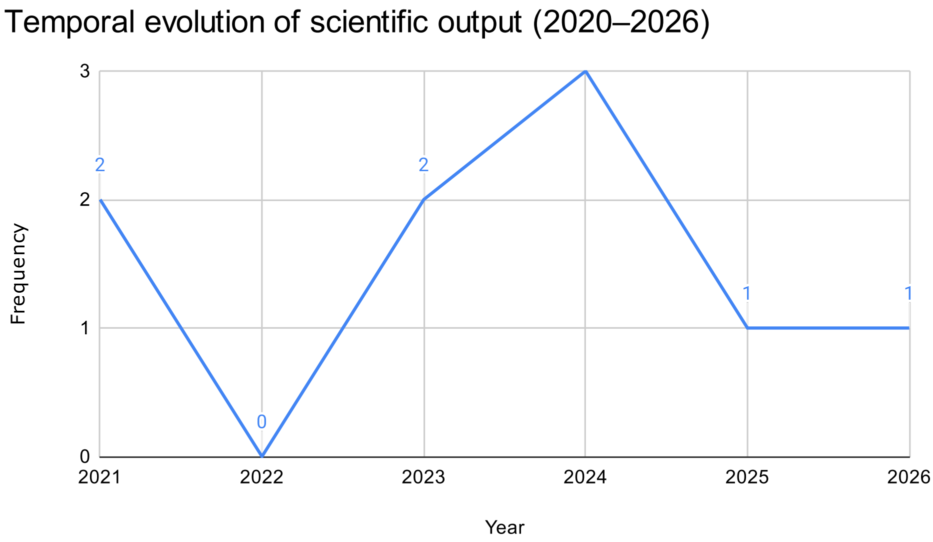

Figure 3: Temporal evolution of scientific production (2021–2026)

4.2 Methodological Approaches, Research Designs, and Data Collection Instruments on Collaborative Learning Supported by Digital Technologies in Mathematics

The predominance of quantitative and quasi-experimental approaches in four of the nine studies reflects the field's tendency to demonstrate the effectiveness of digital collaborative learning through measurable performance evidence, prioritizing internal validity over interpretive depth. This orientation is characteristic of a disciplinary consolidation phase, in which the research community seeks to pedagogically legitimize technology use with robust statistical evidence.

However, the increasing presence of mixed designs integrating eye-tracking data, multimodal recordings, and discourse transcriptions signals a relevant methodological shift: the field recognizes that the impact of digital collaborative learning is not limited to performance outcomes but also manifests in interaction, reasoning, and shared meaning-making processes, which require more sophisticated capture methods.

The range of sample sizes from six participants in case studies (Aksu & Zengin, 2021) to 879 in surveys (Burke et al., 2021) illustrates the methodological heterogeneity of the field and highlights the difficulty of directly comparing findings. This variability points to the need for more rigorous synthesis protocols in future reviews, including meta-analyses that weigh effect sizes according to methodological design. (See Table 3).

Table 3: Methodological approaches, research designs, and data collection instruments in studies on collaborative learning supported by digital technologies in mathematics

Authors	Methodological Approach	Research Design	Data Collection Instruments	Sample Characteristics
Wellington et al. (2026); Abu Bakar et al. (2023); Mohammed & Bello (2024); Gurmu et al. (2024)	Quantitative	Experimental and quasi-experimental; pretest-posttest; some with control group	Mathematics performance tests (MAT, GCUT), pretest and posttest, retention tests; repeated measures ANOVA, Student's t-test, Kolmogorov–Smirnov; reliability analysis (KR-20, PPMC)	Samples between 70 and 128 secondary students (7th–10th grade). Structured instruments based on curricular specifications.
Mahmuti & Arifi (2025); Aksu & Zengin (2021); Haataja et al. (2025)	Mixed (quantitative + qualitative)	Sequential or integrated mixed designs; statistical analysis with SPSS and multi-source qualitative analysis	Pretest-posttest tests; Likert questionnaires; checklists; observation; written productions; discourse transcriptions; GeoGebra; mobile eye-tracking glasses; video and audio recordings; SmartPens; multimodal synchronization	Purposeful samples between 17 and 32 secondary students (7th and 9th grade). Integration of statistical data with observational and technological records.
Demir & Zengin (2025)	Qualitative	Case study and interpretative interaction analysis	Semi-structured interviews; open-ended questionnaires; mathematics tasks with multiple representations; written productions; video recordings; observation notes	Purposeful samples between 3 and 20 participants. Focus on collaborative processes and mathematical productions.
Burke et al. (2021)	Quantitative	Survey study with statistical modeling	iPAC survey (19 items + 8 background items); descriptive analysis; mean difference tests; Structural Equation Modeling (SEM)	Large sample (n = 879 valid responses). Instrument validated by authors with structural analysis.

