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Digital Technology in Strengthening Mathematical Concepts in Early Childhood: A Systematic Literature Review

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Abstract

The development of digital learning media has grown rapidly over the past decade; however, socioeconomic background has a strong influence on its use. Due to the vast diversity of users, there is no effective map. This study provides a literature review (SLR) on the use of digital technology in mathematics learning for early childhood through an analysis of 16 recent studies (studies that meet the exclusion and inclusion criteria in the PICOS framework). This paper attempts to bridge the gap between digital technology advancements and meaningful mathematics education practices. The conclusion is that game-based educational applications and interactive tools have become a primary approach proven effective in improving the understanding of basic mathematical concepts. However, behind this great potential, real challenges are found in their implementation - from the limitations of long-term studies to disparities in access across socioeconomic backgrounds. This study also highlights the need for synergy between technological innovation and appropriate pedagogical approaches. For educators, these findings provide practical guidance on selecting and implementing learning technologies, while for researchers, several critical areas are identified that require further exploration.

INTRODUCTION

The development of digital technology over the past decade has brought significant transformations to various sectors, including early childhood education (PAUD). The integration of digital technology into early childhood mathematics education is one innovation that is being widely implemented in various countries. Technologies such as mobile applications, educational software, digital games, and artificial intelligence-based platforms are believed to provide a more interactive and adaptive learning experience tailored to children's needs and characteristics (Cevik Bas et al., 2023; Supriyadi & Kuncoro, 2023). With the digitalisation of learning, educators can facilitate a more visual, multimodal, and enjoyable understanding of mathematical concepts, thereby increasing student motivation and learning outcomes (Al Ghazali et al., 2024).

Technology plays a crucial role in early childhood numeracy instruction because it can make the learning process more interactive, engaging, and understandable. The use of multimedia, such as animated videos, interactive apps, and other digital tools, can increase children's enthusiasm for understanding number concepts and arithmetic operations. Furthermore, technology helps teachers present material in a more varied and contextual way, enabling children to learn numeracy independently and enjoyably. Implementing technology in numeracy instruction can also foster creativity, imagination, and language skills, all of which contribute to strengthening overall numeracy skills. Despite challenges such as limited access and inadequate infrastructure, technology remains an effective tool in supporting the development of early childhood education (Noviarini, 2025; Ismawati, 2024; Bintang, 2024).

However, the use of digital technology in early childhood mathematics learning is not without challenges, including unequal access to digital tools, issues with educator competency, and concerns regarding ethical and data security (Ibda et al., 2023; Yu, 2024). Numerous studies have examined the effectiveness of various types of digital technology in improving early childhood mathematics learning outcomes, with varying results depending on the implementation context, technological features, and the role of teacher and parent support (Yang, 2022; Darragh & Franke, 2023).

The urgency of systematic research on the use of digital technology to strengthen mathematical concepts in early childhood is increasing. This systematic literature review (SLR) aims to review and analyse the types of digital technologies used in early childhood mathematics learning, the effectiveness of each technology in improving students' mathematics learning outcomes, and the factors influencing their successful implementation. This research is expected to provide a comprehensive overview and serve as a reference for education practitioners, researchers, and policymakers in designing optimal digital-based mathematics learning strategies for early childhood.

METHOD

This study employed a systematic literature review method, collecting scientific papers on the topic of digital technology in mathematics learning. These papers were then screened using quality assurance, and inclusion and exclusion criteria were applied to ensure the discussion was broad and unbiased. To establish the inclusion and exclusion criteria, the PICOS (Population, Intervention, Comparison, Outcome, Study Design) framework was used as follows:

1. Population: Early childhood children who are the subjects of research in the context of learning
2. Intervention: Use of digital technology in learning mathematical concepts.
3. Comparison: Studies that compare with non-digital approaches or conventional methods
4. Outcome: Learning outcomes or reinforcement of mathematical concepts that are cognitively measurable.
5. Study Type: Quantitative and mixed studies published in Scopus journals in the last 10 years.

After obtaining the filtered articles, each was analysed to answer the Research Questions raised, specifically regarding the types of applications, their effectiveness, and the supporting factors for the use of digital technology in mathematics learning.

