

Technology-Based Interactive Numeracy Learning Media in Inclusive Education: A Systematic Literature Review

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Abstract: The lack of comprehensive evidence synthesizing the characteristics and effectiveness of technology-based interactive numeracy tools for inclusive education has limited the development of evidence-informed instructional practices. This study aims to analyze research trends, key characteristics, educational contributions, implementation challenges, and future directions of technology-based interactive numeracy learning in inclusive education through a Systematic Literature Review (SLR). Following PRISMA 2020 guidelines, the review analyzed 31 eligible studies published between 2020 and 2025, retrieved from Google Scholar, Crossref, DOAJ, and Garuda databases. The selected studies were synthesized using thematic analysis to identify recurring patterns, emerging themes, and research gaps. The findings reveal that technology-based interactive approaches improve students' learning motivation, engagement, conceptual understanding of numeracy, and accessibility in inclusive classrooms. Effective instructional tools consistently integrate audiovisual features, interactivity, gamification, immediate feedback, and adaptability to diverse learner needs. The review also identifies major implementation challenges, including limited digital infrastructure, insufficient teacher competencies, and the need for adaptive instructional design. This study contributes by synthesizing current evidence and proposing a conceptual framework to guide future research and the design of more adaptive, interactive, and inclusive numeracy instruction.

Keywords: Inclusive education, interactive learning, numeracy, systematic literature review, technology-based



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A. Introduction

Despite the growing number of studies on technology-based instruction in inclusive education, current evidence remains fragmented. It lacks a comprehensive synthesis of the instructional characteristics that effectively support numeracy learning for students with special educational needs. Existing studies have primarily focused on the development or evaluation of individual technologies, such as Augmented Reality (AR), Virtual Manipulatives, QR Code-based media, interactive multimedia, assistive technologies, and Smart Apps Creator (Afriani, Wilmanda, & Gamaradika, 2023; Dhuha & Astutik, 2025; Dwiasnati et al., 2025; Fitri & Amiruddin, 2025; Hidayah & Budijanto, 2003; Lestari, Dinarzah, Yusufi, Muhammad, & Nadhif, 2025; Mulyahati, Ayudia,

Mustika, Fransyaigu, & Kenedi, 2025; Munasaroh & Mizan, 2025; Priyadi, Monica, & Saputri, 2024; Rochmania, Makruf, & Muhammada, 2024; Suarjana, Setemen, & Diputra, 2024; Zayyadi et al., 2023). Although these studies consistently report positive educational outcomes, they investigate different technologies, learner populations, instructional objectives, and research designs. However, because these studies adopted different technological approaches, research designs, and learner populations, their findings remain difficult to compare. They cannot yet provide a coherent evidence base for designing effective technology-supported numeracy instruction in inclusive education. Consequently, the fragmented nature of previous studies provides limited evidence regarding the technological and pedagogical characteristics that consistently support effective numeracy instruction in inclusive education, creating a significant knowledge gap for educators, instructional designers, and student researchers with diverse educational needs.

Inclusive education aims to provide equitable learning opportunities for all learners regardless of their physical, intellectual, social, emotional, or cultural characteristics. Achieving this goal requires instructional approaches that accommodate diverse learning needs through differentiated teaching strategies, accessible learning environments, and adaptive educational technologies (Pratiwi & Sukartono, 2025). Nevertheless, previous studies continue to report substantial challenges in implementing inclusive education, including inadequate educational infrastructure, limited teacher competence in differentiated instruction, and the scarcity of instructional resources specifically designed for students with special educational needs (Adnyani & Pradnyana, 2025; Azizah, Sa'dah, & Firdausiyah, 2024; Azzahra, Mawarsari, & Suprayitno, 2025). These limitations hinder equitable access to quality learning and reinforce the need for technology-supported instructional innovations.

Numeracy is a fundamental competency that requires adaptive instructional support in inclusive classrooms. Beyond performing arithmetic operations, numeracy encompasses understanding numerical concepts, interpreting quantitative information, reasoning mathematically, and applying mathematical knowledge in everyday situations (Prananto, 2022). Developing numeracy skills contributes to learners' logical thinking, problem-solving, and decision-making abilities and has therefore become a central priority in primary education (Megawati & Sutarto, 2021). However, students in inclusive classrooms have diverse cognitive abilities, learning characteristics, and educational support needs, making conventional instructional approaches insufficient to support conceptual understanding. Consequently, interactive and accessible instructional technologies have become increasingly important for supporting numeracy learning among students with diverse educational needs and abilities (Khairunnisa & Andini, 2025; Rustandar & Widinarsih, 2023; Swinita, Suarjana, & Trisna, 2024).

