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Review Article

The role of technology in reducing mathematics anxiety in primary school students

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ABSTRACT

Mathematics anxiety is a significant problem in education that affects students' learning outcomes, academic success, and well-being. This systematic literature review aimed to explore the role of technological interventions in reducing mathematics anxiety and promoting positive learning experiences in mathematics learning. Our findings revealed a mixed picture, where learning mathematics through online distance education increases mathematics anxiety, especially among primary school students, while interventions such as game-based learning and digital tools show positive results in reducing students' mathematics anxiety levels. Additionally, the results of this study contribute to ongoing discussions on effective strategies to reduce mathematics anxiety and improve mathematics education through the integration of technology, providing new understanding among educators, parents, researchers, and policymakers in creating inclusive and effective learning environments. Using technology to reduce mathematics anxiety and increase student achievement emphasizes the importance of collaborative efforts.

Keywords: mathematics anxiety, technology, digital tools, primary school students, positive attitudes towards mathematics

INTRODUCTION

Mathematics anxiety, commonly understood as a negative emotional reaction and nervousness when presented with mathematical tasks, is a common problem affecting students of all ages and proficiency levels (Ashcraft & Krause, 2007; Dowker et al., 2016). This troubling phenomenon can negatively impact educational performance, learning, and even career aspirations in mathematics-related industries.

Mathematics anxiety not only hinders academic performance of students, but also weakens individuals' confidence and dispositions towards mathematics and potentially impedes their educational and career trajectories (Hembree, 1990). It is especially a major problem among primary school children reducing their confidence in their mathematical abilities in early learning experiences (Ersozlu et al., 2022). Research suggests that mathematics anxiety can emerge as early as the primary school years and is often influenced by factors such as individual cognitive abilities, past experiences, and classroom environments (Dowker et al., 2016; Ersozlu et al., 2022). For many students, negative experiences or perceived difficulties with mathematics can contribute to the development of mathematics anxiety from a very young age (Maloney et al., 2015). The consequences of mathematics anxiety in primary schools not only affect academic results, but also students' attitudes towards mathematics and their future educational and career aspirations (Hembree, 1990). Children experiencing mathematics anxiety may avoid or choose to stay away from mathematics activities, supporting a vicious cycle and leading to more anxiety.

In response to the challenges caused by mathematics anxiety, educators and researchers have explored a variety of interventions aimed at supporting elementary school students. These interventions range from

implementing strategies that foster a supportive learning environment to the integration of technology-based tools and resources (Bawa, 2019; Zainuddin et al., 2019).

It is known that mathematics anxiety is not simply a standalone issue, but rather a multifaceted interplay of various known and unknown elements including general anxiety, cognitive abilities, cultural influences, gender differences, past experiences, internal and external demands, family or school related reasons, motivation, and self-esteem, etc. The intricate nature of mathematics anxiety underscores the necessity for thorough investigation and examination. The complex nature of mathematics anxiety underscores the need for nuanced research that considers its unique psychological, educational, and environmental contexts. In this context, exploring the integration of technology offers a promising way to understand and address the role of technology in reducing mathematics anxiety.

In recent years, the integration of technology into mathematics education has emerged as a promising approach to address mathematics anxiety and improve learning outcomes (Bawa, 2019; Ding et al., 2018; Hamari et al., 2016; Yu et al., 2021; Zainuddin et al., 2019). Educational technology encompasses a wide range of tools, platforms, and applications designed to facilitate teaching and learning processes, offering innovative solutions to engage students and promote conceptual understanding. Technology-supported interventions utilizing interactive software, simulations, educational games, and online resources aim to create dynamic and immersive learning experiences that promote meaningful learning experiences to students.

Interactive software and digital platforms can play an important role in demystifying abstract mathematical concepts and encouraging active engagement among students (del Olmo-Muñoz et al., 2023). Technology can also be used to motivate students to learn mathematical content knowledge in a more active and fun way (Huang et al., 2014; Nurnberger-Haag, 2023), which can help reduce mathematics anxiety. Research supports the notion that that low levels of mathematics content knowledge led to high mathematics anxiety (Chang & Beilock, 2016; Ersozlu et al., 2022; Geary et al., 2019; Sokolowski & Ansari, 2017; Wang et al., 2020). Educational games represent another effective way to utilize technology to reduce mathematics anxiety and increase motivation. Game-based learning environments combine entertainment with educational goals, providing students with opportunities for experiential learning, skill development, and mastery of mathematical concepts (Annetta et al., 2009).