4.2 Theoretical Frameworks and Instructional Strategies Underpinning the Implementation of Collaborative Learning Supported by Digital Technologies in Mathematics Education

The analysis of theoretical frameworks reveals a clear predominance of socioconstructivism in its various formulations: Vygotsky, Sfard, Bandura as the epistemological foundations of the field. This framework conceives mathematical learning as a social process mediated by cultural and technological tools, explaining its natural affinity with digitally collaborative designs. Alongside this dominant core, complementary and more specialized frameworks emerge: the embodied cognition theory (Haataja et al., 2025), mathematical discourse theory (Aksu & Zengin, 2021), and cognitive load theory (Mahmuti & Arifi, 2025). This diversification indicates that the field is moving from a generic foundation toward more specific frameworks that attempt to explain the cognitive and discursive mechanisms of technology-mediated collaborative mathematical learning.

Regarding technology, the predominance of GeoGebra in three of the nine studies (Aksu & Zengin, 2021; Haataja et al., 2025; Gurmu et al., 2024) is noteworthy: as dynamic geometry software, it serves as the primary mediating artifact for collaborative exploration of visual mathematical concepts. The inclusion of emerging technologies, such as augmented reality (Walkington et al., 2026) and eye-tracking (Haataja et al., 2025), signals a shift in the technological frontier toward resources that allow the capture and analysis of collaboration at a multimodal level, beyond mere academic output. (See Table 4).

Table 4: Theoretical frameworks, pedagogical models, collaborative strategies, and technologies used in collaborative learning supported by digital technologies in mathematics

Authors	Theoretical Framework	Pedagogical Model	Collaborative Instructional Strategy	Type of Mathematical Task	Digital Technology	Implementation Format
Walkington et al. (2026)	Sociocultural learning theory; gesture-speech nexus analysis	Structured collaborative learning in experimental conditions	Collaborative problem solving with differentiated roles (parallel, observer/ observed, joint)	Euclidean geometry problems (2D & 3D, congruence, similarity, transformations)	Augmented reality (headsets + interactive AR environment)	In-person with technology
Abu Bakar et al. (2023)	Game-based learning; flow theory (Csikszentmihalyi); intrinsic motivation	Game-based collaborative learning	Digital Escape Room in teams	Algebra problems	Digital Escape Room platform	In-person with technological support
Mahmuti & Arifi (2025)	Constructivism (Piaget, Vygotsky); artifact-mediated learning; cognitive load theory (Sweller)	Active learning with technological mediation	Use of virtual manipulatives and guided team exploration	Construction of figures; area and perimeter; equivalences; geometric problems	Virtual manipulatives and interactive math games in digital lab	In-person with technology