The Publish Or Perish (POP) application is used to search and filter scientific papers available in various sources, including Google Scholar, WOS, Scopus, etc. The keywords used to obtain results from POP are ("mobile" OR "digital technology" OR "educational apps" OR "digital media") AND ("children" OR "early childhood" OR "young children" OR "preschool") AND ("mathematical" OR "mathematics" OR "numeracy" OR "math learning" OR "math"). English is used to make the search more global and comprehensive. On August 1, a POP search was conducted, and 152 journals were obtained. Then, the selected journals were analysed based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) framework, which includes the stages of planning, article identification, article suitability testing, and analysis, to obtain strong answers to the Research Question. Researchers filtered the data by adjusting the theme, keywords, and title according to the study's focus. Then, the data is imported into the RIS form and entered into the fourth application, VOS Viewers, so that a visual image of the research distribution is obtained in terms of its keywords

RESULTS

The following shows the VOS viewer view of 152 journals obtained from Publish Or Perish:

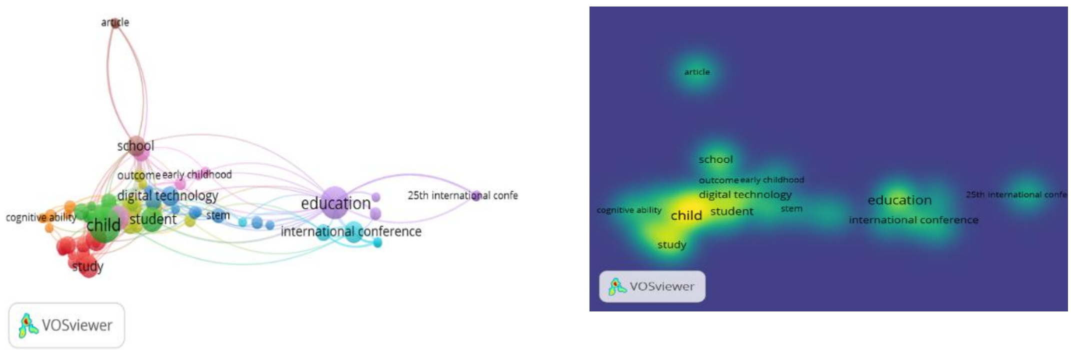

Figure 1. Vos Viewer Display of 152 Journals

Based on the VOSviewer visualisation above, we can identify several trends regarding the research focus of studies related to the discussed theme. First, the keywords "digital technology" and "early childhood" emerged as core keywords, indicating that in the past two years, digital technology has become a hot approach in early childhood studies. Second, the keywords "cognitive ability" and "child student STEM" suggest that recent studies also examine the impact of technology on cognitive abilities and STEM (Science, Technology, Engineering, and Math) approaches for children.

Furthermore, in the context of education, the keywords "education" and "school" are closely linked to the keyword "outcome," emphasising that the implementation of digital technology in schools aims to improve children's learning outcomes. Furthermore, the keyword "International conference" (including "25th international conference") indicates that this topic is widely discussed in global academic forums, demonstrating its relevance and strong research trends.

Examining the relationship patterns between concepts reveals two strong relationships: the keyword "digital technology" and "cognitive ability" in the context of "early childhood." This suggests that digital technology can be viewed as a tool for enhancing early childhood cognitive abilities. The second strong relationship is between "child student STEM" and "study." It can also be concluded that recent empirical studies support the STEM approach to childhood learning.

It is seen that the implications of digital technology (such as GPT Chat, interactive applications) are not only used as aids, but also to strengthen mathematical concepts through STEM and cognitive approaches.

DISCUSSION

Description of Selected Studies

An initial search was conducted through the Scopus database using relevant keywords, resulting in 152 journals published between 2023 and 2025. After screening, 98 journals were excluded because they did not meet the inclusion criteria. Forty-seven journals were excluded because their topics fell outside the scope of early childhood mathematics learning (e.g., sensor networks, health, and chemistry). Furthermore, 28 journals did not meet the population criteria because they did not focus on children under 7 years of age or examine specific groups such as children with ADHD or disabilities. Another 23 journals were excluded because they were of ineligible study types, such as conference papers, book chapters, errata, or reviews.

Of the remaining 54 journals, eligibility was assessed, and 38 were again excluded. Fifteen journals did not meet outcome criteria because they only measured non-cognitive aspects such as interest or motivation. Another 12 journals were excluded because their digital technology interventions were not described in detail, and 11 journals were not available in open access.

Finally, 16 journals remained that met the PICOS (Population, Intervention, Comparison, Outcome, and Study) criteria. These journals studied children aged 3–6 years who received digital technology-based interventions, such as math apps, educational games, or augmented reality. The outcomes measured included improvements in number concepts, geometry, or problem-solving skills. All selected studies employed quantitative or mixed-methods approaches, including experiments and quasi-experiments. Therefore, these 16 journals were deemed suitable for further analysis in this systematic review.

