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Unlocking Early Mathematics through Digital Manipulatives: A Scoping Review

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Abstract. Globally, teachers are mandated to use digital manipulatives in their mathematics classrooms. Nevertheless, there is still limited access to digital technologies, especially in under-resourced schools. As a result, the full potential role of digital manipulatives remains under-examined. Additionally, South African learners continue to perform poorly in mathematics compared to learners in other countries. This scoping review examined the role of digital manipulatives in early childhood mathematics through the lens of Vygotsky's sociocultural theory, which conceptualises learning as a socially mediated process that is supported through tools, interaction and scaffolding. To ensure transparency and replicability, this paper followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) guidelines. Guided by a structured search strategy across multiple databases, a broad body of recent literature was identified, screened and assessed against clear inclusion and exclusion criteria. In total 19 peer-reviewed studies published between 2021 and 2025 were reviewed to map evidence that is available on how digital tools support foundational mathematical development in young learners. The analysis focused on how digital manipulatives function as mediating tools that support conceptual understanding, learner engagement and collaborative meaning-making in early mathematics. The findings reveal that the consistently positive role of digital manipulatives contributes to a deeper conceptual understanding of mathematics, increased engagement and the use of visual and multimodal representations. However, the effective use of digital manipulatives is strongly influenced by teacher competence, pedagogical design and access to suitable technological resources. In the South African context, practices concerning the use of digital manipulatives remain uneven and are often constrained by shortcomings regarding infrastructure, insufficient professional development and minimal curriculum guidance. This paper contributes to identifying the need for professional development, clearer policy direction, and further context-specific research to strengthen the meaningful integration of digital manipulatives in early mathematics teaching.

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1. Introduction

Manipulatives are 3D objects or tools that represent mathematical concepts and that learners can move or interact with; they have long been central to early mathematics teaching because they serve as a bridge between concrete experience and symbolic reasoning (Bungao-Abarquez, 2020). Many countries, including South Africa, explicitly encourage the use of digital manipulatives. South Africa's Curriculum and Assessment Policy Statement (CAPS) for the foundation phase emphasises that the development of number concepts and problem-solving is enhanced by using hands-on, activity-based learning and resources (Department of Basic Education [DBE], 2019). Although the CAPS document does not explicitly mention digital manipulatives, it encourages the use of innovative strategies to build number sense, spatial reasoning and problem-solving skills.

CAPS promotes hand-on and play-based learning approaches that require learners to explore mathematical concepts using concrete and visual resources before progressing to abstract understanding (DBE, 2019). This approach allows the integration of digital manipulatives such as virtual number lines, interactive counting applications, pattern and shape exploration software and dynamic geometry tools that support visualisation and conceptual learning. Abrahan et al. (2024) had emphasised the importance of concrete manipulatives, such as counters, bottle caps or blocks to enhance learners' conceptual understanding. However, in the 21st century, the integration of digital manipulatives, which allow learners to explore mathematical relationships, emerged as a powerful extension of traditional practice.

Many countries are reimagining their curricula to integrate technology-enhanced learning. National curriculum documents in the United Kingdom, such as England's the Early Years Foundation Stage framework, encourage the use of concrete, pictorial and abstract representations (Gripton, 2023). Similarly, Singapore's Mathematics Curriculum Framework and Australia's Early Years Learning Framework promote the use of digital tools and interactive representations to support conceptual understanding in early mathematics (Cohrssen, 2023; Toh, 2021).

Many resources that support curricula include digital manipulatives. Singapore's Mathematics Curriculum Framework prioritises problem-solving and digital literacy; these approaches encourage teachers to employ interactive digital tools to promote conceptual understanding (Suthish & Venkatesan, 2025). These global curricula indicate a shift in approach: Digital manipulatives are no longer optional but essential components that help deepen mathematical reasoning, support differentiation and equip young learners with skills required for the emerging technological world.

Despite encouragement by the CAPS to use digital manipulatives, classroom implementation in South Africa remains imbalanced. Gumiero and Pazuch (2024) report that many teachers, especially in public primary schools, lack access to suitable digital tools, adequate infrastructure and professional training opportunities to integrate them meaningfully in their mathematics lessons. Furthermore, studies such as those by Byrne et al. (2023), which primarily focused on physical rather than digital manipulatives, leave a gap in understanding how digital manipulatives operate in early childhood mathematics learning, especially in under-resourced settings such as South African public schools. This review is intended to address the question: What role do digital manipulatives play in enhancing mathematics learning in early childhood education?

2. Literature Review

The literature indicates that integrating digital manipulatives in early childhood mathematics education is becoming more important. Moyer-Packenham et al. (2022) emphasise that manipulatives that are interactive and tactile can enhance learners' conceptual understanding of number sense, spatial reasoning and operations by allowing learners to explore mathematical relationships. Barbosa and Vale (2025) agree that integrating features associated with digital manipulatives fosters learner motivation and sustained engagement and increases early mathematics learning resilience.

Nwikpo and Chiemeka (2024) state that many countries increasingly highlight the transformative potential of digital manipulatives for enhancing early mathematical understanding. However, in South African foundation phase classrooms, the use of digital manipulatives remains limited and underexplored. Ngozwana (2025) reports that most public primary schools, especially those in under-resourced areas, still rely solely on traditional, physical manipulatives such as bottle tops, counters and number charts. While these tools have been proven effective for supporting the concrete learning of foundation phase learners, they do not fully exploit the interactive, visual and dynamic affordances that digital manipulatives provide for concept formation, spatial reasoning and problem-solving (Sarama & Clements, 2021).