Understanding the power of digital tools and immersive learning experiences can uncover patterns and determinants of mathematics anxiety in different populations and educational environments. It can further allow for the exploration of new intervention strategies for future research in mathematics anxiety. Because AI-driven personalized learning systems can tailor the content and pace of instruction to individual learners, they can provide targeted support to reduce anxiety triggers and promote confidence-building experiences (Moyer-Packenham et al., 2013). Online platforms and mobile applications can also provide on-demand resources, support networks, and self-assessment tools for individuals struggling with mathematics anxiety, regardless of geographic location or socioeconomic status (Major et al., 2021; Moyer-Packenham et al., 2013).

Recent research has focused on highlighting the potential of technology in reducing mathematics anxiety among primary school children. Educational software, games, and online platforms provide interactive and engaging opportunities to learn mathematics, helping to reduce anxiety and develop positive attitudes towards mathematics (Ding et al., 2018; Yu et al., 2021).

The purpose of this research is to investigate the role of technology in reducing mathematics anxiety by synthesizing existing literature sources. By analyzing published research on the integration of digital tools and technology resources in addressing mathematics anxiety, this research aims to understand how technological interventions can help reduce this universal problem. Through a comprehensive review of scholarly articles and empirical studies I aim to identify key technological tools used for the purpose of reducing mathematics anxiety and how did they work across different populations and educational contexts.

In line with this purpose, the research question guiding this systematic review is: *What types of technological interventions have been used in the literature to reduce mathematics anxiety and what are the general findings regarding their effectiveness?* By shedding light on the potential benefits and limitations of technology-driven approaches, the findings of this research seek to inform educators, researchers, and policymakers about evidence-based strategies to support individuals struggling with mathematics anxiety and promote positive learning experiences in math-related domains.

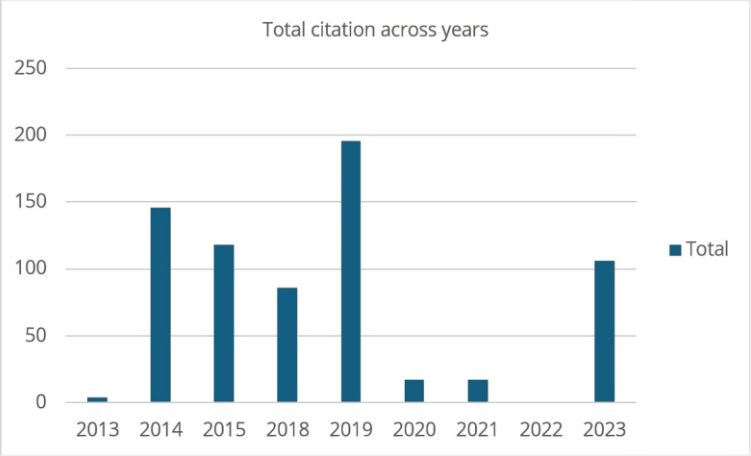

Figure 1. Bibliographic details of publications (Source: Author's own elaboration)

METHOD

A systematic review methodology was employed to identify, select, and analyze relevant literature pertaining to the impact of technology on reducing mathematics anxiety in primary school children.

Search Strategy

A rigorous search strategy was utilized using the Web of Science database. Web of Science was selected because of their comprehensive coverage of globally influential articles, providing a wider reach and impact. The search strategy integrated the keywords "mathematics anxiety", "technology" and "primary school", "elementary school", and "students" considering different terminology worldwide.

Inclusion & Exclusion Criteria

Peer-reviewed articles, conference proceedings and review articles were considered for inclusion, while review articles and editorials were excluded from the analysis. Only publications in English were included. Studies that addressed preservice and in-service teachers, secondary school, and university students rather than primary school students were also excluded. We also excluded studies in disciplines outside of education, STEM education or psychology like dentistry, astronomy or medical informatics. After a thorough literature review, one article was excluded due to its subject matter. Using exclusion criteria, unrelated publications in different areas and articles in a language other than English and duplications were removed.

Data Extraction & Refinement

The initial search yielded 31 publications in the Web of Science database. After applying exclusion criteria, unrelated publications from different fields and articles in languages other than English were removed. Also, duplicates were identified and eliminated. After these steps, 13 publications were selected for analysis phase.

The selected publications were thoroughly reviewed and analyzed to extract relevant data. Study design, sample size, methodologies used, and findings related to mathematics anxiety and use of technology use in primary school students were analyzed in response to research questions. Data were synthesized to identify themes and insights into role of technology use in reducing primary school students' mathematics anxiety.

