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Integrating Technology in Mathematics Education: A Research Synthesis of Learning Outcomes and Pedagogical Implications

Roni Amaludin[1], Irwan Akib[1], Sukmawati[1]
[1]Universitas Muhammadiyah Makassar, South Sulawesi, Indonesia

Corresponding author e-mail: roni@umkendari.ac.id

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Abstract: The integration of digital technologies is transforming mathematics education, yet empirical findings on its impact remain varied. This research synthesis examines the effects of technology integration on learning outcomes and pedagogical practices. A systematic search of the Scopus database was conducted for peer-reviewed articles published between 2020 and 2024 using keywords such as "technology integration," "digital learning," and "mathematics education." The synthesis of 20 studies indicates that tools like GeoGebra, Augmented Reality (AR), and Artificial Intelligence (AI) enhance conceptual understanding, student engagement, and personalized learning. Furthermore, pedagogical approaches like Realistic Mathematics Education (RME) and Flipped Learning, when combined with technology, foster active and student-centered environments. The critical role of teacher digital competence (TPACK) was a consistent theme. While technology shows significant benefits, future efforts must address equitable access, develop effective feedback mechanisms, and explore culturally adaptive AI applications to ensure inclusive and sustainable integration.

Keywords: Learning Outcomes, Math Education, Pedagogical Implications, Research Synthesis, Technology Integration

A. Introduction

The 21st-century environment of mathematics education has been drastically altered by the quick development of digital technology. Through visualization, interaction, and adaptive feedback, emerging technologies like artificial intelligence (AI), augmented reality (AR), and game-based learning environments present exciting prospects to promote mathematics knowledge (Awang et al., 2025; Nandiyanto & Sidik, 2026; Saat et al., 2024). Global educational agendas that prioritize digital competency, individualized learning, and the development of higher-order cognitive abilities necessary for sustained knowledge economies are in line with these technologies (González-Salamanca et al., 2020; Ye et al., 2023). Because of its potential to improve students' engagement, problem-solving, and conceptual reasoning, the use of technology in mathematics instruction has garnered a lot of scholarly attention.

Despite this increased attention, empirical research on how technology affects arithmetic learning is still dispersed and occasionally inconsistent. While many studies show that using digital tools improves student motivation and achievement significantly (Li et al., 2022; Ramaila & Mpinga, 2022), other studies show little to no effect, frequently because of differences in instructional design, implementation fidelity, and contextual factors (Armstrong & Landers, 2018). Numerous studies limit the generalizability of their findings by using small sample sizes, brief intervention durations, or unreliable experimental designs. These methodological flaws make it difficult to develop a cohesive knowledge of the best times and ways for technology to support learning outcomes in mathematics.

The unequal adoption of technology in various educational environments is another enduring issue. The success of technology-enhanced learning settings is heavily influenced by elements including curriculum alignment, infrastructure availability, pedagogical views, and teachers' digital literacy (Öztop, 2023; Xie & Luo, 2025; Young, 2017). Even though particular technologies-like GeoGebra, augmented reality apps, and AI-powered platforms-have been studied separately, there isn't much data comparing how effective they are across different mathematical topics and learner groups. This suggests that in order to find broad patterns and moderating factors affecting the effects of technology interventions, thorough investigations that go beyond discrete case studies are required.

Since technology-based tools are acknowledged for their capacity to improve students' comprehension of abstract mathematical concepts, the incorporation of digital technology into mathematics education has grown in significance in the twenty-first century. Digital resources including educational games, simulations, and dynamic geometry software have been shown to increase students' motivation, engagement, and conceptual thinking (Hsu & Hsu, 2025; Schmid & Korenova, 2024). The actual use of digital tools in math classes is still uneven across various educational levels and circumstances, despite these acknowledged benefits. Lack of clear instructional models that link technology use with mathematical learning objectives, poor infrastructure, and a lack of technological pedagogical expertise are some of the issues that many teachers deal with.

The effects of integrating technology into mathematics education have been the subject of numerous research, although the results are still unclear. Some show little to no impact, while others indicate significant gains in student achievement and attitudes toward mathematics (Wen & Dubé, 2022; Yalçin & Hasan, 2018). This discrepancy could be the result of variations in the study design, the makeup of the sample, and the kinds of digital resources or teaching techniques used. Therefore, it is imperative to combine the current research in order to gain a more thorough understanding of how and when digital technology can improve learning outcomes in mathematics. Because it enables the pooling of results from several research to ascertain general patterns and effect sizes, a research synthesis approach is suitable for this goal.