Furthermore, the CAPS for the foundation phase (DBE, 2019) encourages the use of hands-on, activity-based learning. However, it does not explicitly reference digital technologies or provide structured guidance on integrating digital manipulatives into early mathematics teaching and learning. Elmalı et al. (2025) agree that most early childhood teachers who have access to digital manipulatives usually use them for drills, which suggests that teachers are not receiving sufficient support on how to properly utilise technology for teaching mathematics. As a result, policy intent and classroom practice remain misaligned.

Moreover, most research in South Africa, including the study of Naidoo (2022), primarily focuses on digital learning at the secondary and tertiary education levels, leaving a notable gap in the foundation phase (Grades R–3), where early mathematical concepts are introduced. There is little research examining how digital manipulatives can enhance early numeracy and problem-solving skills in South African contexts, particularly regarding teacher readiness, digital resource accessibility, teaching methods and meeting curriculum expectations during the transition from physical to digital manipulatives. Scholars such as Abrahan et al. (2024) examined the role of manipulatives in early mathematics learning and provide strong evidence supporting the use of concrete manipulatives to develop number sense and problem-solving skills in the foundation phase. Recent research by Zakelj and Klančar (2022), furthermore, suggest that digital manipulatives significantly contribute to developing geometric representations and procedural and problem-solving competencies and can enhance conceptual understanding, engagement and visualisation of mathematical relationships by young learners.

However, most research focuses broadly on technology integration rather than specifically on digital manipulatives in the foundation phase. In the South African context, research has mostly focused on teachers' reliance on the use of concrete manipulatives because the teachers lack digital resources and have had little professional development (Ngozwana, 2025). Not much research has explored how digital manipulatives can be implemented in early mathematics classrooms. Therefore, this scoping review addresses a critical gap by exploring and mapping evidence on the implementation of digital manipulatives in early mathematics education.

It also examines the challenges faced by teachers, their readiness to integrate innovative teaching manipulatives in Grade 3 mathematics classrooms and aligning the curriculum with the use of the innovative manipulatives. These dimensions can inform subject advisers about creating professional development sessions for teachers that explicitly emphasise the use of digital manipulatives. Policy can be updated to guide teachers on integrating digital manipulatives and designing contextually appropriate digital resources for early mathematics teaching.

3. Theoretical Framework

Lev Vygotsky's sociocultural theory guided this paper. According to Li et al. (2024), teaching and learning in early childhood mathematics align with theories that emphasise active exploration and social interaction. Alsaeed and Aladil (2024) explain digital manipulatives as interactive, technology-based tools that allow learners to explicitly explore mathematical ideas in a way that is consistent with theoretical lenses. The sociocultural theory suggests that learning occurs when people interact with others and use tools from their culture, which helps them understand and connect more deeply with what they are learning (Pervaiz & Tatlah, 2025). Learning is mediated by language, symbols and tools that shape cognitive development (Stahl & Hakkarainen, 2021). Digital manipulatives act as a mediating technological tool that facilitates shared learning experiences between teachers and learners.

In early mathematics classrooms, learners working together to solve problems, discuss outcomes and negotiate meaning through digital manipulatives encourages collaboration. Taber and Li (2021) emphasise that this social engagement positions digital tools as mediating artefacts that enable scaffolded learning through interaction with peers and teachers, thereby supporting learners' mathematics development within Vygotsky's zone of proximal development (ZPD). Teachers act as facilitators to guide learners through tasks using digital platforms that adjust in complexity according to learners' abilities (Kim et al., 2022). Environments that utilise interactive digital tools (Sujatha & Vinayakan, 2022) can enhance peer dialogue and shared reasoning and contribute to deeper conceptual understanding. Stanziale (2024) confirms that digital manipulatives also promote active exploration through immediate feedback and multimedia representations, which strengthen mathematical thinking. Taylor et al. (2021) corroborate that digital manipulatives have been found to support diverse learners and enable differentiated instruction in the same classroom. Therefore, digital manipulatives not only enrich engagement in mathematics but also create learning opportunities in which every learner can participate meaningfully to address appropriate challenges.

4. Methodology

For this paper, the Arksey and O'Malley framework was used to clarify the usefulness and methods inherent in a scoping study. Mahmodi et al. (2025) emphasise that a scoping review, according to Arksey and O'Malley, includes creating clear research questions, selecting studies, analysing data, combining results, and consulting stakeholders, which ensures the process is thorough and well structured. Shortland et al. (2024) corroborate that the Arksey and O'Malley framework provides a rigorous and transparent approach to scoping reviews, thereby ensuring comprehensive coverage of the literature.

This methodology was complemented by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) guidelines (Tricco et al., 2018), which provide a structured reporting framework that improves transparency, consistency and completeness when scoping review processes and findings are presented (Sarkis-Onofre et al., 2021). The scoping review in this study aimed to gather and share research results, as well as identify gaps in recent literature on the use of digital manipulatives in early mathematics education.

4.1 Search Strategy

Searches were conducted with multiple search engines, including Google Scholar, Scopus and the UNISA library, because these databases provide broad coverage of peer-reviewed education research, including international and African scholarship. Scopus was selected for its high-quality indexed journals, Google Scholar for its wide accessibility and inclusion of grey literature, and the UNISA library for access to subscription-based academic databases relevant to education studies. The researchers used primary search terms such as digital manipulatives, virtual manipulatives, interactive learning tools, early childhood mathematics, foundation phase, technology integration and mathematics learning. The search was not limited to a specific geographical region; however, to ensure the depth of the search, it was limited to peer-reviewed articles published in English between 2020 and 2025. A total of 86 studies were found, which were categorised according to inclusion and exclusion criteria.