RESULTS

Bibliographic Details of Reducing Mathematics Anxiety Using Technological Tools

Figure 1 represents the number of citations received by research papers in various years. In 2023, six publications were recorded, while one publication was recorded in 2013, 2014, 2015, 2018, 2019, 2020, and 2021. The sum of citations for each year is listed and the total citations varies over time. It is noteworthy that a paper received the highest number of citations in 2019 with 196, followed by peaks in 2015 and 2014 with 118 and 146 citations, respectively. The total number of citations for all years is 690.

In terms of research trends, bibliographic data reveals several insights. The varying number of publications each year may be because of the changing levels of research productivity in the research area. On the other hand, the variability in the number of citations in different years addresses the changing impact of research publications over time. 2019-, 2015-, and 2014- have a higher number of citations, which is interesting because although there was only one publication in each of these years, the fact that the number of citations was only received by this single publication may indicate how the publications received significant attention and recognition in the academic literature in each year. A lack of publications in certain years, e.g., 2022, can be interpreted as shifts in research focus, emerging topics, and changes in relevance of published research.

Types of Technological Interventions Have Been Used in Literature to Reduce Mathematics Anxiety & General Findings Regarding Their Effectiveness

The results of this study revealed important insights into the use of technological tools and approaches to reduce mathematics anxiety, improve learning outcomes and promote student engagement in primary school students. **Table 1** provides a summary of the author's names, publication years, objectives of the publications, the technological tools utilized in the publications and the key outcomes from the publications.

Table 1. Descriptive & types of technological tools & their effectiveness across publications

Author	Objectives	Technological tools	Key outcomes
Herman et al. (2023)	It aimed to understand how much primary school kids (aged nine-12) have when they learn from home (distance learning).	Online teaching tools, video conferencing, online meetings, & electronic devices	During COVID-19 pandemic, learning from home (online) made kids more anxious about mathematics. Also, difficulty in understanding mathematics during online classes has a big impact on how worried students feel about it.
Yohannes and Chen (2023)	It looked at papers in Web of Science database from 2010 to 2020 that talked about using GeoGebra, a dynamic geometric software, in mathematics classes.	GeoGebra is digital software for all schooling levels.	They found that most studies focused on high school & college students, with fewer focusing on younger students. Publications they found looked at how well students learned, what they thought about subject, & how they felt about it. But they did not look much at things like how hard it was for students to learn, how anxious they felt, or how interested they were.
Nurnberger-Haag et al. (2023)	It combined different theories to understand how students felt when they played games during a mathematics lesson about integers. They wanted to know: "Did features of game affect how motivated & engaged students were in their learning?"	Three games used: Go-high/go-low (Nurnberger-Haag & Wernet, 2019), integer product game (Lappan et al., 2014), integers 24TM	In general, students liked playing games, but how much they enjoyed & got into them depended on features of game. Games that relied solely on speed & skill, without any element of chance, made many students stressed, & less motivated. So, it's important to be careful when choosing or making classroom games; they should include elements like taking turns & chance to avoid causing stress.
Alam and Dube (2023)	It wanted to see how well digital home numeracy practice model worked and how it affected kids' mathematics skills in five areas (counting, adding/subtracting, recognizing patterns, understanding space, & solving real-world problems). They focused on children in grade 1 to grade 5.	Digital home numeracy practice tools	Their findings showed a strong link between children's mathematics anxiety & their mathematics abilities. Kids who were less anxious about mathematics tended to do better in subject. Also, parents' beliefs about their children's mathematics skills were linked to how well kids performed in mathematics. Surprisingly, many aspects of digital home numeracy practice model did not seem to predict children's mathematics knowledge.
Hilz et al. (2023)	It aimed to explore how well different factors predicted how much 5th-grade students used an adaptive arithmetic learning program. They looked at things like students' prior mathematics knowledge, personality traits (like being conscientious), how they felt about mathematics (their mathematics self-concept & anxiety), & background factors like their family's socio-economic status & migration background.	Arithmetic learning program 'math garden' (Klinkenberg et al., 2011), which is characterized by its adaptive format, which makes it possible for students to practice at their individual arithmetic skill level.	Findings revealed that students who were anxious about mathematics spent less time using the program. But there was not a clear connection found with the other characteristics studied. Researchers suggested that anxious students might need extra support & encouragement while using mathematics learning programs to ensure they benefit from them effectively.