The potential for technology-enhanced mathematics education has increased recently thanks to new developments like artificial intelligence (AI), augmented reality (AR), and adaptive learning systems. More individualized, interactive, and data-driven learning experiences that meet the various requirements of students are promised by these developments (Song et al., 2024). A concise, quantitative overview of how these technological interventions affect math proficiency across various learning domains and educational levels is still lacking in the literature. Therefore, performing a research synthesis on this subject can reveal important moderating elements that affect the performance of digital technology in mathematics teaching as well as offer insightful information about its overall efficacy. Teachers, curriculum designers, and legislators must have this evidence-based knowledge in order to create and carry out successful plans that support fair and long-lasting technology integration in math classes.

To fill up these gaps, a research synthesis offers a reliable way to compile the body of research on the usefulness of digital tools in math teaching. A research synthesis can estimate overall effect sizes, analyze study heterogeneity, and pinpoint important moderators that account for variances in results by combining data from several empirical investigations. In addition to bolstering the body of research, this method has important ramifications for theory, pedagogy, and policy that strive to maximize the use of technology in math classes. This synthesis aims to educate academics and educators on the best ways for technology to enhance mathematical learning and cognitive development.

The goal of this critical synthesis is to offer a thorough grasp of how research findings are used and consumed in mathematics education, especially when it comes to technology integration. Technology is now an essential part of learning mathematics due to the growth of digital innovation and the change in 21st-century pedagogy. Numerous studies have demonstrated that integrating technology, including online learning environments, augmented reality, artificial intelligence, and GeoGebra, can enhance student motivation, engagement, and learning results. The setting, instructional strategy, and level of preparedness of both teachers and students frequently affect how effective these tools are. This circumstance highlights the urgent necessity to thoroughly examine the empirical data now available in order to have a more complete understanding of the effects and pedagogical ramifications of integrating technology into mathematics instruction.

B. Methods

This study employed a systematic literature review following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency and reproducibility. A research synthesis can be defined as a systematic process of integrating and interpreting empirical findings from multiple studies with the goal of generating broader generalizations, identifying patterns, and providing a comprehensive understanding of a particular research area (Cooper et al., 2019) The inclusion and exclusion criteria were defined using the PICOS framework: Population: studies involving junior high school students, Intervention: integration of digital technology (e.g., dynamic software, AI, AR, LMS) in mathematics education, Comparison: studies with or without a control group/comparison condition were considered, Outcomes: cognitive outcomes and non-cognitive outcomes, and Study Design: empirical studies (quantitative, qualitative, mixed-methods) published in peer-reviewed journals. A systematic search was conducted in the Scopus database in 2020-2025 with keywords such as “technology integration” and “mathematics education”, peer-reviewed studies authored in English.