4.2 Inclusion and Exclusion Criteria

Studies were included in the review if they had been published between 2020 and 2025. The studies had to have focused on foundation phase learners (Grades R−3) and examined the use of digital manipulatives, virtual tools and/or technology-based manipulatives in mathematics teaching and learning. For example, a synthesis of intervention studies found that learners exposed to virtual manipulatives demonstrated measurable improvements in mathematics achievement and were able to maintain and generalise newly acquired skills (Xu & Dieckmann, 2025).

Similarly, a study conducted by Siller and Ahmad (2024) found that there is a significant improvement in mathematical achievement after the use of virtual manipulative-based instructional media, thereby confirming their effectiveness in supporting early mathematics learning. The studies were conducted in classrooms, early learning centres or intervention programmes. Additionally, the studies had to be published in English and offer open access to full text. Furthermore, the studies had to explicitly report findings related to mathematics learning, such as conceptual understanding, engagement, problem-solving, or technology implementation by teachers. In total 28 full-text reports were sought for retrieval, and 25 full-text reports were assessed for eligibility, resulting in 19 studies being included in the final review.

Studies were excluded if they focused only on physical manipulatives, such as blocks, bottle tops or counters. Studies were excluded if they were not published in English or if full text was not accessible. Additionally, studies focusing on learning areas unrelated to mathematics were excluded, to maintain alignment with the focus of this review. A total of 46 records were excluded during the title and abstract screening. After full texts had been assessed, 11 reports were excluded for reasons such as not covering early childhood, not focusing on mathematics, not involving digital manipulatives, or lacking full-text access. Furthermore, no records were marked as ineligible by automation tools, and no records were removed for reasons other than those illustrated in Figure 1.

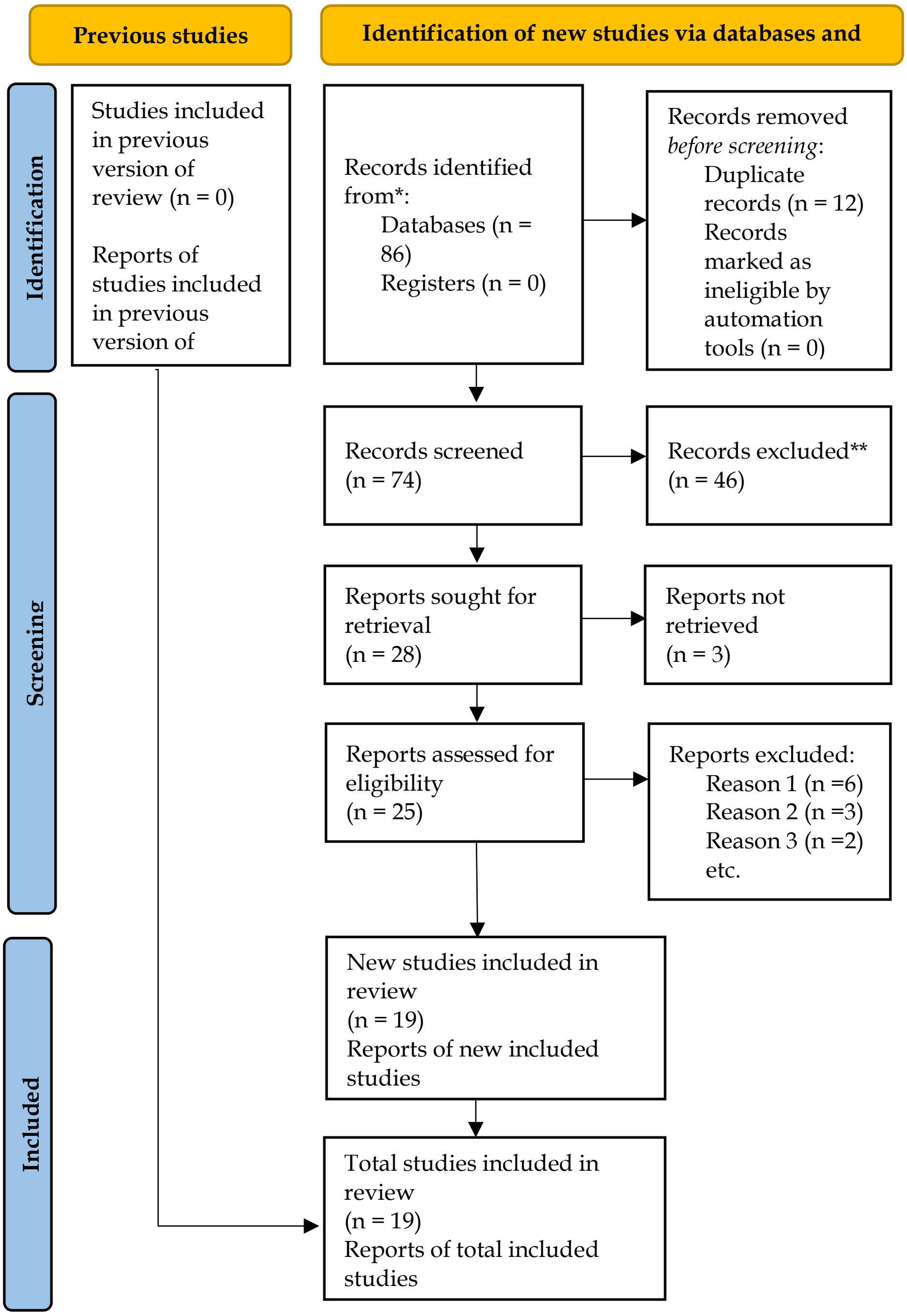

Figure 1: PRISMA diagram summary of review process

** Includes records identified through database searching and other sources*

*** Reports excluded after full-text screening for reasons such as wrong population, irrelevant focus or methodological mismatch*