Table 1 (Continued). Descriptive & types of technological tools & their effectiveness across publications

Author	Objectives	Technological tools	Key outcomes
Yang and Chen (2023)	It aimed to create a learning system on games that incorporated a prediction-observation-explanation (POE) learning strategy. This system was designed to give 5th-grade students guidance & feedback as they learned, with goal of enhancing their retention of what they learned.	A POE-integrated digital game was developed to help student learn concept of percentage.	Their findings indicated that suggested approach significantly enhanced students' academic performance & their ability to retain what they learned. By analyzing students' behavioral patterns, it was evident that approach helped them concentrate on game's learning material. Proposed approach stands as a promising & efficient approach to support students' long-term learning outcomes.
Reinhold et al. (2021)	It argued that emotional & behavioral engagement could play a crucial role in effectiveness of digital curriculum resources. They examined how 6th-grade students' domain-specific motivations & emotional orientations, which ultimately impacted their academic achievement.	An electronic textbook on fractions	They found that there were significant differences in students' motivational & emotional orientations before intervention, as well as in how engaged they were during intervention. It discovered strong correlations between students' motivational & emotional attitudes (like anxiety, self-concept, & enjoyment) & their emotional engagement during learning (such as intrinsic motivation, feeling competent & autonomy support, finding topic interesting, & perceiving difficulty of task) with positive attitudes linked to positive emotional engagement, as anticipated.
Saha et al. (2020)	It introduced an ICT-based mathematics skill development program (MSDP) web service designed to improve students' (both primary & secondary) positive attitudes toward mathematics.	MSDP web service	Their findings showed that students who participated in MSDP program developed significantly more positive attitudes toward mathematics, which in turn helped them overcome mathematics anxiety.
Chen (2019)	It explored whether mobile AR had varying effects on learning, motivation, & mathematics anxiety among students with differing levels of anxiety.	AR apps integrating Keller's ARCS (attention-relevance-confidence-satisfaction) model on learning motivation, anxiety, & outcomes between students with different levels of anxiety in primary mathematics education.	Their findings showed that group using AR outperformed non-AR group, with high-anxiety learners in AR group showing particularly strong performance in algebra & geometry. Also, AR group showed higher motivation according to Keller's ARCS model. Moreover, high-anxiety learners reported increased confidence & satisfaction, along with reduced anxiety, when learning with mobile AR.
Schaeffer et al. (2018)	It aimed to investigate whether randomly assigning students to a mathematics app could eliminate negative link between parents' mathematics anxiety & their children's mathematics achievement in early elementary school years, spanning across multiple school years.	Mathematics app via iPad mini.	Their study found that using a mathematics app together (student & parent) helped stabilize negative impact of parents' mathematics anxiety on their children's mathematics achievement in first grade. Apps that involve both parents & children may be more beneficial than those used independently by children. This joint engagement can change parental attitudes & interactions positively, but it may not be effective alone without structured support. They suggested offering structured ways for mathematics-anxious parents to engage in mathematics activities with their children, such as through a mathematics app, can help positive outcomes for children.
Verkijika and De Wet (2015)	It aimed to investigate whether utilizing a BCI mathematics educational game, which uses low-cost commercial devices (capable of capturing human emotions in real-time), could effectively reduce mathematics anxiety among students.	BCI mathematics educational game	Their findings showed that mathematics anxiety can be effectively mitigated & reduced through use of a BCI.

Table 1 (Continued). Descriptive & types of technological tools & their effectiveness across publications

Author	Objectives	Technological tools	Key outcomes
Huang et al. (2014)	It used input-process-outcome game-based learning (GBL) model to create a diagnostic learning system for primary school mathematics. It investigated how various learning methods affected learning performance & analyzed these methods regarding learner anxiety, motivation, & satisfaction, focusing on aspect of attention.	Digital game-based learning (DGBL)	Their study found that students using DGBL method showed positive motivation. They suggest that focusing on learners' daily life experiences, integrating suitable game models into mathematics learning, & offering diagnostic mechanisms can effectively boost interest in learning mathematics & reduce anxiety. As anxiety reduces, both motivation & performance in learning improve.
Huang et al. (2013)	It used GBL model to create a mathematics learning system with diagnostic learning for primary school students.	Input-process-outcome based game-based learning	Their study found that employing GBL system in education outdoes traditional paper-based learning, & incorporating a diagnostic mechanism into teaching further enhances this advantage. This approach can boost both learning motivation & achievement.

