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Professional Development for K–12 Mathematics Teachers: A Systematic Literature Review of Technology, Pedagogy, and Equity.

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Abstract: This systematic literature review (SLR) analyzed peer-reviewed journal articles published between 2009 and 2024 to identify key characteristics, patterns, and emerging trends in professional development programs for K–12 STEM teachers. The review placed particular emphasis on the integration of emerging technologies, mathematics education practices, and equity-oriented initiatives. Studies involving both pre-service and in-service teachers were included to capture professional learning across the teacher preparation and career continuum, while dissertations, gray literature, and higher education–focused studies were excluded to ensure consistency, relevance, and comparability across sources. Priority was given to empirical journal articles that explicitly examined teacher professional growth in relation to technology integration, pedagogical change, and equity-focused practices within mathematics education. The findings indicate a growing emphasis on technology-enabled instruction, with increased attention to digital tools that support conceptual understanding, student engagement, and inquiry-based learning. At the same time, the literature reflects evolving pedagogical approaches that foreground teacher capacity building, collaborative learning, and the development of Technological Pedagogical Content Knowledge (TPACK). Equity-oriented frameworks were also prominent, highlighting efforts to address access, inclusion, and culturally responsive instruction in technology-enhanced mathematics classrooms. Despite these advances, the review identified notable gaps, particularly the limited presence of cross-cutting professional development models that meaningfully integrate technology, pedagogy, and equity in sustained and coherent ways. Additionally, relatively few studies examined long-term impacts of professional development on instructional practice and student outcomes. Limitations of this review include the potential exclusion of relevant insights from non-journal publications and non-English sources. Future research should prioritize longitudinal investigations of integrated professional development models and expand inquiry into underrepresented international contexts, especially in the Global South, to enhance the global relevance and equity of STEM teacher professional development.

Keywords: Emerging technologies, Equity in mathematics, Mathematics education, Professional development, Systematic literature review
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Introduction

The National Council of Teachers of Mathematics (NCTM, 2023) and Bray and Tangney (2016) define emerging technologies as tools that transition traditional, teacher-centered instruction to student-centered, inquiry-based learning environments. These technologies promote collaboration, critical thinking, and deeper engagement with mathematical concepts beyond textbook learning. Examples include dynamic math programs like GeoGebra and Desmos (Kartal & Çınar, 2024); adaptive learning systems such as ALEKS and DreamBox Learning (Meletiou-Mavrotheris & Prodromou, 2016); virtual and augmented reality tools like Google Expeditions and CoSpaces Edu (Moon et al., 2024); and collaborative platforms such as Padlet and Microsoft Teams (Lyublinskaya & Du, 2024). NCTM (2023) emphasizes that mathematics education involves the teaching and learning of concepts, processes, and applications to enhance students' understanding, fluency, reasoning, and attitudes toward mathematics. Bray and Tangney (2016) further describe it as a dynamic, context-sensitive process that prioritizes student-centered, technology-integrated strategies over traditional lectures. They outline three instructional approaches: traditional teaching, inquiry-based learning, and technology-enhanced mathematics education.

Equity in mathematics education, as defined by NCTM (2023), extends beyond equal access to include the removal of systemic barriers and biases, ensuring that all students, especially those from marginalized backgrounds, can thrive. Bray and Tangney (2016) highlight key components of equitable math instruction: access to quality resources, culturally responsive teaching, systemic reforms, differentiated instruction, and inclusive technology use. Professional development needs vary significantly between pre-service teachers and in-service teachers. Pre-service teachers' professional development programs emphasize foundational knowledge (Davis & Witt, 2022), pedagogical theory (Lyublinskaya & Du, 2024), and introductory technology integration (Li et al., 2024), preparing future teachers for technology use during student teaching. In contrast, in-service teachers' professional development programs address real-time classroom challenges, focusing on advanced instructional strategies (Blanchard et al., 2016), current classroom issues (Liu et al., 2018), and emerging technologies (Mailizar et al., 2021).

Structurally, pre-service teachers' professional development programs are typically longer in duration and embedded in teacher education development through coursework, practicum, and mentorship (Akçay, 2024). In-service teachers' professional development programs, however, are often shorter and more flexible, delivered through workshops or online modules that respond to immediate instructional needs, such as using learning management systems to tailor lessons (Ratnayake et al., 2020). Regarding technology use, pre-service teachers are introduced to general digital tools with limited classroom application (Dockendorff & Zaccarelli, 2024), while in-service teachers receive hands-on training with emerging technologies for day-to-day use (Xie et al., 2017). The approaches to equity also differ since pre-service teachers tend to address equity from a theoretical standpoint (Kartal & Çınar, 2024), whereas in-service teachers professional development programs emphasize practical classroom strategies for fairness and inclusion (Hidayat & Firmanti, 2024). Both types of professional development programs are critical in equipping teachers to integrate emerging technologies in ways that promote equity and inclusiveness in STEM education.

Research Problem

The integration of emerging technologies into mathematics education holds strong potential to enhance conceptual understanding, engagement, and instructional effectiveness; however, this potential remains unevenly realized across educational contexts. A persistent challenge is the limited capacity of teachers to meaningfully integrate digital tools into mathematics instruction. Many educators report low confidence and insufficient pedagogical preparation to use technologies such as GeoGebra, artificial intelligence–supported tools, and game-based platforms in ways that support deep mathematical learning rather than surface engagement (Agyei & Voogt, 2011; Kartal & Çınar, 2024). Although short-term workshops are common, research consistently indicates that fragmented professional development fails to translate into sustained instructional change, particularly when technology use is not grounded in content-specific pedagogy and classroom practice (Saralar-Aras & Türker-Biber, 2024; Xie et al., 2017).