Mohammed & Bello (2024)	Social constructivism (Vygotsky); social learning (Bandura); Bloom's taxonomy	Collaborative flipped classroom	Asynchronous video viewing + small-group discussions	Curriculum content (logarithms and other secondary topics)	Digital educational videos and ICT resources	In-person with technology (flipped model)
Aksu & Zengin (2021)	Sociocultural perspective (Vygotsky); mathematical discourse theory (Sfard); semiotic mediation (Bartolini Bussi)	ACODESA Method (Collaborative Learning, Scientific Debate, Self-Reflection)	Individual work, group work, scientific debate, self-reflection	Exploration of polygons; conjecture formulation and validation	GeoGebra as semiotic mediating artifact	In-person with computer lab
Haataja et al. (2025)	Embodied cognition; gesture theory in mathematics education (McNeill); collaborative problem solving	Group instruction oriented to collaborative problem solving	Small-group work with teacher scaffolding	Complex geometric problem (Steiner tree)	Mobile eye-tracking glasses, SmartPens, GeoGebra	In-person with technological support
Demir & Zengin (2025)	Algebraic generalization theory; socioconstructivism; Zone of Proximal Development (Vygotsky)	Collaborative problem solving centered on patterns	Analysis and generalization of patterns in small groups	Numerical and geometric patterns	Multiple representations with digital support (software unspecified)	In-person
Gurmu et al. (2024)	Social constructivism (Vygotsky); mathematical visualization theories; dynamic geometry systems (Laborde)	5E Instructional Model (Engage, Explore, Explain, Elaborate, Evaluate)	Collaborative work with GeoGebra (groups of 4–5 students)	Plane and solid geometry; dynamic visualization and manipulation	GeoGebra installed on PCs in lab	In-person in computer lab
Burke et al. (2021)	iPAC pedagogical framework (Personalization, Authenticity, Collaboration); sociocultural basis	iPAC as analytical m-learning model	Measurement of collaborative m-learning experiences	Not specified (multiple subjects)	Mobile devices (BYOD); mobile learning environment	In-person with intensive device use

4.3 Effects of Technology-Mediated Collaborative Learning on Mathematics Learning and Associated Variables

The distribution of results across the three defined categories reveals a meaningful interpretive pattern: the most robust and statistically significant effects are concentrated in experimental or quasi-experimental studies focused on geometry and algebra content (Abu Bakar et al., 2023; Mahmuti & Arifi, 2025; Mohammed & Bello, 2024; Gurmu et al., 2024). This finding aligns with the hypothesis that technology-mediated collaborative learning particularly enhances the construction of mathematical concepts that benefit from dynamic and interactive visualization. However, the magnitude of these effects should be interpreted with caution due to the small sample sizes and short duration of interventions.

Mixed or condition-specific results (Walkington et al., 2026; Burke et al., 2021) indicate that the effectiveness of digital collaborative learning is not homogeneous: it depends on the specific collaborative format, subject area, and variable evaluated.

Notably, Walkington et al. (2026) provided novel evidence showing that different collaboration formats in augmented reality generate distinct interaction and performance patterns, highlighting critical nuances for the design of future interventions. Overall, the available evidence shifts the question from *"Does collaborative technology work?"* to *"Under which pedagogical conditions are its effects most robust and transferable?"* (See tables 5A, 5B and 5C). To achieve greater analytical precision, the effects were disaggregated into three dimensions: (1) mathematics learning (Table 5A), (2) participation and interaction (Table 5B), and (3) affective and cognitive variables (Table 5C).

Table 5A: Effects on mathematics learning in collaborative environments supported by digital technologies

Authors	Type of Evidence	Mathematical Content	Learning Outcomes	Type of Effect
Abu Bakar et al. (2023)	Quantitative (experimental)	Algebra	Significant improvement in performance and academic achievement through gamified collaborative learning	Significant positive
Mahmuti & Arifi (2025)	Mixed methods	Geometry (area and perimeter)	Increased conceptual understanding and performance compared to traditional methods	Significant positive
Mohammed & Bello (2024)	Quantitative (quasi-experimental)	Logarithms	Better performance and retention outcomes in flipped collaborative learning settings	Significant positive
Gurmu et al. (2024)	Quantitative (experimental)	Geometry	Significant improvement in conceptual understanding through the use of GeoGebra	Significant positive
Walkington et al. (2026)	Quantitative (experimental)	Geometry (2D and 3D)	Differences in performance according to collaboration format (parallel, joint, observer)	Mixed / condition-dependent
Aksu & Zengin (2021)	Mixed methods	Geometry (polygons)	Development of mathematical reasoning and validation of conjectures	Positive (qualitative)
Demir & Zengin (2025)	Qualitative	Algebraic patterns	Improvement in algebraic generalization processes	Positive (qualitative)
Haataja et al. (2025)	Mixed methods	Complex geometry	Evidence of progress in collaborative problem-solving, without direct measurement of performance	Positive (indirect)
Burke et al. (2021)	Quantitative (survey)	General	Perceived improvement in learning (not objectively measured)	Positive (perceptual)