The rapid advancement of digital technology has expanded opportunities to develop technology-based learning media that integrate audiovisual representation, interactivity, immediate feedback, gamification, and adaptive learning experiences. Previous studies have shown that technology-based learning media can improve students' motivation,

participation, accessibility, and conceptual understanding by presenting mathematical concepts through multisensory learning experiences. (Dhuha & Astutik, 2025; Erliani, Herdi, & Jumaryadi, 2025; Febrianti, Rahman, Alani, & Nuriyanti, 2025; Sekar, 2025; Zahroh, Wardani, Salimah, Putri, & Delta, 2025). Nevertheless, these findings remain largely descriptive because each study evaluates a particular technology or instructional context. Few studies critically compare their findings to identify the common characteristics of technology-based learning media, implementation challenges, and pedagogical principles that consistently support numeracy learning across diverse inclusive educational settings.

In inclusive classrooms, the diversity of learners' abilities requires teachers to simultaneously accommodate the needs of both typically developing students and students with special educational needs. This situation is often challenging because currently available instructional media are generally designed for the broader student population and are insufficiently adaptive to diverse learning needs. Previous studies indicate that teachers continue to struggle to select instructional media appropriate for students with special educational needs, particularly for abstract numeracy concepts (Rahma, 2019). Furthermore, limited educational facilities, insufficient integration of digital technologies, and the scarcity of interactive learning media have reduced the effectiveness of numeracy instruction and limited students' active participation in classroom activities (Lestari et al., 2025; Putri & Ramadhani, 2024; Sekar, 2025; Zahroh et al., 2025). Consequently, innovative instructional media are needed not only to deliver learning content but also to provide engaging, adaptive, and learner-centered educational experiences within inclusive classrooms.

Unlike previous review studies that primarily summarized individual technologies or evaluated specific interventions, this review critically synthesizes empirical evidence across diverse technological approaches. It proposes an integrated conceptual framework that explains how learner characteristics, instructional design, technological features, and learning outcomes interact to support inclusive numeracy learning. This integrated perspective advances the current body of knowledge by providing evidence-based design principles and identifying future research priorities for technology-supported numeracy instruction in inclusive education.

To address these limitations, this study conducts a Systematic Literature Review (SLR) following the PRISMA 2020 guidelines to synthesize current evidence on technology-based interactive numeracy learning in inclusive education. Unlike previous studies that primarily developed or evaluated individual instructional technologies, this review critically compares existing findings to identify research trends, instructional characteristics, educational contributions, implementation challenges, and future research opportunities. Furthermore, this study proposes an integrated conceptual framework that explains the relationships among learner characteristics, numeracy competencies, digital technology, instructional processes, and learning outcomes. The proposed framework provides a theoretical foundation for future research while offering evidence-based

guidance for educators and instructional designers in developing more adaptive, interactive, and inclusive numeracy learning environments.

B. Method

This study used the Systematic Literature Review (SLR) method to identify, evaluate, and synthesize research findings on technology-based interactive numeracy learning media in inclusive education. The SLR approach was chosen because it enables a systematic, transparent, and replicable review process, resulting in a comprehensive scientific synthesis of research developments, media characteristics, benefits, challenges, and implementation opportunities. The review process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (Page et al., 2021), including the stages of identification, screening, eligibility, and article inclusion.