These challenges are compounded by structural and contextual inequities. Access to reliable digital infrastructure, devices, and technical support remains highly uneven, especially between urban and rural schools and across socioeconomic contexts (Hidayat & Firmanti, 2024; Tan & Hew, 2017). As a result, while some schools experiment with advanced tools such as robotics, VR, or adaptive platforms, others struggle with basic connectivity, limiting equitable opportunities for technology-enhanced mathematics learning (Liang et al., 2023). Even when technologies are available, they are frequently underutilized or misaligned with curricular goals, leading to superficial use that does not support conceptual understanding, problem solving, or higher-order thinking (Baser et al., 2021; Buss et al., 2018).

Within mathematics education specifically, instruction continues to be dominated by procedural approaches and high-stakes testing, with limited emphasis on inquiry-based learning, real-world modeling, and conceptual reasoning (Reichert et al., 2020; Yılmaz et al., 2021). Although tools such as GeoGebra and Desmos have demonstrated potential to support visualization, multiple representations, and exploratory learning, many teachers lack the pedagogical strategies needed to integrate these tools effectively, particularly for diverse learners (Arhin et al., 2024; Chen & Wu, 2020). Consequently, students, especially those from marginalized backgrounds, students with disabilities, and English language learners, often experience mathematics as abstract and disconnected from real-life contexts, reinforcing existing achievement gaps (Blanchard et al., 2016; Radović et al., 2019).

Despite growing interest in emerging technologies, significant research gaps remain. There is limited longitudinal and design-based evidence examining how sustained, technology-integrated professional development influences teachers' conceptual understanding, technological fluency, and instructional competence over time (Mailizar et al., 2021). Moreover, few studies explicitly investigate whether technology-enhanced mathematics instruction mitigates or perpetuates educational inequities, particularly in under-resourced settings (Nicholas & Fletcher, 2017; Qiu & Leung, 2022). This gap emphasizes the need for research that systematically examines how well-designed, constructivist, and equity-oriented professional development can support teachers in using emerging technologies, such as GeoGebra, to foster meaningful, inclusive, and conceptually rich mathematics learning.

Purpose of the Study

The purpose of this SLR was to systematically identify, evaluate, and synthesize existing research on emerging trends in mathematics education. By applying a rigorous and transparent review process, the study aimed to minimize bias, provide a reliable overview of current knowledge, identify key trends and gaps in the literature, and inform future research directions and educational practice.

Research Questions

This SLR sought to answer the following research questions:

1. What are the characteristics of sampled studies on K-12 S-T-E-M/STEM teacher professional development in Emerging Technologies, Mathematics Education, and Equity published in peer-reviewed journal articles between the years 2009 and 2024 (Figure 2)?
2. What patterns exist in Emerging Technologies (Figure 3), Mathematics Education (Figure 4), and Equity (Figure 5)?

Methods

This study adopted SLR methodology to examine the selected body of research. As noted by Hidayat and Firmanti (2024), this approach provides a structured, transparent, and replicable process that supports rigorous synthesis and informs future scholarship. Prior studies further demonstrate that systematic reviews effectively advance theoretical understanding and pedagogical insight across diverse educational contexts (Cheah et al., 2023; Li et al., 2024). Accordingly, this methodology is well suited for analyzing peer-reviewed journal articles published between 2009 and 2024 that address emerging trends in K–12 S-T-E-M/STEM teacher professional development, with a focus on technology, mathematics, and equity initiatives.

SLR articles search

The study data was drawn from literature obtained between January and December 2024 from the following databases: Google Scholar, Scopus, Web of Science (WoS), Educational Resources Information Center (ERIC), and Journal Storage (JSTOR). This population was selected for its accessibility and comprehensive academic coverage of the relevant literature sought. To determine the pre-service teachers' sample, key words included: "emerging technologies" OR "technology" OR "ict" AND "mathematics education" OR "K–12 mathematics" OR "mathematics" AND "pre-service teachers" OR "K–12 teacher candidates" AND "professional development." To determine the in-service teachers' sample, key words included: "emerging technologies" OR "technology" OR "ict" AND "mathematics education" OR "K–12 mathematics" OR "mathematics" AND "practicing teachers" OR "K–12 teacher" OR "K–12 tutors" AND "professional development." The keywords for special topic included: "emerging technologies" OR "K–12 mathematics" AND "equity" AND "professional development." The search was limited to publications from 2009 to 2024 to allow for inclusion of both established and emerging perspectives relevant to the study. Articles were mostly drawn from journals and databases, including Springer, Taylor & Francis, Elsevier, ERIC, Wiley, Sage, and MDPI etc.

SLR article selection criteria

Figure 1 describes the identification, screening, eligibility, and inclusion processes used in this systematic review.

Figure 1

PRISMA 2020 Flow Diagram (Page et al., 2021).