Table 1. Categories of Findings Based on Research Questions

No	Title	Country	Method	RQ 1 (type of Technology)	RQ 2 (Effectiveness)	RQ 3 (Success Factors)
1	Understanding how educational maths apps can enhance learning: A content analysis and qualitative comparative analysis	UK	Content analysis, QCA	Educational mathematics applications	Effectiveness varies depending on design	Application design, teacher involvement
2	Digital technology and the subjects of literacy and mathematics in the preschool atelier	Sweden	Qualitative case study	Tablets, creative applications	Increasing learning engagement	Integration with curriculum, teacher training
3	Design and empirical evaluation of a multitouch interaction game-like app for fostering early embodied math learning	Germany	experiment	Multitouch game application	Significantly improves learning outcomes	Interactivity, instant feedback
4	Exploring the Use of Escribo Play Mobile Learning Games to Foster Early Mathematics for Low-Income First-Grade Children	Brazil	Mixed-methods	Game mobile Escribo Play	Effective for low-income children Accessibility	adaptation to local context
5	Evaluating educational apps for preschoolers: Differences and agreements between the assessments of experts, parents, and their children	Germany	Qualitative evaluation	Commercial educational applications	Perceptions of effectiveness vary	Age suitability, user interface
6	Evaluating popular STEM applications for young children	Turkey	Systematic analysis	Popular STEM app	Variations in pedagogical qualities	Alignment with learning standards
7	Learning apps at home prepare children for school	Germany	Longitudinal	Home learning app	Increase school readiness	Frequency of use, parental support
8	Assessment of an educational classroom app's impact on preschoolers' early numeracy skills	France	Quasi-experiment	"Number Beads" class application	Significant improvement in numeracy	Structured implementation, duration of use
9	Measuring Digital Home Numeracy Practice: A Scale Development and Validation Study	US	Scale development	Home numeracy application	Positive correlation with mathematical ability	Parental involvement, content quality
10	Preschoolers' Mathematics Game Preferences and Learning Performance through Designing a Degree of Freedom for a Tablet Game	Taiwan	Participation-based design	Game tablet customizable	Preferences influence learning outcomes	Degrees of freedom in game design

11	mLearning Versus Paper and Pencil Practice for Telling Time: Impact on Attention and Accuracy	US	Controlled experiment	Learning a mobile application	More effective than traditional methods	Interactivity, personalisation
12	Australian early childhood educators' perspectives on digital teaching of geometry: The pedagogical enablers and barriers	Australia	Qualitative survey	Digital geometry software	High potential with proper implementation	Teacher training, technology infrastructure
13	The Impact of Educational Apps on Trajectories of Early Mathematical Thinking	Spain	Longitudinal study	Structured mathematical applications	Faster development of mathematical concepts	Sequencing konten, scaffolding
14	The effects of digital block play on children's mathematical problem-solving ability and flow: A collaborative action research approach.	Korea	Action research	Blok digital interaktif	Improve problem-solving	Collaborative, flow-based design
15	Development of Software that Supports the Improvement of Mathematical Skills in Children	Mexico	Development & validation	Adaptive mathematics software	Basic skills improvement	Adaptability, gamification
16	What Does Play Have to Do With It? A Concrete and Digital Spatial Intervention With 3-Year-Olds Predicts Spatial and Math Learning.	US	Experiment	Spatial digital tools (e.g., AR)	Strong predictor of math ability	Integration of play-based learning

Based on the analysis of 16 journals, it can be concluded that digital technology has been widely used to strengthen early childhood mathematics concepts, especially in the form of mobile applications/educational games (11 studies), interactive software (3 studies), and digital spatial tools such as AR (2 studies). Of the 16 studies above, the majority (14 out of 16) demonstrated that the technologies used were effective in improving mathematics learning outcomes, particularly in terms of mastering basic concepts in numeracy, geometry, and problem-solving. However, their effectiveness is highly dependent on the quality of the available pedagogical design, including interactivity, instant feedback, and adaptation to the child's developmental level.

Key factors influencing successful implementation include age-appropriate design (e.g., intuitive interfaces, gamification elements), teacher training in integrating technology into the curriculum, parental support for home learning, and adequate infrastructure (including device access and connectivity).