Table 5B: Effects on participation and interaction in technology-mediated collaborative learning

Authors	Type of Interaction	Source of Evidence	Reported Effects	Interpretation
Abu Bakar et al. (2023)	Teamwork	Observation and results	Increased group discussion and active collaboration	Strengthened interaction
Mahmuti & Arifi (2025)	Co-construction	Observation + student outputs	Joint construction of solutions and strategies	High collaborative level
Mohammed & Bello (2024)	Group discussions	Results + observation	Greater participation compared to individual learning	Positive interaction
Gurmu et al. (2024)	Small-group work	Observation	Continuous interaction through the use of GeoGebra	Effective collaboration
Walkington et al. (2026)	Interaction by format	Experimental analysis	Differences in interaction patterns according to collaboration type	Design-dependent
Aksu & Zengin (2021)	Mathematical debate	Discourse analysis	Development of argumentation and scientific discussion	Deep interaction
Demir & Zengin (2025)	Discursive interaction	Qualitative analysis	Joint construction of mathematical meanings	High co-construction
Haataja et al. (2025)	Joint attention	Eye-tracking + video	Visual and gestural synchronization among students	Multimodal interaction
Burke et al. (2021)	Interaction in m-learning	Survey	Collaboration was present but had less impact than personalization	Moderate interaction

Table 5C: Effects on affective and cognitive variables in technology-mediated collaborative mathematics learning

Authors	Type of Variable	Measurement Method	Reported Effects	Level of Evidence
Abu Bakar et al. (2023)	Motivation, engagement	Quantitative	Increased motivation and enjoyment of learning	High
Mahmuti & Arifi (2025)	Attitude toward mathematics	Questionnaires	Greater interest and active participation	Medium
Mohammed & Bello (2024)	Motivation	Results + observation	Increased interest and engagement	Medium
Gurmu et al. (2024)	Attitude	Quantitative	Improved perception of learning with technology	Medium

Walkington et al. (2026)	Not central	Experimental	Not reported as a main variable	Low
Aksu & Zengin (2021)	Mathematical thinking	Qualitative analysis	Development of reasoning and critical thinking	Medium
Demir & Zengin (2025)	Cognition (generalization)	Qualitative	Improvement in algebraic cognitive processes	Medium
Haataja et al. (2025)	Cognitive attention	Eye-tracking	Improvement in group cognitive coordination	Medium
Burke et al. (2021)	Perception of learning	Survey (SEM)	High perception of learning influenced by personalization	High (perceptual)

4.4 Methodological Limitations and Research Gaps Reported in Studies on Collaborative Learning Supported by Digital Technologies in Secondary Mathematics Education

The pattern of limitations identified in the corpus is remarkably consistent: eight of the nine studies simultaneously present small sample sizes, lack of longitudinal follow-up, and reliance on a single measurement instrument, typically pretest-posttest. This convergence is structural rather than anecdotal, reflecting typical conditions of mid-level educational research, in which resources rarely allow long-term interventions with representative samples.

For the specific field of technology-mediated collaborative mathematics learning, this limitation is particularly critical: collaborative technology effects may manifest gradually and require longer consolidation periods than those typically evaluated.