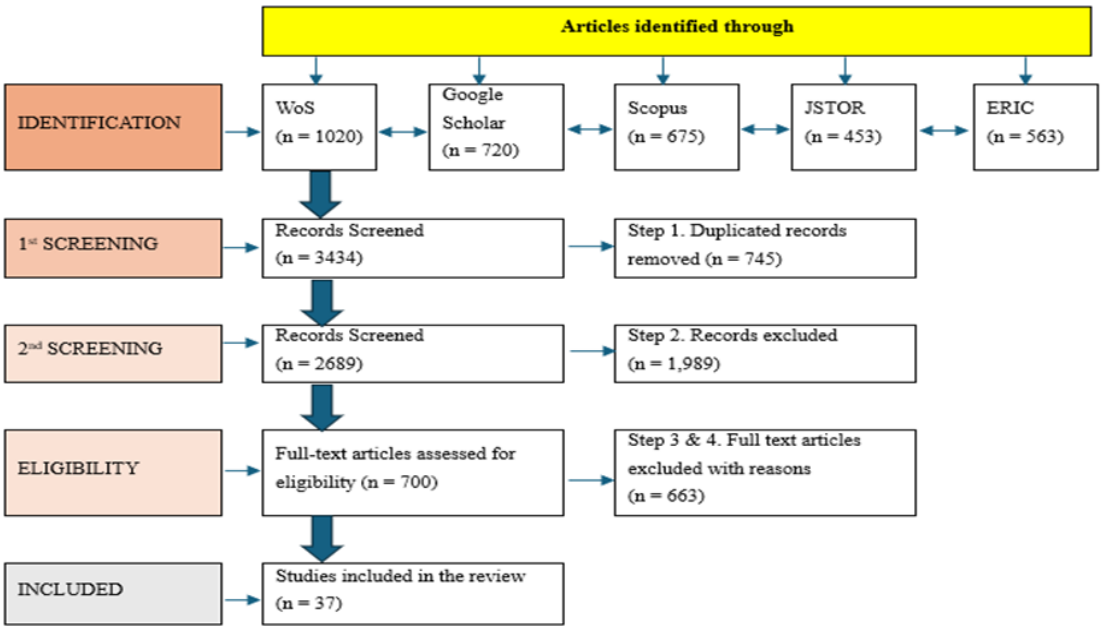

Figure 1 illustrates the article selection process aligned with the PRISMA 2020 guidelines (Page et al., 2021). The identification phase involved a comprehensive database search that yielded 3,434 records from Web of Science (1,020), Google Scholar (720), Scopus (675), JSTOR (453), and ERIC (566). After the initial screening, 745 duplicate entries were detected and removed. The second screening stage involved reviewing 2,689 records against predefined inclusion criteria, which required studies to be peer-reviewed journal articles published between 2009 and 2024, written in English, and explicitly addressing emerging trends in mathematics education (technology, mathematics and equity); this resulted in the exclusion of 1,989 records. Consequently, 700 full-text articles were retained for eligibility evaluation. During the eligibility phase (Steps 3 and 4), full-text articles were excluded if they focused solely on student outcomes, were limited to higher education contexts, or consisted of non-English publications, dissertations, books, or studies not directly related to emerging trends in mathematics education (technology, mathematics and equity) or teacher professional development (n = 663). Following this full-text assessment, 37 studies met all inclusion criteria and were included in the final review. Of these studies, 12 were indexed in Web of Science, 9 in Scopus, 8 in Google Scholar, 7 in JSTOR, and 1 in ERIC. This multi-stage selection process enhanced transparency, minimized selection bias, and produced a clearly defined, methodologically robust evidence base for synthesizing research on emerging trends and professional development in mathematics education.

Data Extraction

Data from the 37 included studies were systematically extracted using Garrard’s (2004) Matrix Method, a widely recognized approach for conducting SLRs (Cho & Egan, 2009). Review matrices were developed in Excel to consistently capture essential study attributes, including research aims, guiding questions, participant characteristics, data sources, analytical methods, and instructional interventions. The matrices also recorded key findings and relevant contextual information, such as emerging themes, analytical insights, and reflective notes, all of which were intentionally aligned with the review’s research questions.

Coding Procedure.

Data coding and analysis were conducted by a single researcher using a structured and systematic coding framework aligned with the study’s research questions. Single-coder analysis is appropriate in systematic literature reviews where clearly defined inclusion criteria, coding categories, and iterative review procedures are applied to ensure consistent interpretation across studies (Garrard, 2009; Xiao & Watson, 2019). This approach has been widely used in education-focused SLRs, particularly when the emphasis is on synthesizing trends, patterns, and thematic relationships rather than calculating inter-rater agreement (Cheah et al., 2023). Through repeated review and refinement of codes, the analysis-maintained coherence and analytical rigor while supporting a focused synthesis of findings across the selected literature.

Results

Figure 2 illustrates the descriptive analysis of the main characteristics of the sampled studies included in the SLR.