Table 1 summarizes various technological tools and applications applied to reduce mathematics anxiety and improve engagement in mathematics, including online teaching tools, digital home arithmetic application models, game-based learning systems, adaptive learning programs, augmented reality (AR) applications, brain-computer interface (BCI) technologies, and educational games.

The technological tools used in these publications have been used to reduce mathematics anxiety, improve learning performance, increase motivation and engagement, and promote positive attitudes towards mathematics.

Several studies have investigated the impact of online teaching mode and digital home arithmetic implementation on students' mathematics anxiety levels and performance. The results showed that the online teaching mode increased mathematics anxiety during the COVID-19 pandemic, while the digital home numeracy app had a significant correlation with children's mathematics knowledge. However, the digital factors of home numeracy practice did not significantly affect children's mathematics knowledge. Game-based learning and adaptive learning programs have also been examined in several studies investigating their potential to promote motivation, engagement, and retention among students. The results of this study showed positive student perceptions of game-based learning and reported that engaging game features had positive effects on motivation and learning outcomes. In some studies, AR and BCI technologies have emerged as promising tools to reduce mathematics anxiety and increase learning motivation in primary school children. Studies investigating the effects of AR on learning outcomes have reported improved performance and motivation, especially among students with high levels of anxiety. Similarly, the use of BCI mathematics educational games was found to effectively reduce mathematics anxiety among students. Parental involvement and emotional engagement were also identified as important factors influencing mathematics learning outcomes. According to the results of the study, supportive parental involvement and emotionally engaging learning experiences were reported to increase students' motivation, engagement, and mathematics achievement, thereby reducing mathematics anxiety.

DISCUSSION

In this study, I sought to provide a comprehensive understanding of the contrasting effects of online distance education, game-based learning, and digital tools on mathematics anxiety. Publications investigating online modes of distance education during the COVID-19 pandemic have reported a steady increase in mathematics anxiety among students. Distance education through virtual classrooms and digital interactions has led to increased levels of anxiety, particularly among primary school students. Difficulties in learning and understanding mathematical concepts through online courses and the absence of face-to-face interactions have been identified as factors contributing to this increase in mathematics anxiety. In contrast, research focusing on the use of game-based learning and digital tools to engage students in learning mathematics has shown a positive effect in reducing mathematics anxiety. Interventions involving game-based learning strategies, adaptive learning programs and educational games have been reported to positively affect

motivation, engagement, and positive attitudes towards mathematics. These interventions provided students with interactive and immersive learning experiences and promoted engagement and retention by reducing mathematics anxiety. Past literature review studies have conducted research on the use of technology-based approaches in teaching mathematics. They took a broader perspective and focused their research results on all school years, from primary school to university. According to their results, the use of technology helps students develop positive attitudes towards the subject and reduces their anxiety levels (Atoyebi & Atoyebi, 2022).

Based on the information obtained from a detailed reading of the publications in **Table 1**, the main results are synthesized under the following headings as the main approaches to reduce mathematics anxiety:

Online Mode of Instruction & Digital Home Numeracy Practice

Alam and Dubé (2023) and Herman et al. (2023) investigated the effects of online teaching methods and digital home arithmetic application on students' mathematics anxiety levels and performance, respectively. According to their findings, careful consideration is needed in the design and implementation of online teaching tools and home-based digital applications to reduce anxiety and improve learning outcomes. Because, while online platforms offer flexibility and accessibility, they can also cause difficulties in understanding mathematical concepts and interacting effectively with students. This situation causes decreased interaction during learning and difficulties in understanding mathematical concepts. Therefore, whenever possible, teaching mathematics face-to-face and in a way that allows interaction can help students increase their mathematics learning levels and decrease their anxiety levels.

Game-Based Learning & Adaptive Learning Programs

Nurnberger-Haag et al. (2023), and Yang and Chen (2023) focused on how game-based learning and adaptive learning programs can increase motivation, engagement, and retention of learning. Common aspects of the findings from these studies are how to provide meaningful learning experiences in mathematics through game-based learning and how to adapt game features to individual student needs. The results of these studies report that interactive and engaging learning experiences provided by game-based learning and digital tools can help reduce anxiety and increase motivation in learning mathematics. From this perspective, game-based learning can be considered as a tool to reduce mathematics anxiety because it provides students with a more fun, less oppressive (because the features in the game can be adapted to the student's level) and interactive experience.