5. Results and Findings

The scoping review found 19 research studies that explored the integration of digital manipulatives and technology in the teaching and learning of mathematics, especially in the early childhood stage. Table 1 lists evidence that, while digital manipulatives have strong potential to develop early mathematics learning, research is largely concentrated in high-income countries or international contexts and often focused on outcomes rather than teachers' readiness, curriculum alignment and implementation challenges in foundation phase settings. This synthesis highlights a clear gap in research grounded in South Africa that examines how digital manipulatives are implemented in early mathematics classrooms, how teachers are supported to use manipulatives, and how these tools align with curriculum gaps that the present study sought to address. Table 1 presents the reviewed studies by summarising their findings and the implications of using digital manipulatives in early mathematics teaching.

Table 1: Summary of findings of reviewed studies and implications for digital manipulatives in early mathematics teaching

Authors	Country/ context	Method	Findings	Implication for digital manipulatives in teaching mathematics in early childhood
Ochogboju and Díez-Palomar (2025)	High-income countries (predominantly United States)	Systematic review	The review analysed 102 interventions, primarily peer-reviewed journal studies from high-income contexts (United States 60%). Over half the studies involved children aged 4–6 years, mostly in school settings. Interventions were often implemented by researchers rather than teachers, indicating limited classroom-based application.	The study suggests that digital manipulatives have significant implications for teaching mathematics in early childhood, because digital manipulatives can enhance young children's engagement, conceptual understanding and problem-solving abilities. Digital tools enable children to explore mathematics concepts through interactive, visual and dynamic representations that cannot be easily replicated with physical materials, thereby supporting deeper reasoning and flexible thinking. The study also implies that, when digital manipulatives are designed well and used purposefully, they can complement traditional resources, provide immediate feedback and promote active learning, thereby making early mathematics experiences more meaningful and accessible to diverse learners.
Johnston et al. (2022)	Worldwide	Systematic review	Research on STEM, STEAM, and makerspaces in early childhood is increasing. STEAM is most relevant because of its creative and inclusive nature. Studies show benefits for problem-solving and collaboration, but there is a limited focus on infants. There is a strong connection between digital technology and the need for educator training in STEM/STEAM integration.	Digital manipulatives hold meaningful potential for enriching early mathematics learning by combining hands-on exploration with the affordances of digital technology. The review highlights that young children benefit from concrete, interactive tools such as coding blocks, robotics kits and tangible digital interfaces that support foundational concepts such as patterning, spatial reasoning, sequencing and problem-solving. These tools bridge the physical and digital worlds and offer developmentally appropriate ways for children to grasp abstract mathematics concepts through active engagement. Importantly, digital manipulatives also promote creativity, collaboration and multimodal expression, and align well with play-based pedagogy. However, their practical use requires intentional guidance from educators and adequate professional development to ensure that technology enhances, rather than replaces, meaningful mathematical inquiry.

Authors	Country/ context	Method	Findings	Implication for digital manipulatives in teaching mathematics in early childhood
Giblin et al. (2022)	Worldwide	Scoping review	The review findings indicate that digital technologies can enhance numeracy development when they are effectively integrated through sound pedagogy, supported by skilled teachers and used to promote conceptual understanding, engagement, and problem-solving across diverse tools, including digital games, virtual manipulatives, robotics, games and computer-assisted systems.	The review suggests that digital manipulatives have strong potential to enrich early childhood mathematics learning by providing dynamic, visual and interactive representations that help young learners build deeper conceptual understanding. Tools such as virtual manipulatives and digital games support children to explore concepts of number, shape and space, while also increasing engagement and motivation. However, the review emphasises that the effectiveness of digital manipulatives depends heavily on teacher knowledge and pedagogical design: Educators must purposefully integrate these tools, guide children's exploration and ensure alignment with learning goals. When used thoughtfully, digital manipulatives can enhance conceptual learning, support differentiation and create more personalised early mathematics experiences.
Low et al. (2024)	Asia (multiple countries)	Systematic review	According to findings, diverse teaching aids were proposed, including digital technologies such as systems, smartphone apps, games, multimedia, augmented reality, virtual reality, as well as manipulatives, number lines and instructional modules. Both digital and hands-on manipulative teaching aids have been utilised in remedial mathematics interventions, yielding promising results. Key findings indicate the effectiveness of teaching aids depend on alignment with learners' individual needs and suitable pedagogical approaches that are based on local contexts.	Digital manipulatives in early childhood mathematics hold important implications for improving young learners' engagement, conceptual understanding and confidence. The review demonstrates that digital tools, including interactive apps, games, augmented and virtual reality and multimedia, can make mathematics concepts more concrete by offering multisensory, playful and repetitive practice opportunities. These technologies motivate learners, sustain their attention and support differentiated learning, which is essential for children who struggle with early numeracy. However, the findings also highlight the need for teachers to select and implement digital manipulatives intentionally, to ensure the manipulatives align with learners' developmental needs and are supported by appropriate instructional strategies. This suggests that professional development and thoughtful integration are key to maximising the benefits of digital manipulatives in early childhood mathematics classrooms.