Figure 2

Characteristics of sample studies

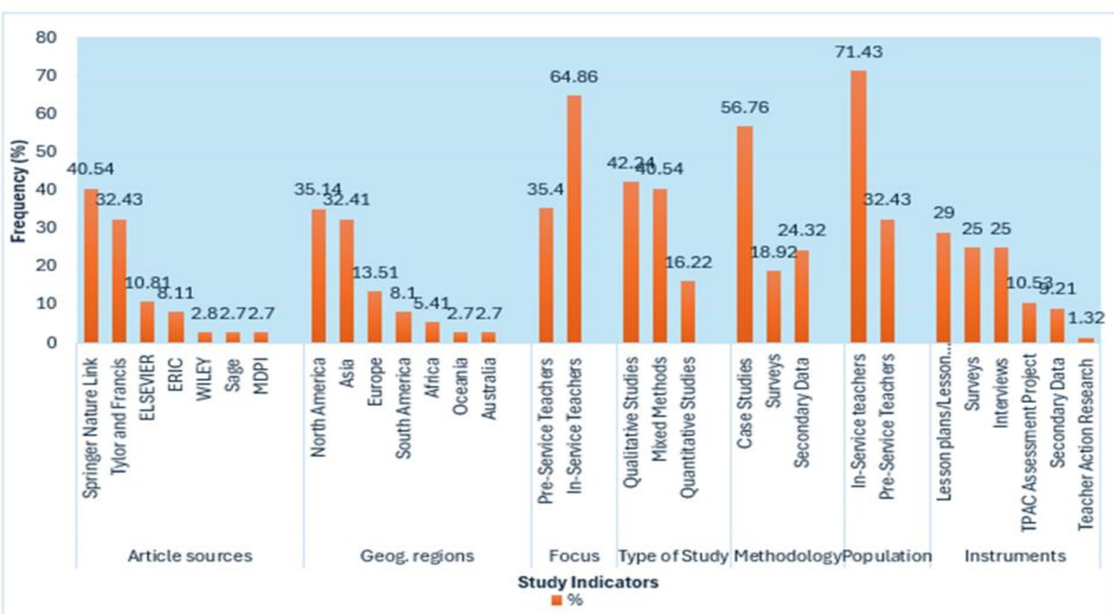

Figure 2 presents the descriptive analysis of key study indicators across the sampled literature. Analysis by publication outlet shows that Springer Nature accounted for the largest share of studies (40.54%), followed by Taylor & Francis (32.43%), Elsevier (10.81%), ERIC (8.11%), and smaller proportions from Wiley, SAGE, and MDPI (each 2.70%). Geographically, the studies were predominantly conducted in the United States (35.14%) and Asia (32.41%), with additional representation from Europe (13.51%), South America (8.10%), Africa (5.41%), Oceania (2.70%), and Australia (2.70%). In terms of research focus, most studies examined in-service teachers (64.86%), while 35.40% focused on pre-service teachers. Methodologically, qualitative approaches were most common (42.24%), followed closely by mixed-methods designs (40.54%), with fewer studies employing quantitative methods (16.22%). Case studies dominated the research designs (56.76%), while secondary data analyses (24.32%) and survey-based studies (18.92%) were less frequent. Regarding participants, most studies involved in-service teachers (71.43%), compared to those focusing on pre-service teachers (32.43%). Finally, a review of data collection instruments revealed that surveys and interviews were most frequently used (each 25%), followed by lesson plans, observations, teaching portfolios, and class assignments (20%), TPACK assessment projects (10.53%), secondary data sources (9.21%), and teacher action research (1.32%).

Figure 3 summarizes the patterns of digital and innovative technology use in mathematics education identified in the reviewed studies.

Figure 3

The Use of Digital and Innovative Technology in Mathematics Education.

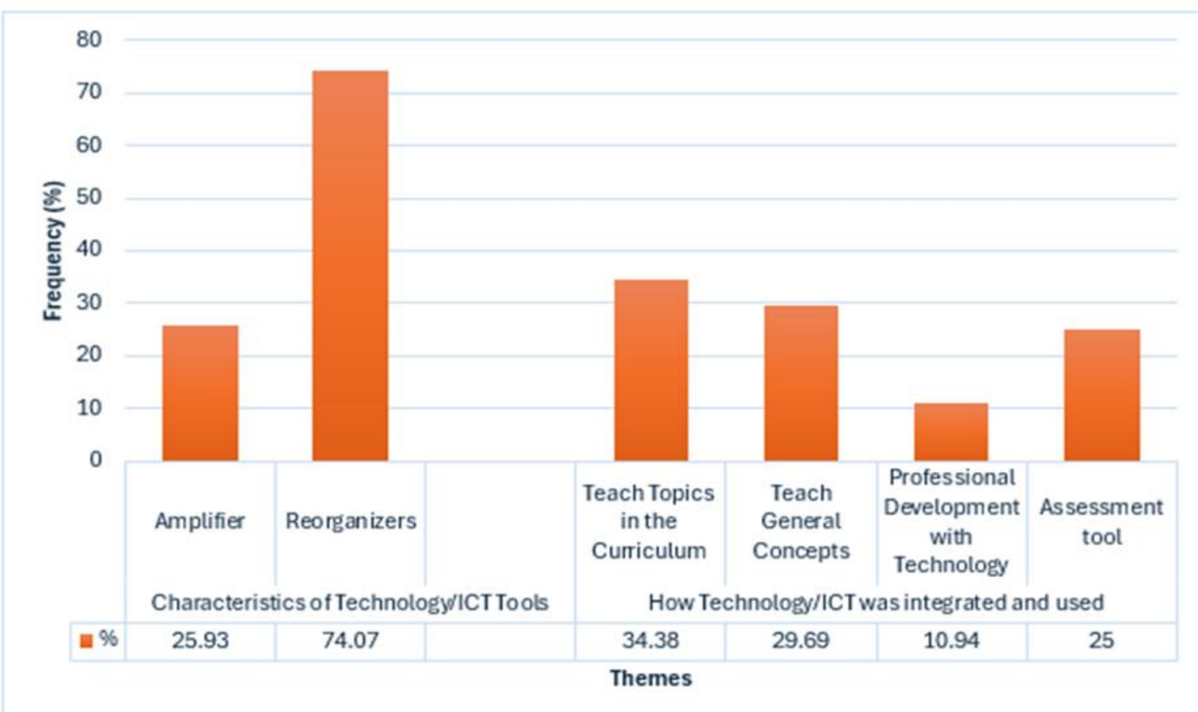

Figure 3 summarizes the use of digital and innovative technologies in mathematics education across the reviewed studies, organized into key thematic categories. The first theme examines how technology was conceptualized, revealing that most studies framed digital tools as reorganizers of instruction (74.07%), while a smaller proportion viewed them as amplifiers of existing practices (23.93%). The second theme highlights instructional integration, indicating that technologies were most used to support the teaching of specific mathematics topics (34.38%) and general mathematical concepts (29.69%), followed by assessment purposes (25%) and professional development activities (10.94%).