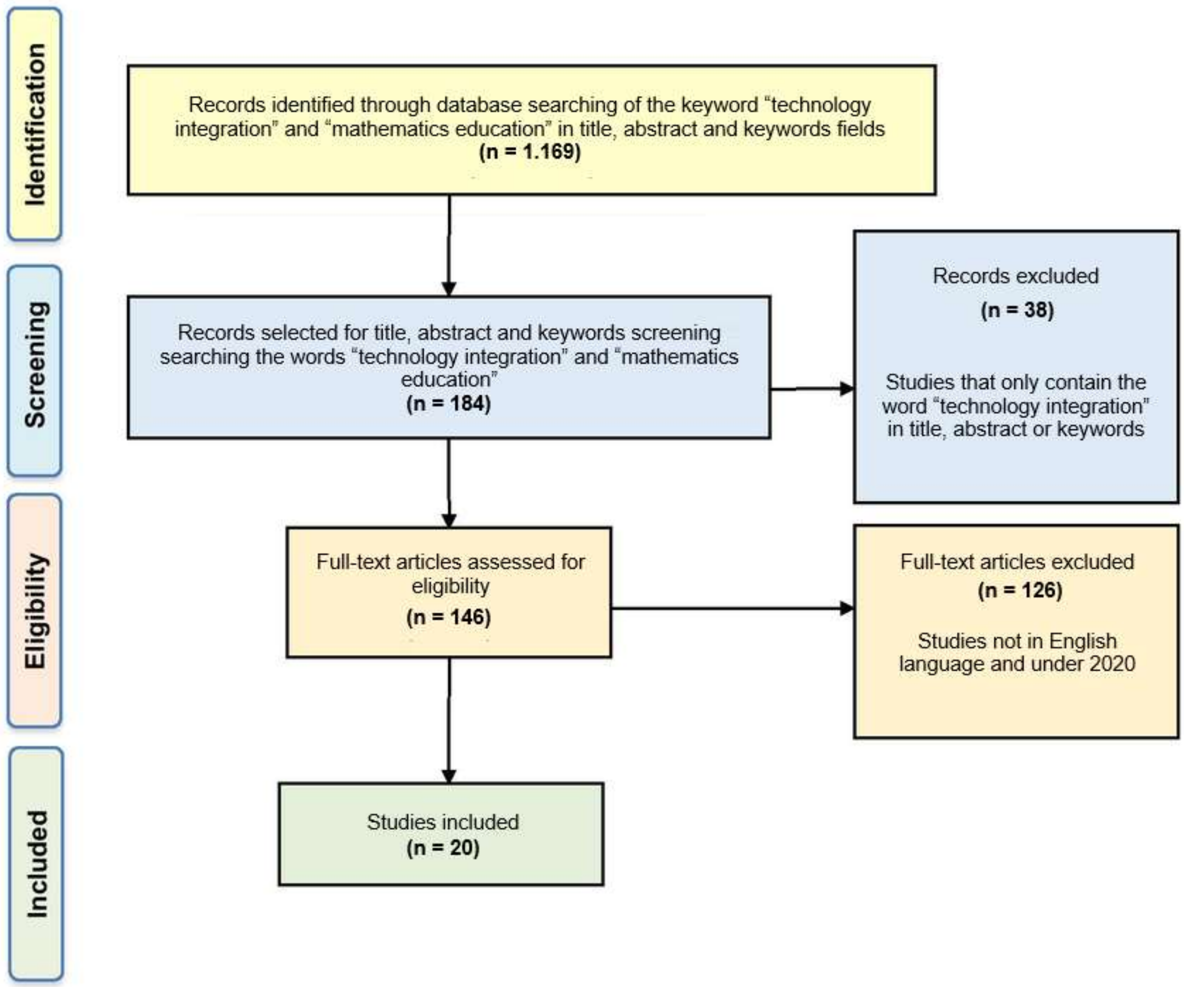

Figure 1. PRISMA Flow Diagram

This detailed analysis evaluates findings from worldwide publications to provide insights into how technology integration helped to improve mathematics teaching and learning. A standardized data extraction form was used to collect information from each study: authors, year, research objectives, methodology, technology used, key findings, and limitations. The extracted data were analyzed using thematic analysis to identify recurring themes and patterns.

C. Results and Discussion

The articles examined in this research synthesis are English-language, full-text accessible, Scopus-indexed from 2020 to 2025 works that are relevant to the study's goals. The papers that have been evaluated center on the use of digital learning and technology in mathematics education. These papers were chosen to ensure a thorough grasp of how technology affects pedagogical practices and learning outcomes by representing a variety of approaches and educational levels. The review results are shown in the following table.

Table 1. Article Review Results

No	Title	Research Results
1	Trends and insights of AI in mathematics education: A bibliometric analysis (Yıldız & Körpeoğlu, 2025)	The study conducted a bibliometric analysis of 313 publications on the use of artificial intelligence in mathematics education from 1987 to 2023. Results showed that the United States, China, and Australia lead in research output and citations, with collaboration across 28 countries. The findings highlight the growing global interest in leveraging AI to enhance cognitive skills, personalize mathematics learning, and promote sustainable development in education and applied sciences.
2	Augmented Reality for Mathematics Achievement: A Meta-Analysis of Main and Moderator Effects (Flavin et al., 2025)	The meta-analysis of 22 studies revealed that augmented reality (AR) has a medium positive effect (g = 0.765) on K-12 students' mathematics achievement. Among the examined factors, only the integration of virtual objects significantly influenced AR's effectiveness, suggesting that how virtual elements are embedded in learning activities plays a key role. The findings confirm AR's potential to enhance mathematics learning while highlighting areas for future research and pedagogical refinement.
3	Mathematics teaching, learning, and assessment in the digital age (Weigand et al., 2024)	The study reveals that digital technology has significantly enhanced mathematics education by promoting innovative teaching practices, supporting diverse learning resources, and enabling adaptive, formative assessments. It concludes that technology continues to reshape how mathematics is taught, learned, and evaluated, fostering more personalized and effective educational experiences.
4	Research on curriculum resources in mathematics education: a survey of the field (Rezat, 2024)	The survey found that from 2018 to 2023, research on curriculum resources in mathematics education remained dominated by studies on textbooks, particularly in areas such as content analysis, user studies, design, and effects. However, emerging trends include growing attention to students' use of curriculum resources and the use of digital resource data for