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Dardanou et al. (2023)	Europe	Systematic review	The review reveals that, to effectively develop digital skills in early childhood education, it is essential to utilise frameworks tailored to each specific situation, to provide ongoing training for teachers, and to integrate digital skills in teaching methods.	The study suggests that digital manipulatives play a significant role in enhancing early childhood mathematics learning because they provide dynamic, interactive and visually engaging ways for young learners to explore mathematics concepts. Findings are that digital tools help children manipulate shapes, numbers and patterns more easily, which promotes conceptual understanding and creativity and have problem-solving benefits that extend beyond what traditional physical manipulatives can offer. Therefore, incorporating digital manipulatives in early mathematics teaching can enhance learners' engagement, promote deeper mathematical thinking and create more inclusive learning environments in which children can experiment, receive immediate feedback and learn at their own pace.
Sunzuma and Uba Umbara (2025)	Africa	Qualitative study	The findings reveal that utilising innovative pedagogical approaches and technology enables educators to create engaging, culturally relevant learning experiences and foster a deeper understanding and appreciation of mathematics in students.	Using digital manipulatives in early childhood mathematics has important implications for making learning more meaningful, engaging and culturally relevant. The study found that integrating digital tools with cultural elements helped young learners connect mathematical ideas to familiar experiences, which supported deeper conceptual understanding. Digital media such as interactive e-books, augmented-reality resources and culture-based mathematics games helped children to explore shapes, patterns, measurement and counting in ways that are both visual and hands-on. These tools also helped simplify abstract concepts and promote active participation, especially for young learners who learn best through play. However, the article suggests that teachers must intentionally select and design digital manipulatives that match the developmental levels and cultural contexts of their students to ensure that technology enhances, rather than replaces, authentic mathematics exploration.

Authors	Country/ context	Method	Findings	Implication for digital manipulatives in teaching mathematics in early childhood
Mamolo and Shugano (2024)	Philippines	Quasi-experimental study	Results reveal that interactive instructional materials, such as the DIMaC app, can help students decrease their learning anxiety in the 'new normal' setup and improve learning gains. Learning materials that students manipulate and interact with have a significant impact on their mathematics performance. Therefore, school stakeholders, especially subject teachers, should develop interactive materials to support students in the new educational setup.	This study suggests that digital manipulatives such as interactive mathematics apps can play a valuable role in early childhood mathematics education by reducing learning anxiety and enhancing engagement. The article reports that, when learners interact with visually appealing, game-like digital tools, their confidence increases and they become more willing to explore mathematical ideas. For young children, this means digital manipulatives can create a playful and supportive learning environment in which abstract concepts become more concrete through touch, movement and visual storytelling. These tools also promote independent learning and can help teachers personalise instruction and make mathematics more enjoyable and less intimidating for early learners.
Chan et al. (2022)		Systematic review	The review found that block-based programming, robotics and unplugged activities were the most common tools for linking computational thinking and mathematics, thereby highlighting that effective integration requires clear pedagogical goals, teacher support and curriculum alignment to enhance mathematical reasoning and problem-solving.	The review suggests that digital manipulatives have significant potential in early childhood mathematics by making abstract ideas more concrete through interactive, playful learning experiences. Because young children learn best through hands-on exploration, using digital tools such as interactive apps, virtual blocks and programmable toys can strengthen conceptual understanding while also introducing early computational thinking in developmentally appropriate ways. The review reports that these tools encourage problem-solving, experimentation and creativity, thereby helping learners build foundational mathematical reasoning. For teachers, digital manipulatives offer accessible ways to design engaging tasks that support differentiated learning and integrate technology meaningfully in early mathematics classrooms.
Lin and Powell (2021)	United States	Longitudinal quantitative study	The study found that being fluent in mathematics and reading, along with having a strong memory for working tasks, had a considerable effect on future	The study emphasises that young children's mathematics performance is strongly influenced by their early cognitive skills, foundational numeracy understanding and early reading of mathematical symbols and representations. This

Authors	Country/ context	Method	Findings	Implication for digital manipulatives in teaching mathematics in early childhood
			mathematics performance. Age also played a significant role in how these factors affected mathematics skills. As children grew, the influence of being good at mathematics and having a good memory became stronger, but the effect of paying attention and controlling one's behaviour became weaker.	suggests that, because digital manipulatives provide visual, interactive and repeatable experiences, they can support these early skills by giving young learners multiple ways to explore number concepts, reinforce symbol–meaning connections and receive immediate feedback. Therefore, an important implication is that digital manipulatives can serve as valuable scaffolding tools that strengthen early cognitive foundations and help young children develop the basic mathematics competencies highlighted in the article, which are critical for later achievement.
Ke et al. (2024)	China	Experimen-tal study	The results show that using mathematising supports had a positive effect on the way students practiced mathematisation, both in their records and observations, and improved their performance in solving mathematics problems during and after playing games.	The study findings suggest that digital manipulatives can significantly enhance early childhood mathematics learning by facilitating a transition from intuitive, trial-and-error thinking to more structured, quantitative reasoning. Because children often begin with visual or exploratory strategies, digital tools that prompt them to notice relationships, organise information and connect actions to mathematical ideas can gently guide them towards early mathematics. The study advises that supports must be simple, visually clear, motivating and instantly helpful, because children are unlikely to persist with cognitively demanding features that feel 'too wordy'. Finally, the strong role of peer and teacher scaffolding suggests that digital manipulatives work best when they are combined with social interaction and helping young learners verbalise their thinking and making sense of mathematical patterns.
Demir et al. (2024)		Meta-analysis	The findings indicate that the impact of technology-based instruction on mathematics performance is at a medium level. Additionally, studies about technology-based instruction determined that the location where the studies are	Using digital manipulatives has significant implications for early childhood mathematics teaching, because they make abstract concepts more concrete and interactive for young learners. The study found that technology-based tools such as dynamic visual models, simulations, and touch-screen applications help children visualise mathematical relationships, explore multiple representations, and develop problem-solving strategies more effectively. Because digital