Figure 4 provides an overview of mathematics education–focused information extracted from the studies included in this review.

Figure 4

Information on Mathematics Education

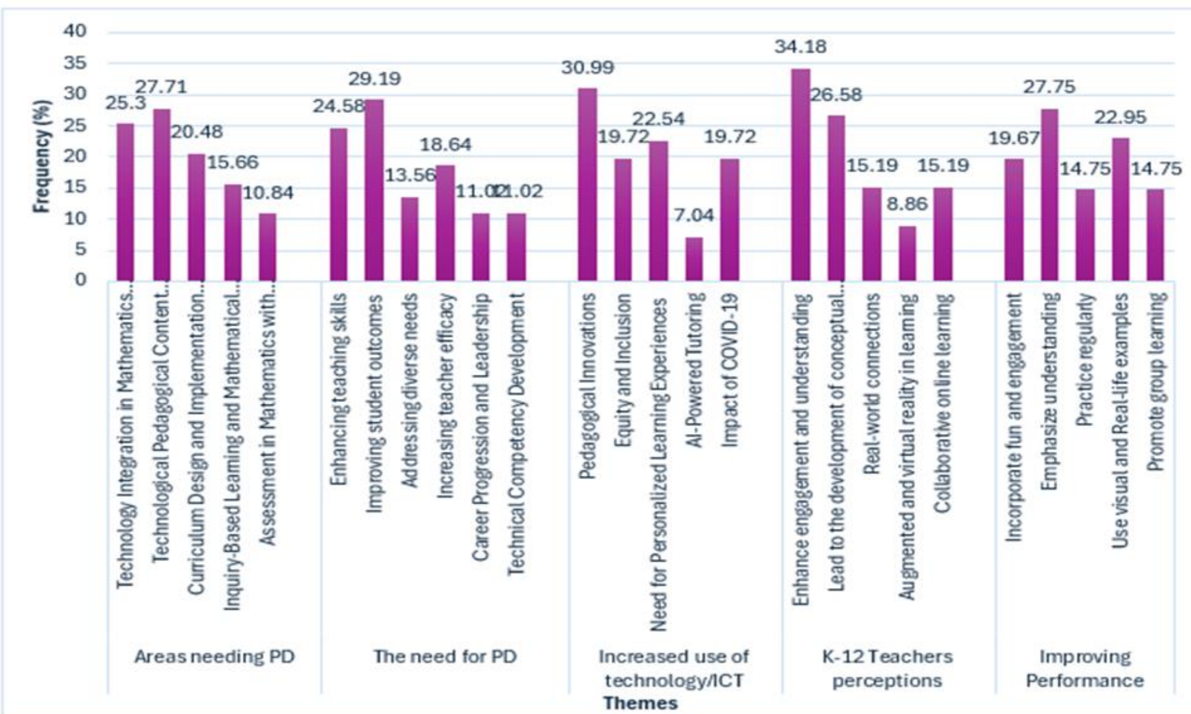

Figure 4 summarizes key findings on mathematics education across five thematic areas. Professional development priorities included TPACK (27.71%), technology integration in mathematics instruction (25.30%), curriculum design with technology (20.48%), inquiry-based learning (15.66%), and technology-supported assessment (10.84%). Reasons for mathematics teachers' professional development focused on improving student outcomes (29.19%), enhancing teaching skills (24.58%), increasing teacher efficacy (18.64%), addressing diverse learner needs (13.56%), and supporting career advancement (11.02%). Drivers of increased technology use included pedagogical innovation (30.99%), personalized learning (22.54%), equity and inclusion (19.72%), COVID-19 impacts (19.72%), and AI-powered tutoring (7.04%). Reported benefits of technology use were enhanced student engagement and understanding (34.18%), conceptual development (26.58%), real-world connections (15.19%), collaborative learning (15.19%), and augmented and virtual reality applications (8.86%). Instructional practices associated with improved mathematics performance emphasized conceptual understanding (27.75%), visual and real-life representations (22.95%), engaging instruction (19.67%), regular practice (14.75%), and collaborative learning (12.75%).

Figure 5 summarizes key information on the equitable use of technologies in mathematics education, drawn from the studies included in this review.

Figure 5

Information on Equity in the Use of Technologies in Mathematics Education.