Furthermore, technological infrastructure dependence emerges as a cross-cutting constraint affecting contexts differently. In high-income countries (Finland, USA, Australia), this limitation is confined to specialized devices such as eye-tracking; in contexts like Nigeria (Mohammed & Bello, 2024) and Ethiopia (Gurmu et al., 2024), it encompasses basic connectivity and electricity. This asymmetry highlights that those technological constraints are not uniform and that implementation strategies must adapt to the structural realities of each educational setting (See Table 6).

Table 6: Effects categorized summary of methodological limitations, technological constraints, and research gaps in studies on technology-mediated collaborative learning in mathematics

Authors	Sample Size / Representativeness Limitations	Temporal / Lack of Longitudinal Follow-Up	Learning Measurement / Instrument Limitations	Infrastructure / Technological Constraints	Research Gaps Identified by Authors
Walkington et al. (2026)	Limited sample; gender imbalance; specific context (summer camps)	No longitudinal follow-up reported	No explicit instrument limitations reported	Students had no prior AR experience; potential novelty effect	Explore how different collaborative formats influence discourse processes and learning in immersive digital environments
Abu Bakar et al. (2023)	Limited to a single school	No longitudinal follow-up	No explicit instrument limitations reported	Dependence on adequate technological resources	Replicate in other contexts and educational levels
Mahmuti & Arifi (2025)	Small sample (N=32); single institution	Short intervention (2 weeks); no long-term follow-up	Instruments limited to short-term pre/post tests	Dependent on teacher guidance; connectivity/infrastructure not analyzed	Conduct longitudinal studies; expand populations; evaluate long-term effects across contexts
Mohammed & Bello (2024)	Small sample (70 students); only two private schools	Four-week treatment; no follow-up	Focused on performance tests; no triangulation	Dependence on stable ICT infrastructure and electricity	Integrate video learning, flipped classroom, and collaborative learning; expand contexts and subjects
Aksu & Zengin (2021)	Small sample (6 students); single-case study	No longitudinal follow-up	Lack of consistent theoretical frameworks for reasoning analysis	Requires prior GeoGebra training; task design dependent	Expand studies on mathematical reasoning in collaborative tech environments
Haataja et al. (2025)	Limited by number of sessions and teachers; small subsample for eye-tracking	Observation limited to two sessions; no longitudinal follow-up	Difficulty linking attention patterns to quantified academic performance	Technical limitations of eye-tracking devices; data synchronization complexity	Conduct studies with larger samples; establish quantitative relationships between visual attention and math learning

Demir & Zengin (2025)	Small sample; single institution	No longitudinal follow-up	Qualitative design focused on processes; no quantitative learning measures	No technological limitations specified	Expand samples; explore other educational levels; generalize to different algebra tasks
Gurmu et al. (2024)	Intentional sampling; intact sections; limited regional generalization	No longitudinal follow-up	Measurement focused on conceptual understanding; attitudes or retention not evaluated	Dependence on computer labs and teacher competence in GeoGebra	Explore other variables, conduct longitudinal studies, compare platforms
Burke et al. (2021)	Limited to BYOD schools; possible selection bias	Cross-sectional survey; no longitudinal/experimental design	Self-report; no objective performance measures	Connectivity and access outside the classroom; institutional restrictions	Measure objective learning effects; conduct longitudinal studies

5. Discussion

5.1 Temporal Evolution and Geographic Distribution of Research

The results show a sustained increase in scientific production since 2020, confirming the consolidation of technology-mediated collaborative learning as an emerging line of research in mathematics education (Burke et al., 2021; Walkington et al., 2026; Filiz, 2025). Despite this growth, meta-analyses indicate that effects on mathematical performance are positive but of moderate and heterogeneous magnitude, achieving greater impact when technology explicitly structures collaborative interaction rather than serving merely as a complementary resource (Xu et al., 2025).