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			conducted and quality of those studies influence the results.	manipulatives provide immediate feedback and encourage hands-on exploration, they support a deeper conceptual understanding and increase motivation and more positive attitudes towards mathematics in early learners. This suggests that incorporating well-designed digital manipulatives in early childhood classrooms can strengthen foundational mathematical thinking and improve overall learning outcomes.
Ran et al. (2022)	Worldwide	Meta-analysis	This study reveals a statistically significant and positive effect of technology on students' mathematics achievement. The most considerable and significant effect that was revealed is that, when technology was used to support collaborative and communicative environments, this was followed by roles using technology as a support for problem-solving, as a support for conceptual development, and as a tool for adaptive mathematics practices. Furthermore, the influence of technology on mathematics achievement significantly varied according to study features.	Digital manipulatives in early childhood mathematics provide young learners with interactive, visual and dynamic tools that make abstract concepts more concrete and accessible. In addition, these manipulatives boost engagement and support play-based learning, though their success depends on strong teacher guidance. With proper scaffolding and teacher training, digital manipulatives can meaningfully improve early learners' number sense, problem-solving skills and motivation learn mathematics.
Fokuo et al. (2023)	Ghana	Systematic review	The findings of the reviewed literature shed light on the positive effects of visualisation tools in promoting active engagement, conceptual understanding and motivation of college of education students. While these results provide useful insights, their applicability to early childhood education contexts is limited because of differences in learner characteristics and pedagogical needs. Additionally, the review uncovered	According to the study findings, an important implication of using digital manipulatives in teaching mathematics in early childhood is that these tools can significantly strengthen young children's understanding of abstract ideas by turning these abstract ideas into concrete, visual, and interactive learning experiences. The study found that visualisation tools such as virtual manipulatives, interactive simulations and dynamic geometry software enhance engagement, support diverse learning needs and improve conceptual understanding by making mathematical relationships easier to notice and explore. However, the findings also highlight

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			potential challenges, including technological barriers, instructional strategies, and varying learning preferences, that educators and curriculum designers need to consider when integrating visualisation tools in mathematics classrooms.	the need for thoughtful teacher guidance, appropriate instructional design and adequate technology access to ensure that digital manipulatives lead to deep, rather than superficial, mathematical thinking.
Güler et al. (2022)		Meta-analysis	The results show that mobile learning has a medium-level positive effect on learners' mathematics achievement. Moderator analyses show that effect sizes were not significantly moderated by grade level and implementer, while content area was found to be a moderator.	Using digital manipulatives has substantial implications for early childhood mathematics because manipulatives provide young learners with interactive ways to explore mathematical ideas using visual, symbolic and concrete representations that naturally support learners' developmental needs. The study demonstrates that virtual manipulatives can enhance conceptual understanding, foster critical thinking and improve procedural fluency by enabling children to manipulate objects, test their ideas and receive instant feedback. Digital manipulatives also offer multiple representations, such as fraction bars, number lines and diagrams, which help young children connect abstract concepts to concrete actions. When paired with appropriate teacher guidance and well-designed learning tasks, digital manipulatives can significantly enhance engagement, support differentiation and promote deeper mathematical understanding in early childhood settings.
Mohamed et al. (2021)	Malaysia	Quasi-experimental study	The results indicate that most studies emphasise both conceptual and procedural understandings. Multiple representations utilise sequential or parallel concepts related to fractions to improve students' knowledge, particularly for understanding fractions. Meanwhile, developing fraction learning through multiple explicit representations at	Using digital manipulatives has substantial implications for early childhood mathematics teaching, as they enable young learners to build a deeper conceptual understanding by interacting with mathematical ideas in concrete, visual and symbolic ways. The article demonstrates that, when children engage with multiple representations, such as virtual models, number lines, pictures and manipulatives, they gain a better understanding of concepts such as part-whole relationships and fraction magnitude. These tools also support teachers by offering flexible and engaging ways to introduce abstract

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			the initial grade level of fraction instruction is recommended for elementary school.	ideas and address common misconceptions. Additionally, digital manipulatives can significantly enhance early mathematical learning when integrated thoughtfully and paired with clear instructional guidance.
Bognar et al. (2025)	Europe		The results of this study suggest that effective foundation phase mathematics instruction should foster students' conceptual understanding and procedural fluency through problem-solving, active learning and mathematical games.	Using digital manipulatives has significant implications for teaching mathematics in early childhood. The study reports that technology-enhanced tools, such as virtual manipulatives, interactive software and digital representations, help young learners build a stronger conceptual understanding by making abstract ideas more concrete and visually accessible. These tools support early reasoning by offering multiple representations and opportunities for exploration, which aligns with principles of effective mathematics teaching that emphasise conceptual understanding, communication and the use of varied representations. The study suggests that digital manipulatives can enhance engagement and formative assessment, but their use requires thoughtful teacher guidance, proper integration and attention to learners' individual needs to maximise their impact.
Muhaimin and Juandi (2023)	Indonesia	Meta-analysis	The study found that various types of media facilitate the development of diverse mathematics materials through learning media. Learning media can also develop cognitive abilities required for mathematics, including mathematical problem-solving, mathematical understanding, mathematical communication, critical mathematical thinking, mathematical representation, mathematical reasoning, and spatial abilities.	Digital manipulatives offer significant benefits for early childhood mathematics education because they enable young learners to engage with mathematics concepts through visual, hands-on and dynamic representations, which make abstract ideas easier to understand. The study reports that these tools can enhance children's conceptual development, support experimentation and encourage exploration by allowing them to manipulate objects freely and receive immediate feedback. Digital manipulatives also promote engagement and can help teachers differentiate instruction by providing varied representations and adjustable levels of difficulty. When combined with purposeful teacher guidance, digital manipulatives can deepen understanding, strengthen