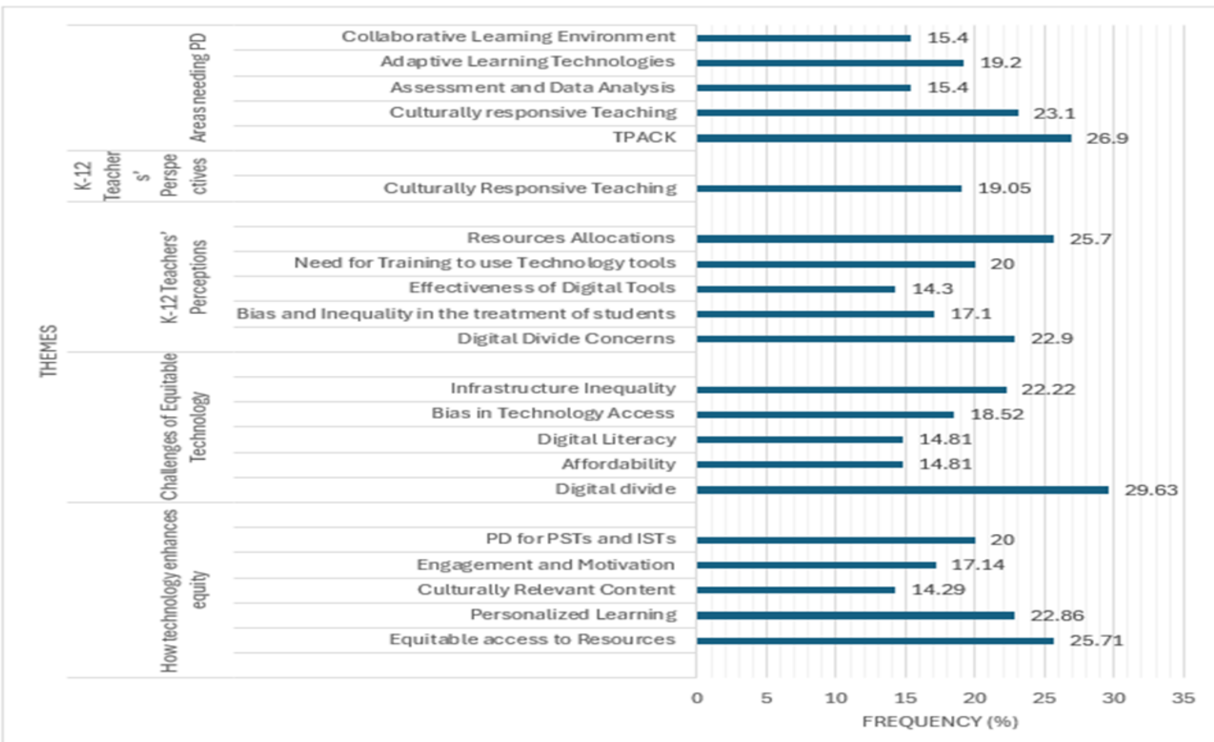

Figure 5 summarizes equity-focused findings on technology use in mathematics education across five themes. Technology supported equitable access to mathematics resources (25.71%), personalized learning (22.86%), professional development for pre-service and in-service teachers (20.00%), student engagement (17.14%), and culturally relevant instruction (14.29%). Key barriers included the digital divide (29.63%), infrastructure inequities (22.22%), biased access to technology (18.52%), and challenges related to affordability and digital literacy (14.81%). Teachers reported inequities in resource allocation (25.70%), unequal access across socioeconomic and geographic contexts (22.90%), and the need for targeted professional development on digital tool use (20.00%). Inclusivity-related perspectives emphasized culturally responsive and differentiated instruction (19.05%), sustained professional learning (21.43%), and community engagement (11.90%). Priority professional development needs focused on TPACK (26.90%), culturally responsive pedagogy (23.10%), adaptive learning technologies (19.20%), and collaborative learning and assessment practices (15.40%).

Discussion

Figure 2: Study Indicators

The findings presented in Figure 2 align closely with existing literature on professional development in mathematics education, particularly the sustained emphasis on in-service teachers. Prior studies consistently foreground in-service teachers because they are actively engaged in classroom implementation and face immediate demands related to technology integration, instructional adaptation, and equity-driven practice (Blanchard et al., 2016; Arhin et al., 2024). At the same time, the inclusion of pre-service teachers in a substantial portion of the reviewed studies extends the literature by highlighting the importance of early exposure to TPACK during initial teacher preparation (Kartal & Çınar, 2024; Lyublinskaya & Du, 2024). This dual focus supports earlier work by Agyei and Voogt (2011), who argue that embedding ICT-rich experiences in pre-service programs, particularly in under-resourced contexts, builds foundational competence and reduces later resistance to technology use.

Methodologically, the dominance of qualitative and mixed-methods designs, particularly case studies, reflects a broader trend in mathematics education research toward capturing the complexity of instructional change and teachers' sense-making processes (Moon et al., 2024; Li et al., 2024). Qualitative approaches have been shown to be especially effective in examining teachers' beliefs, attitudes, and pedagogical reasoning related to technology integration (Gonscherowski & Rott, 2022). Mixed-methods designs further strengthen this work by linking rich classroom-level insights with broader patterns related to equity, access, and instructional outcomes (Cheah et al., 2023). Similarly, the varied use of data collection instruments, including interviews, surveys, lesson observations, and instructional artifacts, mirrors established practices in the field and emphasizes the need for multiple data sources to capture changes in TPACK, instructional practice, and professional learning trajectories (Hill & Uribe-Florez, 2020; Davis & Witt, 2022; Meletiou-Mavrotheris & Prodromou, 2016).

The geographic breadth of the reviewed studies reinforces the growing recognition that technology integration and equity in mathematics education are global concerns shaped by contextual factors. Research from regions such as Asia, Africa, Oceania, and Europe extend earlier U.S.-centric work by illustrating how infrastructure, policy, culture, and access influence technology-supported professional development programs and classroom practice (Hidayat & Firmanti, 2024; Nicholas & Fletcher, 2017; Qiu & Leung, 2022). These studies emphasize equity not only in terms of access to digital tools but also in culturally responsive implementation and gender inclusion, particularly in STEM pathways (Liang et al., 2023). Collectively, the findings support the view that emerging technologies function not merely as instructional supplements but as catalysts for pedagogical reorganization, with implications for teacher learning, equity, and systemic reform in mathematics education (Cheah et al., 2023; Li et al., 2024).