No	Title	Research Results
		research, signaling a shift toward more technology-driven and data-informed approaches in the field.
5	The role of digital technologies in mathematics education: purposes and perspectives (Drijvers & Sinclair, 2024)	The study concludes that digital technologies have clear benefits for mathematics learning and have driven new theoretical and design developments in the field. However, challenges remain, particularly regarding equitable access, curriculum adaptation, and assessment practices. As research shifts beyond questions of simple effectiveness, future work is urged to explore how digital technologies reshape learning time, mathematical thinking, skill development, and equity in education.
6	The Cognitive and Non-Cognitive Effects of Geogebra Integration (Ardina & Boholano, 2024)	The study found that integrating GeoGebra into geometry lessons improved students' engagement and test performance, though their motivation levels remained unchanged. A positive link was observed between engagement and motivation, but not between either of these and test performance. Despite some challenges in using GeoGebra, the results support its potential as an effective tool to enhance technology-aided instruction in geometry education.
7	Feedback in mathematics education research: a systematic literature review (Söderström & Palm, 2024)	The systematic review of studies from 2012-2021 found that most mathematics education research on feedback focused on correctness and solution processes, while feedback supporting students' self-regulation received little attention. Twelve feedback categories and five descriptive variables were identified, revealing an imbalance in research emphasis and highlighting the need for more studies exploring feedback that fosters self-regulated learning in mathematics.
8	Factors that influence student engagement with technology-enhanced resources for formative assessments in first-year undergraduate mathematics (Shé et al., 2024)	The study found that technology-enhanced formative assessment resources can effectively support undergraduate mathematics learning by helping students identify knowledge gaps and take corrective action. Through evaluations of several such resources, twelve key factors were identified that influence successful student engagement, including educational context, technology type, and communication features. These insights offer valuable guidance for designing effective technology-based learning tools in mathematics education.
9	Developing Ethnomathematical-Based Learning Stages on Mathematical Communication Skills with Kastolan Error Analysis (Hamidah & Kusuma, 2024)	The study revealed that ethnomathematics-based learning supported by GeoGebra improves students' mathematical communication skills but still requires optimization to reduce procedural errors, especially among students with medium and low ability levels. Analysis identified two key stages exercise and research as essential for minimizing errors. The proposed ethnomathematics learning model includes six stages: exploration, mapping, explanation, exercise, research, and reflection, offering a structured approach for enhancing students' mathematical communication in future studies.
10	Integrating digital technology in mathematics	The study found that the main challenge in integrating digital technology into mathematics learning lies in the social dimension of technology use. When teachers do not actively

No	Title	Research Results
	education: a Swedish case study (Viberg et al., 2023)	engage with digital tools or establish shared classroom practices, students struggle to connect technological and instructional guidance effectively. As a result, technology becomes a separate element rather than an integrated part of learning, causing confusion and reducing its potential to enhance understanding. Strengthening teacher involvement and collaborative use of digital tools is therefore essential to optimize their educational impact.
11	Embracing Digital Technologies into Mathematics Education (Gamit, 2023)	The study found that effective digital technology integration in mathematics classrooms depends on teachers' active use and clear procedures. When teachers lack consistent strategies for using the Learning Management System (LMS), students struggle to connect digital tools with instruction, leading to fragmented learning. Strengthening teachers' digital competence and classroom practices is essential for creating cohesive, technology-supported learning experiences.
12	An exploration of teacher and student perceptions of blended learning in four secondary mathematics classrooms (Attard & Holmes, 2022)	The study found that blended learning approaches in mathematics classrooms enhance student engagement by offering multiple pathways to access and understand concepts. Technology use enabled personalized learning, visualization, and dynamic interaction, while also improving feedback and communication between teachers and students. Overall, the findings suggest that blended learning can create more flexible and inclusive mathematics learning experiences tailored to individual needs.
13	Mathematical Modeling Learning Design with PISA Framework on Grade X Function (Saputri et al., 2022)	The study developed a learning trajectory for mathematical modeling of functions using an online taxibike context based on the PISA framework. Results showed that the designed learning activities effectively helped students navigate the modeling cycle formulating, employing, and interpreting/evaluating leading to improved understanding of functions and greater ability to apply modeling processes in solving real-world contextual problems.
14	Designing geometrical learning activities assisted with ICT media for supporting students' higher order thinking skills (Meryansumayeka et al., 2022)	The study developed an ICT-assisted learning trajectory for teaching cuboid volume that effectively fostered students' higher-order thinking skills. Through activities designed within the Realistic Mathematics Education (RME) framework, students demonstrated the ability to analyze, evaluate, and think creatively when solving problems. The results suggest that such ICT-based designs can guide teachers and educators in creating more effective, higher-order thinking–oriented mathematics learning experiences.
15	Digital Games and the Teaching and Learning of Mathematics: A Survey Study (Denham et al., 2022)	The study introduced and validated the Digital Game Usage in the Mathematics Classroom Survey to examine how teachers use digital games in teaching mathematics and the barriers they face. Pilot results confirmed the instrument's reliability and validity, providing a foundation for future research to better understand and support the integration of digital games in mathematics education.