Authors	Country/ context	Method	Findings	Implication for digital manipulatives in teaching mathematics in early childhood
				problem-solving skills and create more effective early mathematics learning experiences.
Hodgen et al. (2020)	United Kingdom	Systematic review	The review found that high-quality early mathematics learning is best promoted through play-based, language-rich and intentional teaching approaches that emphasise early number sense and spatial reasoning; teacher professional development is a key factor for improving mathematics outcomes.	Digital manipulatives can enhance early mathematics learning by providing young children with hands-on, visual and interactive ways to explore core concepts such as counting, number relationships, patterns and shapes. The review highlights that manipulatives help children move from concrete actions to more abstract understanding, and digital versions of these tools offer added benefits such as instant feedback, opportunities for repeated practise and the ability to represent ideas dynamically. They can also support early problem-solving by helping children reason flexibly and test their ideas in multiple ways. When used purposefully with guided teacher support, digital manipulatives can deepen children's conceptual understanding and enrich early mathematics experiences.
Ludwigs (2024)	Europe	Conceptual /empirical study	The findings underscore the importance of targeted development and deployment of digital technologies for talented mathematics students, by recognising them as a distinct user group.	Digital manipulatives have significant implications for early childhood mathematics teaching because they provide young learners with visual, interactive and dynamic ways to explore mathematical concepts that are challenging to grasp using traditional materials. Evidence suggests that virtual manipulatives can facilitate deeper reasoning, flexible thinking and more complex mathematical explanations by providing multiple representations and opportunities for self-correction. They also enhance engagement and motivation, mainly when used on touch-screen devices that allow children to manipulate objects intuitively. However, their effectiveness depends on strong teacher guidance, purposeful task design, and alignment with learning goals. When supported with appropriate scaffolding, digital manipulatives can significantly enrich early mathematics learning experiences.

Note. STEAM = science, technology, engineering, arts, and mathematics; STEM = Science, technology, engineering, and mathematics.

6. Discussion

The studies reveal four major themes: learner engagement and conceptual understanding of early mathematics, pedagogical practices and affordances of digital manipulatives, teacher readiness and professional development, and contextual and infrastructural challenges. All these themes positively affect implementation of digital manipulatives.

6.1 Theme 1: Learner Engagement and Conceptual Understanding of Early Mathematics

The findings of most studies reviewed reveal that digital manipulatives such as virtual manipulatives, dynamic geometry software, mathematics applications and interactive games enhance learners' engagement, conceptual understanding, and motivation in early mathematics. Moyer-Packenham et al. (2022) and Butler et al. (2022) report that digital manipulatives such as visual, dynamic geometry systems and mathematics-based applications allow learners to visualise mathematical relationships dynamically. These manipulatives facilitate active exploration and strengthen the learners' number sense, special reasoning and problem-solving skills.

Learning is conducted through guided interaction with the learners; teachers scaffold their engagement with digital tools by posing questions, modelling strategies and facilitating peer collaboration. According to Vygotsky's sociocultural theory, these digital manipulatives function as mediating artefacts that support learning through social interaction and scaffolding within the ZPD, to allow learners to move from supported exploration to more independent mathematical reasoning. Additionally, Mamolo and Sugano (2023) and Low et al. (2024) demonstrate that digital manipulatives can reduce mathematics learning anxiety and foster a positive attitude towards learning the subject, especially in the early years when learners develop curiosity, when tactile interaction is pivotal.

6.2 Theme 2: Pedagogical Practices and Affordances of Digital Manipulatives

The studies reviewed emphasise that, when digital manipulatives are purposefully integrated with sound pedagogy, they go beyond traditional hands-on manipulatives and support higher-order mathematical thinking and social interaction. Empirical studies show that digital manipulatives such as block-based programming, robotics and interactive games promote collaborative problem-solving and computational thinking in the mathematics context (Chan et al., 2022; Dardanou et al., 2023). Similarly, Ran et al. (2022) and Fokuo et al. (2023) found that digital models and visualisation improve the mathematical reasoning and presentation skills of learners when these manipulatives are aligned with effective pedagogy.

Research indicates that many countries use digital manipulatives in early mathematics with positive effect (Nwikpo & Chiemeka, 2024). In contrast, South African teachers often rely on concrete manipulatives to support meaningful pedagogical approaches because these teachers lack access to digital manipulatives (Ngozwana, 2025). The findings align well with Vygotsky's sociocultural theory, according to which digital manipulatives serve as mediating tools that support interaction and scaffolded learning within the ZPD (Kim et al., 2022; Stanziale, 2024). However, the literature reveals gaps in context-specific evidence on how digital manipulatives can be systematically integrated into play-based pedagogies, as mandated by the DBE (2011), which highlights the need for further research on sustainable pedagogical models, teacher support and equitable access.

6.3 Theme 3: Teacher Readiness and Professional Development

Despite teachers having the potential to use digital manipulatives, some studies reveal that teacher readiness to effectively integrate the digital manipulative is limited. Many of the studies analysed report that teacher readiness gaps were primarily related to insufficient technological pedagogical integration skills rather than a lack of awareness of the potential benefits of digital tools (Dardanou et al., 2023; Elmalı et al., 2025; Johnston et al., 2022).