Figure 3: The Use of Digital and Innovative Technology in Mathematics Education

The reviewed literature both affirms and extends current understandings of emerging technologies in mathematics education, highlighting the critical role of professional development, pedagogical alignment, infrastructure, and equity (Figure 3). Across pre-service and in-service teacher contexts, studies consistently show that effective technological integration requires early and sustained opportunities to develop TPACK. For instance, Agyei and Voogt (2011) identify persistent gaps in pre-service preparation, where limited exposure often confines technology use to surface-level, amplifier functions. As an amplifier, technology tends to support static representations, such as textbook-related tasks and basic applications including Zoom, Nearpod (basic use), Moodle, Digital Content Evaluation, ICT Tool Alternatives, and Traditional Tools in Remote Education, which aligns with Sherman's (2014) observation that a substantial portion of classroom technology use remains procedural. In contrast, Davis and Witt (2022) and Kartal and Çınar (2024) demonstrate that when teachers engage in targeted, scaffolded learning with tools like GeoGebra, technology can act as a reorganizer, fostering dynamic, interactive representations that enhance conceptual understanding and higher-order reasoning. Examples of such reorganizing technologies include GeoGebra, spreadsheets, TI-Nspire, Cabri, virtual manipulatives, touchscreens and tablets, dynamic geometry software, web-based resources (e.g., animations, videos, podcasts), game-based learning, adaptive learning platforms, gamification, robotics-integrated professional development, automated feedback systems, art integration in mathematics, blended professional development, 3D design and printing tools, computational thinking, ICT-enabled inclusive learning, the eZbirka communication system, and interactive tools for remote learning.

At the same time, the literature cautions against viewing TPACK development as a linear process. Lyublinskaya and Du (2024) show that teachers' technological growth varies considerably and requires sustained, iterative learning experiences rather than isolated workshops. This insight reinforces calls for long-term, practice-embedded professional development models, particularly in under-resourced settings. Research on rural and high-poverty contexts further highlights structural inequities that constrain implementation. Blanchard et al. (2016) and Hidayat and Firmanti (2024) confirm that limited infrastructure, inconsistent access to devices, and inadequate contextualized training continue to hinder equitable technology integration. These challenges are compounded by the lack of robust longitudinal evidence on the instructional impact of emerging tools such as robotics and VR, with studies noting that innovations are often adopted without sufficient evaluation of pedagogical coherence or long-term outcomes (Mailizar et al., 2021; You et al., 2021).

Equity and inclusivity emerge as critical yet unevenly addressed dimensions of technology-enhanced mathematics education. Nutov (2021) and Saralar-Aras and Türker-Biber (2024) extend the literature by illustrating how culturally responsive and inclusive ICT-supported instruction can broaden access and participation for marginalized learners. However, resistance to technology, rooted in discomfort, perceived threats to traditional practices, and emotional factors, continues to limit adoption (Gonscherowski & Rott, 2022; Hill & Uribe-Florez, 2020; Thurm, 2020). While emerging strategies such as game-based learning show promise in increasing engagement and conceptual understanding, their limited presence in professional development contexts points to missed opportunities (Meletiou-Mavrotheris & Prodromou, 2016; Moon et al., 2024). Collectively, the literature emphasizes that technology can serve as a catalyst for equitable pedagogical reform only when supported by sustained professional development, intentional design, and systemic attention to access, teacher beliefs, and contextual realities.

Figure 4: Information on Mathematics Education

The reviewed literature confirms that mathematics education requires substantial reform to address persistent gaps in technology integration, equity, curriculum relevance, and professional development, particularly at the pre-service teacher level as shown in Figure 4. Across studies, the development of TPACK emerges as a central priority, reinforcing findings from this review that identified TPACK as the most critical professional development need. Agyei and Voogt (2011) affirm that even in low-resource contexts, structured and purposeful professional development enables pre-service teachers to move beyond superficial technology use. This is extended by Lyublinskaya and Du (2024), who show that pre-service teachers TPACK development follows non-linear trajectories and benefits from sustained, targeted exposure to tools such as GeoGebra and Desmos. Similarly, Kartal and Çınar (2024) demonstrate that platform-specific training not only strengthens pre-service teachers' technological competence but also enhances pedagogical creativity and instructional confidence, emphasizing the importance of embedding technology deeply within teacher preparation programs.

A consistent theme across the reviewed studies is the need to shift mathematics instruction away from procedural approaches toward conceptual understanding and inquiry-based learning. Davis and Witt (2022) support this shift by illustrating how technology functions as a reorganizer of mathematical thinking, enabling students to explore relationships, representations, and reasoning rather than rote procedures. This aligns with broader critiques of the underuse of inquiry-based learning in mathematics education (Reichert et al., 2020). Extensions of this work highlight the role of technology-supported formative assessment in reinforcing conceptual learning, as digital feedback tools provide timely insights that support reasoning and reflection (Weigand et al., 2024). Saralar-Aras and Türker-Biber (2024) further demonstrate that engaging pre-service teachers in technology-based lesson planning strengthens their capacity to design inquiry-driven instruction, suggesting that pedagogical practice, not tool familiarity alone, is essential for meaningful integration.

Equity, engagement, and inclusivity represent another critical dimension of the findings. Game-based learning and gamified platforms are consistently identified as effective strategies for increasing motivation, fostering growth mindsets, and supporting pedagogical flexibility among pre-service teachers, yet they remain underutilized in professional development contexts (Meletiou-Mavrotheris & Prodromou, 2016; Moon et al., 2024). Studies emphasizing culturally responsive and inclusive approaches extend this discussion by showing how technology can support diverse learners, including students with disabilities and multilingual backgrounds, when instruction is grounded in real-world relevance and cultural context (Blanchard et al., 2016; Nutov, 2021; Dockendorff &

Zaccarelli, 2024). At the same time, research by Gonscherowski and Rott (2022) challenges the assumption that access and training alone guarantee adoption, revealing that teacher beliefs, confidence, and professional identity strongly shape technology use. Collectively, these findings suggest that effective professional development must move beyond technical skill-building to address mindset, equity, and pedagogical adaptability, positioning emerging technologies as tools for inclusive, conceptually rich, and socially responsive mathematics education.