Geographically, production is concentrated in Europe, Oceania, and North America, whereas Africa and Southeast Asia show limited contributions (Gurmu et al., 2024; Mohammed & Bello, 2024). While this distribution may reflect structural limitations in research and publication capacity in the Global South, an alternative interpretation suggests a methodological bias associated with the search strategy, particularly the predominance of English-language indexed databases. Consequently, the apparent absence of studies from Latin America does not necessarily imply a lack of pedagogical implementation, but rather a limitation in academic visibility. This highlights the need for future reviews to integrate regional sources and non-indexed literature to promote epistemic equity.

5.2 Predominant Methodological Approaches and Research Strategies

Regarding methodological approaches, there is a clear predominance of quantitative experimental and quasi-experimental studies (Abu Bakar et al., 2023; Gurmu et al., 2024; Mohammed & Bello, 2024). This reflects the field's orientation toward measuring effectiveness in terms of mathematical performance. However, the reported effects tend to be small or moderate, which could be explained by inherent limitations in standard instruments that fail to adequately capture the interactive dimensions of collaborative learning.

The increasing use of mixed methods designs represents a significant advancement, integrating statistical data with qualitative evidence from observations and multimodal recordings (Mahmuti & Arifi, 2025; Haataja et al., 2025). While this facilitates the understanding of meaning negotiation and mathematical argumentation, an alternative interpretation suggests that the apparent superiority of mixed approaches might be influenced by a design bias, in which methodological triangulation merely increases the probability of identifying positive effects. Therefore, purely qualitative studies remain indispensable for explaining the causal mechanisms underlying these outcomes (Demir & Zengin, 2023).

5.2 Theoretical Frameworks, Pedagogical Models, and Collaborative Strategies
The analyzed studies are predominantly grounded in constructivist and socio-constructivist frameworks, conceiving mathematical learning as a social process mediated by interaction and cultural tools (Aksu & Zengin, 2021; Demir & Zengin, 2023; Mahmuti & Arifi, 2025). In this framework, technology acts as a mediating artifact for the co-construction of meanings (Mor & Abdu, 2018). Furthermore, the computer-supported collaborative learning (CSCL) framework provides a robust basis for understanding how digital environments can optimize peer interaction (Bringula, 2022).

Pedagogically, effective strategies include small-group work, role assignment, and argumentation mediated by dynamic software such as GeoGebra (Birgin & Acar, 2020). However, alternative explanations must be considered. The positive results associated with dynamic software could be heavily influenced by the visual nature of the mathematical content such as geometry or by the students' prior familiarity with the tools, rather than the collaborative dynamics themselves (Haataja et al., 2025). This suggests the need to isolate the relative weight of technology, pedagogy, and content characteristics in future research.

5.3 Effects of Digital Collaborative Learning on Mathematical Learning
The reviewed evidence indicates positive effects on mathematical performance and conceptual understanding (Abu Bakar et al., 2023; Gurmu et al., 2024; Mahmuti & Arifi, 2025). However, the magnitude of these effects is highly variable and depends on the level of pedagogical structuring and teacher scaffolding (Walkington et al., 2026). Consistent with recent meta-analyses, the largest effects occur when technology facilitates communication rather than acting as an isolated resource (Ran et al., 2022).

Beyond performance, studies report improvements in participation, interaction, and motivation (Mohammed & Bello, 2024), alongside advances in collective argumentation (Aksu & Zengin, 2021; Demir & Zengin, 2023). Nevertheless, these findings must be interpreted cautiously. It is highly plausible that some of the observed positive effects are driven by a "novelty effect," in which the introduction of technology generates an initial spike in student engagement that may not be sustainable over time. Additionally, reliance on self-reports in several studies limits' inferences regarding actual learning (Burke et al., 2021). Ultimately, these findings shift the central question of the field from "Does technology work?" to "Under which pedagogical conditions does technology enhance collaborative learning?"