The most significant factor influencing learning success lies in process management, more specifically, the interaction process of technology in delivering

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content to students. Technology in learning management should focus more on two things: first, content that is integrated with the curriculum, management with learning standards, content quality, structured implementation, duration of use, content sequencing, and second, on delivery methods that include instant feedback, accessibility, delivery frequency, delivery duration, interactivity, personalisation, adaptability, and active learning.

The study identified several challenges, including variations in app quality and the need for adaptation to local contexts, particularly for children from low-income backgrounds. These findings underscore the importance of collaboration among technology developers, educators, and researchers in developing digital solutions that are evidence-based, inclusive, and aligned with early childhood pedagogical approaches.

Critical Appraisal: Methodological Quality

The majority of included studies (10 of 16) used experimental or quasi-experimental methods, which align with the principles of Evidence-Based Management (EBM) in education (Davies, 1999). This approach enables the objective measurement of the impact of digital technologies through pre-tests and post-tests, as well as the use of control groups. However, some studies (Magnusson, 2023; Barrocas, 2023) relied on qualitative or case study designs, which, while providing in-depth analysis, have limitations in terms of the generalizability of findings.

Methodologically, several weaknesses were identified, including sample bias. Amorim's (2023) study only involved participants from specific socioeconomic backgrounds, so the findings may not necessarily apply to a broader context. Second, the short duration of interventions in some experimental studies (4–8 weeks) makes it difficult to assess long-term effects (Kirkpatrick & Kirkpatrick, 2006). However, overall, supported by the assurance of Scopus-indexed journals, the methodological quality of these studies is strong enough to support claims of the effectiveness of digital technology.

Relevance of Findings in Learning Management Theory

According to Cognitive Load Theory (Sweller, 1988), Mathematics applications designed with structured interactivity (as in the study by Barrocas, 2023) will help reduce the cognitive load of young children by breaking down complex concepts into small steps. On the other hand, studies by Niklas (2025) and Alam (2023), examined from the perspective of social learning theory (Bandura, 1977), show that parental/teacher support in the use of technology strengthens learning outcomes, in accordance with the principles of modelling and reinforcement. However, a theoretical gap was identified in digital change management, where only a few studies (e.g., Zhao, 2025) have addressed the challenges of implementing technology in schools from an institutional management perspective, such as teacher resistance or inadequate infrastructure.

Research Gap

Based on a review of 16 related journals, several research gaps require attention. First, most studies only measure the short-term effects of digital technology use, so it is unknown whether improvements in learning outcomes persist until children enter elementary school. Studies are needed that examine the impact of digital technology on mathematics development over a more extended period (5+ years).

Second, the integration of digital technology with the formal curriculum and the role of teachers in its implementation remain underexplored. Many applications are used in isolation without proper alignment with institutional learning objectives. Action research or design-based research is necessary to develop structured implementation models, such as blended learning, specifically tailored for early childhood education.

Third, the potential of artificial intelligence (AI) for personalised mathematics learning in early childhood remains largely unexplored, despite AI being mentioned explicitly in search queries. Most existing applications are static and unable to adapt to individual learning styles. The development and evaluation of AI-based tutoring systems specifically designed for early childhood presents a promising research opportunity.

CONCLUSION

Based on a systematic review of 16 journals, it can be concluded that first, the dominant types of digital technology used include game-based mathematics applications (11 studies), interactive software (3 studies), and spatial digital tools such as AR (2 studies). Second, the effectiveness of technology in improving early childhood mathematics learning outcomes was significantly proven in 14 of the 16 studies, particularly in the mastery of basic concepts such as numeracy, geometry, and problem-solving. Third, determining factors for success include: age-appropriate design, teacher training, parental involvement, and adequate infrastructure.

Digital technology contributes to learning practices in three main ways: first, by simplifying abstract concepts through visualisation and simulation (e.g., digital blocks for geometry); second, by increasing learning motivation through gamification elements; and third, by enabling personalised learning. However, these contributions are optimal only when integrated with the curriculum and supported by teachers and parents.

For teachers, these findings emphasise the importance of evidence-based app selection, training in managing digital learning, and collaboration with parents for home use. For researchers, the study's findings underscore the importance of further investigating the long-term impacts, factors contributing to the digital divide, and the role of AI in personalised learning.

Future research is expected to take the form of comparative studies across socioeconomic contexts and the development of management-based learning implementations (such as integration with the national curriculum). By addressing these gaps, digital technology can be optimised as an inclusive and sustainable support tool for early childhood mathematics education.

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