Augmented Reality & Brain-Computer Interface Technologies

Chen (2019) and Verkijika and De Wet (2015) investigated the use of AR and BCI technologies to increase learning motivation and reduce anxiety in mathematics education. According to their findings, AR and BCI technologies are effective in providing immersive and interactive learning experiences and therefore show promise in increasing engagement and reducing anxiety among students. The use of AR increases students' motivation and improves their performance, therefore reduces their mathematics anxiety (Chen, 2019). However, more research is needed to investigate the long-term effects of these technologies and their optimal integration into classroom practices.

Parental Involvement & Emotional Commitment

Reinhold et al. (2021) and Schaeffer et al. (2018) in their research, they emphasize the importance of parental involvement and emotional involvement in mathematics learning. Their findings suggest that supportive parental involvement combined with emotionally engaging learning experiences can positively impact students' motivation, engagement, and achievement in mathematics. This finding suggests that when parents are actively involved in their children's learning processes and provide support and encouragement as well as emotionally stimulating learning experiences, they help students become motivated to learn mathematics, participate in and succeed in mathematical activities, and therefore reduce students' mathematics anxiety.

The point here is that parents go beyond simply helping their children with homework or participating in school activities together; It is ideal for them to create a supportive and nurturing environment at home that

encourages positive attitudes towards mathematics. Because when students feel emotionally connected to their learning experiences and receive support from their parents, they are more motivated to learn and actively participate in mathematics activities. In this case, it is expected as a natural result that it will lead to an increase in academic success in mathematics and a decrease in mathematics anxiety. Adopting a collaborative perspective between teachers, all stakeholders in education, parents and teachers is very likely to help maximize students' learning outcomes and increase their well-being by reducing their anxiety.

To summarize, it is crucial to note that despite the promising potential of technology in reducing mathematics anxiety, there are limitations and challenges associated with its integration. For example, the effectiveness of technology-based activities may vary depending on factors such as access to resources, teacher expertise, and cultural contexts. Ongoing research is also needed to evaluate the long-term effects of technology use on students' mathematics anxiety and learning outcomes and to identify potential unintended consequences or disadvantages. Additionally, the ethical implications of using AI-assisted learning systems in educational settings require careful consideration and review. It is certain that technology has its own limitations, difficulties, and strengths, but what is important is how and for what purpose we, its first-hand users, use it. This research, in line with other research results above, reminded us that the human factor is the most important factor in education, regardless of the type of technology used.

CONCLUSIONS & IMPLICATIONS

The findings from this research provided important information about how technology is used rather than how it is used. It clarifies an important point in terms of showing that mathematics anxiety among students, especially in primary school environments, cannot be reduced by using technology alone. The use of technology may not always lead to good results, according to the specific focus of this study. In contrast, interventions such as game-based learning and digital tools have shown promising results in reducing anxiety levels and promoting positive attitudes towards mathematics.

While technology has the potential to revolutionize mathematics education by providing personalized learning opportunities, increasing engagement, and reducing anxiety, it is important to note that these alone are not enough. Parents and teachers should also provide guidance and create a positive, supportive environment for learning to ensure students' academic success, engagement, and reduce anxiety. Educators, parents, researchers, and policymakers must collaborate to create inclusive and effective learning environments that encourage all students to succeed in mathematics and increase the enjoyment of learning and using mathematics.

Based on the insights gained from the reviewed studies shed light on various suggestions for mathematics education practices and future research. Teachers should leverage technology to design engaging and interactive learning experiences that appeal to a variety of student needs and preferences. Researchers and policymakers should prioritize investing in educational technology infrastructure and professional development to support effective technology integration in classrooms. Future research should focus on exploring innovative approaches to technology-supported mathematics education, addressing the impact of socioemotional factors on learning outcomes, and investigating the long-term effects of technology interventions on student achievement and attitudes toward mathematics.

It should be noted that this study has some limitations. For example, the current study primarily focuses on the use of technology in reducing mathematics anxiety among primary school students. As a result, it may not fully capture a broader range of factors contributing to mathematics anxiety or the potential of technology in other educational contexts. Since this study focuses on publications that emphasize the importance of technology as a solution to reduce mathematics anxiety in primary school students, the results reflect a synthesis of the results from these publications based on their comparison. Information from the reviewed literature is limited to studies that report on their results. The publications used in this study may overrepresent positive outcomes of technology integration to reduce mathematics anxiety compared to null or negative findings, which may lead to biased views.

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