No	Title	Research Results
16	Emergent modelling to introduce the distributivity property of multiplication: a design research study in a primary school (Passarella, 2022)	The study found that a modelling activity designed through didactical phenomenology, guided reinvention, and emergent modelling effectively helped 2nd-grade students understand the distributive property of multiplication over addition. By engaging with a realistic problem, using supportive artifacts, and receiving guided instruction, students were able to reinvent the concept meaningfully, connecting formal mathematics with real-world experiences.
17	Integrating GeoGebra into the flipped learning approach to improve students' self-regulated learning during the covid-19 pandemic (Ishartono et al., 2022)	The study showed that integrating GeoGebra into the Flipped Learning approach significantly improved students' self-regulated learning in online mathematics classes during the Covid-19 pandemic. Compared to conventional Flipped Learning and traditional teaching, the GeoGebra-integrated model yielded higher N-Gain scores and effect sizes, demonstrating its effectiveness in helping students construct mathematical understanding more independently and actively.
18	Designing Learning Trajectory of Set Through the Indonesian Shadow Puppets and Mahabharata Stories (Risdiyanti & Prahmana, 2021)	The study designed a Hypothetical Learning Trajectory (HLT) for teaching the concept of sets using the Realistic Mathematics Education (RME) approach with Wayang and Mahabharata stories as cultural contexts. The HLT includes learning goals, activities, and conjectures for each stage, allowing students to learn about sets by classifying Wayang characters. This culturally grounded design offers a meaningful way to enhance students' understanding of sets while integrating local culture and character development.
19	Mathematics training in engineering degrees: An intervention from teaching staff to students (López-Díaz & Pẽna, 2021)	The study demonstrated that integrating real engineering applications into mathematics teaching effectively increased engineering students' motivation and engagement, particularly in linear algebra. Through targeted sessions for both instructors and students, the intervention helped students better understand the relevance of mathematics to their field, suggesting the approach's potential for broader application across other mathematical and scientific subjects in engineering education.
20	The learning trajectory of number pattern learning using barathayudha war stories and uno stacko (Risdiyanti & Prahmana, 2020)	The study designed a learning trajectory for teaching number patterns using the Barathayudha War stories and Uno Stacko games within the Indonesian Realistic Mathematics Education (IRME) framework. Consisting of four contextual activities, the design successfully engaged students and helped them develop a deeper understanding of number pattern concepts. The findings indicate that integrating stories and games can make mathematics learning more meaningful and enjoyable for students.

20 research articles from journals with a Scopus index were reviewed as part of a literature analysis to investigate the use of technology in mathematics education. The results of the study show that:

Integration of Technology in Mathematics Education

Across multiple studies, technology has emerged as a transformative force in mathematics education, reshaping how students learn, teachers teach, and assessments are conducted. Digital tools such as GeoGebra, augmented reality, and artificial intelligence (AI) have been shown to enhance engagement, understanding, and adaptability in mathematical learning. Research on GeoGebra integration demonstrates improvements in student engagement and cognitive performance, while research synthesis findings on augmented reality reveal medium positive effects on students′ mathematics achievement. Other studies also support these findings, showing that the integration of digital tools in mathematics learning enhances students′ conceptual understanding, motivation, and problem-solving skills (Boadu & Boateng, 2024; Cirneanu & Moldoveanu, 2024; Elhilal, 2025). AI-driven learning systems highlight the potential for personalized instruction tailored to individual needs. Previous studies have found that AI-based learning environments can adapt instructional content in real time, leading to improved learning efficiency and stronger mathematical reasoning among students (Cho & Kim, 2025). Collectively, these studies illustrate how digital technologies not only facilitate understanding but also open opportunities for more interactive, individualized, and data-driven learning environments.