Figure 5: Information on Equity in the Use of Technologies in Mathematics Education.

The reviewed literature consistently affirms that equitable technology integration in mathematics education is constrained by interconnected challenges related to teacher preparedness, access, and instructional design, while also extending understanding of how these barriers can be addressed through targeted professional development as shown in Figure 5. Central to this discussion is TPACK, which emerged as a dominant professional development need in the reviewed studies. Empirical evidence demonstrates that pre-service teachers who engage with dynamic tools such as GeoGebra develop stronger pedagogical strategies, improved instructional confidence, and greater capacity to support diverse learners (Kartal & Çınar, 2024). These findings align with broader TPACK research showing that technology integration is most effective when it is content-specific and pedagogically grounded rather than tool-driven (Li et al., 2024). Importantly, scholars caution that TPACK development is not achieved through isolated workshops; instead, sustained and iterative exposure embedded within teacher preparation programs is necessary to support equitable and meaningful technology use (Kartal & Çınar, 2024; Li et al., 2024).

Beyond technical competence, the reviewed studies highlight teachers' beliefs and assumptions as critical factors shaping equitable technology use. Studies reveal that some teachers resist digital tools due to deficit-oriented perceptions of students from low socioeconomic backgrounds, reinforcing inequities in access and instructional opportunity (Gonscherowski & Rott, 2022). This aligns with documented concerns regarding bias, unequal treatment, and gaps in digital literacy that disproportionately affect marginalized learners (Hill & Uribe-Florez, 2020). Addressing these issues requires professional development programs that explicitly engages teachers in reflective practice, challenges implicit biases, and emphasizes inclusive pedagogical reasoning alongside skill development (Gonscherowski & Rott, 2022). At the instructional level, emerging evidence positions game-based learning (GBL) as a promising but underutilized equity-oriented strategy. Research shows that well-designed games can support personalized learning, increase engagement, and foster cultural relevance by connecting mathematical ideas to students lived experiences and local contexts (Meletiou-Mavrotheris & Prodromou, 2016; Moon et al., 2024).

Structural inequities related to infrastructure and curriculum further complicate efforts toward equitable technology integration. Cross-national studies confirm that access to digital tools and reliable infrastructure remains uneven, particularly in rural and underfunded schools, with direct implications for mathematics achievement and participation (Tan & Hew, 2017). These findings are reinforced by research demonstrating that even when technologies are available, outdated curricula and limited alignment with technological realities can marginalize students and restrict meaningful use (Hidayat & Firmanti, 2024). However, evidence from technology-enhanced professional development initiatives in high-poverty and rural contexts indicates that sustained, context-sensitive support can improve teacher confidence and student engagement in mathematics (Blanchard et al., 2016). Importantly, student perspectives further extend equity discussions, with research showing that learners' perceptions of fairness, accessibility, and relevance influence their acceptance of digital instruction, particularly during periods of remote learning (Xie et al., 2021). Collectively, these findings emphasize the need for multi-pronged, equity-driven reforms that integrate sustained professional learning, culturally responsive pedagogy, student-centered design, and systemic investment to ensure that technology serves as a catalyst for inclusion rather than a source of further disparity in mathematics education.

Conclusion

Limitations of the SLR.

This review was limited to 37 articles, which restricted the scope of analysis and may have excluded relevant or contrasting perspectives. By focusing solely on peer-reviewed journal articles, the inclusion criteria enhanced quality control but potentially introduced publication bias by omitting dissertations, books, and gray literature. In addition, the emphasis on professional development for pre- and in-service teachers and on emerging technologies in mathematics education may have excluded studies addressing broader instructional contexts, while the exclusion of student-outcome and higher-education research further narrowed the focus. The search was confined to selected databases such as Google Scholar, Scopus, WoS, ERIC, and JSTOR) and publishers (e.g., Springer, Taylor & Francis, Elsevier, ERIC, Wiley, Sage, MDPI, etc.) and to studies published between 2009 and 2024, ensuring contemporary relevance but possibly overlooking foundational work. Finally, time and resource constraints inherent in conducting SLR limited the depth of analysis; therefore, these findings should be interpreted with appropriate caution.

Implications for Research and Practice

The findings of this review emphasize important implications for research, practice, and policy in K–12 mathematics education. Future research should prioritize professional development models that integrate equity and instructional effectiveness, with particular emphasis on strengthening teachers' use of assessment and data to support diverse learners. Continued inquiry into adaptive learning technologies is also needed, alongside targeted professional learning that enables inclusive and personalized mathematics instruction. For practice, the findings highlight the importance of sustained professional development in culturally responsive teaching and the development of strong TPACK to support confident, coherent, and pedagogically grounded technology integration. School leaders and education systems are encouraged to invest in reliable infrastructure, ongoing teacher support, and coherent professional learning models rather than isolated training initiatives. At the policy level, the evidence calls for equity-driven technology integration policies that ensure broad access to digital resources and align curriculum, assessment, and professional development with emerging technologies. Collectively, these implications emphasize that meaningful technology integration in mathematics education requires coordinated action across classrooms, institutions, and policy frameworks to ensure equitable learning opportunities for all students.

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