Studies conducted by Elmalı et al. (2025) and Dardanou et al. (2023) reveal that, in environments where teachers have access to digital manipulatives, they usually use them for repetitive drills rather than exploration, which is the result of inadequate teacher training. Similarly, Johnston et al. (2022) found that, while teachers acknowledge the benefits of technology-enhanced learning, most of them lack confidence and planned support to effectively implement it. This gap stresses the importance of continuous professional development programmes that equip teachers with both the pedagogical and technological skills they need to integrate digital manipulatives effectively.

In addition to teacher competence, contextual factors such as curriculum guidance on technology integration, restricted access to devices, unreliable connectivity and insufficient technological support also influence implementation (Johnston et al., 2022; Ngozwana, 2025). These factors hinder teachers' ability to progress from using basic technology to pedagogically meaningful digital manipulation aligned with play-based learning principles.

The literature, furthermore, identified several solutions, such as implementing targeted professional development programmes focusing on pedagogical uses of digital manipulatives, collaborative teacher learning communities, and scaffolded training models that integrate technology with curriculum objectives to address these challenges (Dardanou et al., 2023; Johnston et al., 2022). Studies suggest that continued professional development rather than once-off training would improve teacher confidence, instructional design, and effective classroom implementation of digital manipulatives.

6.4 Theme 4: Contextual and Infrastructural Challenges

Studies such as that of Naidoo (2022) and Elmalı et al. (2025) emphasise that infrastructural constraints, including limited internet access, insufficient digital devices, and a lack of classroom technology, delay the use of digital manipulatives. Other challenges that affect the implementation of digital manipulatives relate to difficulties teachers experience connecting digital manipulatives to learners' daily life experiences and learning context. When digital manipulatives are not aligned with learners' familiar environments, cultural practices or home experiences, teachers struggle to integrate them meaningfully into play-based and experiential learning. Additionally, policy documents such as South Africa's CAPS (DBE, 2019) promote activity-based learning but provide little explicit guidance on how to integrate digital tools in early mathematics teaching. This gap contributes to inconsistency of implementation between urban and under-resourced schools.

Moreover, Fokuo et al. (2023) observed that both technological barriers and varying teacher beliefs affect the consistency and effectiveness of digital manipulative use. The findings of this paper suggest that the role of digital manipulatives in teaching mathematics in early childhood is to enhance learner engagement, conceptual understanding and motivation in mathematics. Additionally, success depends on teaching strategies, teacher competence and curriculum alignment. Although digital manipulatives could be effective, barriers such as inadequate training, limited infrastructure and lack of explicit policy guidance continue to limit the practical implementation.

The findings reveal that digital manipulatives play an increasingly significant role in strengthening early childhood mathematics teaching and learning. The 19 studies reviewed provide evidence that digital manipulatives enhance learner engagement, support conceptual understanding and promote positive attitudes to mathematics through interactive, visual and dynamic representations (Giblin et al., 2022; Mamolo & Shugano, 2024; Moyer-Packenham et al., 2022). When these tools are integrated effectively, they extend the pedagogical value of traditional manipulatives by offering immediate feedback, opportunities for repeated exploration and multimedia representations that support diverse learners (Bognar et al., 2025; Ke et al., 2024; Low et al., 2024).

However, the effective implementation of digital manipulatives is powerfully shaped by teacher readiness, their professional competence and their access to adequate infrastructure (Dardanou et al., 2023; Demir et al., 2024; Johnston et al., 2022). Many early childhood teachers still lack pedagogical and technological support to integrate digital manipulatives meaningfully, while the CAPS provides limited guidance on technology-enhanced early mathematics teaching (Hodgen et al., 2020; Ngozwana, 2025).

Additionally, while digital manipulatives hold strong potential to transform early numeracy learning, success depends on coherent alignment between pedagogy, professional development and policy support (Ochogboju & Díez-Palomar, 2025; Ran et al., 2022). Further research is needed in South Africa and similar contexts to explore contextually relevant digital resources, teacher training models and classroom-based strategies that can maximise the affordances of digital manipulatives and strengthen foundational mathematics learning for all young children.

7. Conclusion

The findings of this study lead to the conclusion that there is a close link between the effective integration of digital manipulatives and teachers' pedagogical and technological competence. Insufficient professional preparation continues to hinder meaningful classroom implementation. Additionally, the study determined that existing policy, including the CAPS, does not provide enough and often only implicit guidance on the implementation of digital resources in early mathematics, which leads to inconsistencies in practice in the classroom. Furthermore, limited access to digital resources, poor internet connectivity and the absence of appropriate software remain barriers to the integration of digital learning, particularly in disadvantaged schools. Finally, the study concludes that there is a shortage of contextually grounded evidence on the sustained impact of digital manipulatives in South African early childhood education, which highlights the need for further research to deepen understanding of the long-term pedagogical value of digital manipulatives.

8. Recommendations

This study emphasises that there is a need for professional development to equip early childhood teachers with both the pedagogical and technological competencies required to integrate digital manipulatives meaningfully in mathematics teaching. These professional training courses should focus on how to operate digital manipulatives and utilise them to deepen conceptual understanding, support inquiry and scaffold mathematical thinking. Additionally, the DBE and curriculum developers should consider providing more explicit guidance through policy documents, including the CAPS, to ensure that the integration of digital resources in early mathematics is intentional and aligned with developmental expectations.

Further contextual research is needed in South African and other developing settings to inform both subject advisers and teachers, so that they understand how digital manipulatives support early numeracy development in the best way possible. These recommendations aim to support a more equitable, effective and pedagogically sound integration of digital manipulatives to strengthen early mathematics learning.

Conflict of Interest

The authors declare no conflicts of interest.

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