5.4 Methodological Limitations and Research Gaps

The analyzed studies present recurring methodological limitations that restrict the generalizability of results. Small samples and specific institutional contexts predominate (Aksu & Zengin, 2021; Demir & Zengin, 2023). Interventions are generally short in duration and lack longitudinal follow-up, meaning the reported positive effects are primarily short-term (Mahmuti & Arifi, 2025; Gurmu et al., 2024; Haataja et al., 2025). Collectively, these limitations reveal clear gaps: the need for longitudinal studies with larger samples; greater theoretical-methodological integration; and the development of instruments capable of linking instrumental data (e.g., eye-tracking) with robust indicators of mathematical learning, without relying solely on immediate performance tests (Walkington et al., 2026).

5.5 Comparison with Other Systematic Reviews

In comparison with previous reviews, such as Ran et al. (2022) and Bringula (2022), the present findings are consistent in reporting positive but moderate effects of digital technologies on mathematics performance. However, a rigorous comparative analysis reveals distinct contributions. While previous works focus primarily on estimating the overall effect size of technological interventions, this review advances the field by detailing the pedagogical and methodological conditions that explain the variability of those effects. Furthermore, by integrating quantitative and qualitative evidence, this study moves beyond evaluating mere effectiveness to analyzing previously underexplored dimensions such as mathematical argumentation, discursive interaction, and the collective co-construction of knowledge.

The study's limitations are identified at two levels. Within the analyzed evidence, short-duration studies with small or non-representative samples and a scarcity of longitudinal designs predominate, limiting the assessment of sustained effects. Furthermore, there is a reliance on immediate performance tests and self-reports, with limited methodological triangulation. Regarding the review process, the search was conducted exclusively in Scopus, Web of Science, and ERIC using English-language search strings.

This linguistic restriction constitutes a significant limitation, as it systematically excluded relevant studies published in Spanish and Portuguese in regional databases (e.g., SciELO, Redalyc), which likely contributed to the geographic bias and the underrepresentation of Latin American research identified in the results. The final small number of studies (n = 9) reflects the specificity of the focus and highlights the existing gap in literature. Finally, a quantitative meta-analysis was not conducted due to methodological heterogeneity; nevertheless, conducting such analyses constitutes a priority agenda.

From a teaching practice perspective, the results indicate that technology integration must be accompanied by an explicit structuring of collaborative work and task design that promotes argumentation, interaction, and co-construction of meaning. Teacher training should incorporate competencies in digital pedagogical design rather than be limited to the instrumental handling of tools. Theoretically, the findings reinforce the centrality of the socio-constructivist framework and highlight the need to integrate technological models with mathematical learning theories. For educational policy design, the results suggest that school technology investment produces sustainable improvements in mathematics learning only when accompanied by specific pedagogical training and equitable infrastructural conditions, particularly in contexts of high digital vulnerability.

6. Conclusion

This SLR demonstrates that collaborative learning mediated by digital technologies constitutes a pedagogical strategy with positive, yet moderate and highly heterogeneous, effects on secondary mathematics education. The principal contribution of this study lies in shifting the explanatory focus away from technology as a standalone causal factor towards instructional design and pedagogical intentionality as the key mediators of learning outcomes. The findings confirm that effectiveness relies less on technological sophistication and more on teacher scaffolding, role organization, and the explicit structuring of peer interaction. Furthermore, the geographic concentration of studies in the Global North highlights a structural limitation, suggesting that future reviews must incorporate regional databases and diverse languages to overcome linguistic biases and promote epistemic equity.

Methodologically, while mixed methods approaches show promise in capturing the complexity of interactive learning, the reported positive effects must be interpreted with caution. Variables such as the “novelty effect,” students’ prior familiarity with digital tools, and the specific nature of the mathematical content may significantly influence outcomes independent of collaborative dynamics. To consolidate a more robust and critical field of research, it is recommended that future studies: (i) incorporate longitudinal designs to evaluate the sustainability of learning effects over time, (ii) expand the geographic and cultural diversity of samples, (iii) develop instruments specifically calibrated to capture the quality of collaborative interaction, and (iv) isolate the relationships between mathematical content, technological format, and collaborative design.

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