Contextual and Cultural Approaches to Mathematics Learning

Several studies emphasize the importance of cultural and contextual learning in making mathematics more meaningful and relatable. Approaches such as Ethnomathematics and Realistic Mathematics Education (RME) leverage students′ cultural backgrounds, daily experiences, and local traditions as entry points to mathematical concepts. Examples include the use of Wayang and Mahabharata stories to teach sets and number patterns, which effectively connect mathematical reasoning with cultural narratives. These culturally grounded designs help students construct understanding through familiar contexts, fostering both conceptual comprehension and character development. Other studies similarly suggest that incorporating local culture and everyday experiences into mathematics learning enables students to connect abstract concepts with real-life situations, thereby deepening understanding and promoting meaningful learning (Mierluş-Mazilu & Yilmaz, 2024; Novikasari et al., 2024). This line of research reinforces that embedding mathematics in real and culturally rich settings can make learning more authentic and engaging for students.

Pedagogical Innovation and Student-Centered Learning

The reviewed articles consistently advocate for pedagogical models that place students at the center of the learning process. Approaches such as Flipped Learning, blended learning, and design-based learning promote active participation, self-regulation, and critical thinking. Studies show that integrating GeoGebra into the

Flipped Learning approach or combining digital resources with teacher guidance enhances students' independence and motivation. Learning trajectories and modeling activities designed through RME frameworks allow students to rediscover mathematical principles through exploration and reasoning. Consistent with this, other research indicates that RME-based learning trajectories and modeling tasks foster students' active engagement, enabling them to construct and internalize mathematical ideas through guided exploration and reflective reasoning (Kwon, 2025; Yilmaz & Dündar, 2021). These findings underscore the value of active, inquiry-based learning environments supported by technology and thoughtful instructional design.

Teacher Competence and Professional Development

A consistent theme across the reviewed studies highlights the essential role of teachers' digital competence in ensuring the successful integration of technology in mathematics education. Teachers act as mediators between students and technological tools, determining how effectively digital resources enhance learning. Studies show that when teachers receive proper training and continuous professional development, they can better design, facilitate, and evaluate technology-based lessons. Conversely, a lack of pedagogical and technological readiness often results in underutilization of tools and fragmented learning experiences. Similar research also indicates that teachers with strong technological and pedagogical skills are more successful in integrating digital tools to enhance student engagement and mathematical understanding (Montero-Mesa et al., 2023; Zengin, 2023). Professional development programs focusing on technological pedagogical content knowledge (TPACK) are critical to sustaining innovation and maximizing the impact of technology on student learning outcomes.

Emerging Trends and Future Directions

While technology, context, and pedagogy have shown strong impacts on mathematics education, the research also reveals several gaps and future opportunities. Feedback remains an underexplored yet powerful tool, especially feedback that supports students' self-regulation and metacognitive growth. Additionally, studies call for more attention to equity in digital access, integration of virtual objects in AR learning, and cross-cultural adaptations of AI-assisted education. Future research should continue to bridge technological innovation with human-centered pedagogy, ensuring that mathematics education remains inclusive, relevant, and transformative in both local and global contexts.

D. Conclusions

In conclusion, this research synthesis highlights that integrating technology into mathematics education significantly enhances students' learning outcomes, engagement, and conceptual understanding. Tools such as GeoGebra, augmented reality, and AI not only improve cognitive performance but also enable more personalized and interactive learning experiences. Moreover, culturally and contextually grounded approaches, when combined with student-centered pedagogies, make mathematics more meaningful and accessible. However, to fully realize the transformative potential of technology, future research should focus on equitable access, effective feedback mechanisms, and the integration of culturally responsive AI-driven systems. Strengthening these areas will ensure that technology integration in mathematics education remains inclusive, evidence-based, and aligned with global educational goals.

The explicit implications of this review suggest that teachers should pursue professional development focused on the pedagogical use of specific tools such as GeoGebra rather than merely learning their technical functions, while future research is encouraged to adopt longitudinal, mixed-methods designs to investigate the causal relationships between teacher TPACK, student engagement with AR, and long-term learning outcomes. This review is limited to Scopus-indexed, English-language articles, which may introduce publication bias, and the heterogeneity of the included studies also restricted the possibility of conducting a statistical meta-analysis.

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