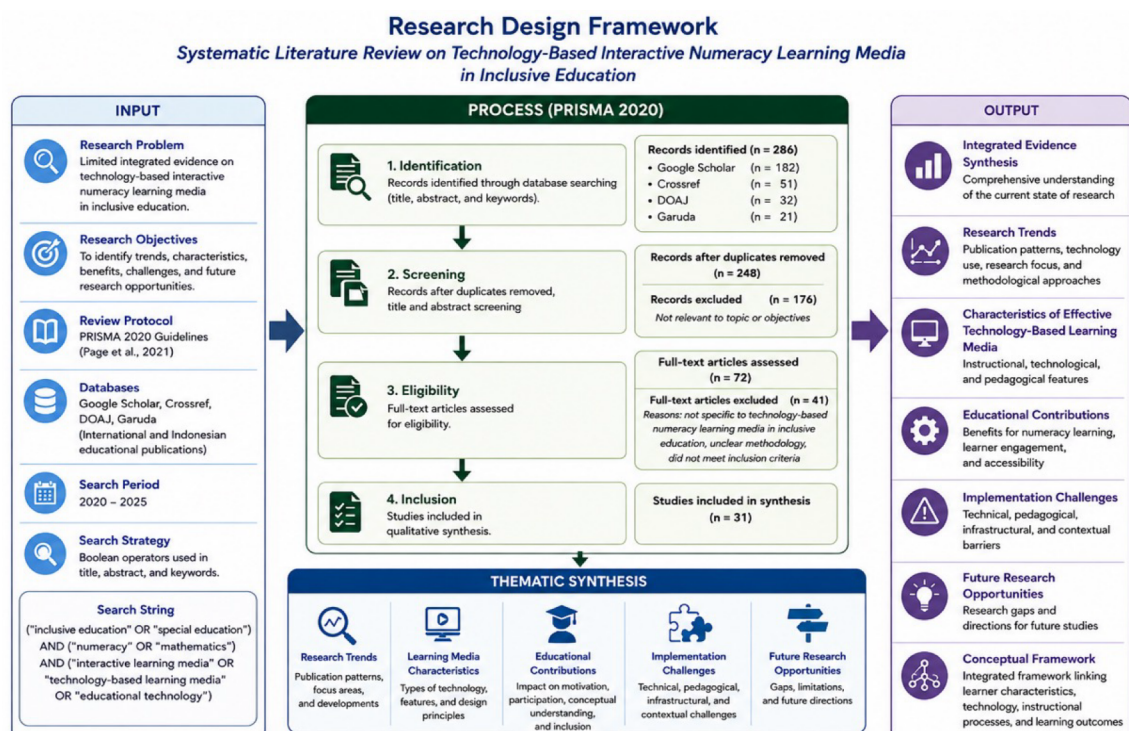


Figure 1. Research Design Framework

The research data consisted of scientific articles obtained from various scientific databases, including Google Scholar, Crossref, Garuda, and DOAJ. The literature search used a combination of keywords: digital learning media, interactive learning media, numeracy, mathematics learning, educational technology, assistive technology, numeracy learning media, and inclusive education. The search focused on articles published between 2020 and 2025 to provide an overview of recent research developments.

The inclusion criteria for this study included: (1) scientific articles published between 2020 and 2025; (2) articles discussing technology-based learning media in inclusive education; (3) research examining numeracy, mathematics, or interactive learning media for students with special needs; (4) articles available in full text; and (5)

articles published in accredited national journals, international journals, or scientific proceedings relevant to the research topic. Exclusion criteria included articles that did not discuss technology-based learning media, articles unrelated to inclusive education or numeracy, duplicate articles, and publications that did not provide clear methodological information.

Data analysis was conducted in four stages. The first stage was identification, which collected articles based on predetermined keywords. The second stage was screening, which screened articles based on titles, abstracts, and their relevance to the research objectives. The third stage was eligibility, which thoroughly reviewed the articles' content to ensure compliance with the inclusion criteria. The final stage was synthesis, which grouped research results by main themes, including the characteristics of learning media, the technology used, the objectives of media development, the benefits for numeracy learning, and the challenges of implementation in inclusive education. Next, the synthesis results were analyzed descriptively and comparatively to identify research trends, research gaps, and recommendations for developing technology-based interactive numeracy learning media in inclusive education.

C. Results and Discussion

Results

The characteristics of the 31 studies included in this systematic literature review. The reviewed studies were conducted in various inclusive educational settings involving elementary school students, children with special educational needs, students with visual impairments, hearing impairments, autism spectrum disorder, intellectual disabilities, dyscalculia, Down syndrome, and learning difficulties. The diversity of participants indicates that technology-based learning media have been increasingly developed to accommodate heterogeneous learner characteristics in inclusive education.

Regarding research design, most studies adopted Research and Development (R&D) or development-oriented methodologies to design and validate innovative learning media. These included STEM-based learning media (Astutik, 2020), Virtual Manipulatives (Suarjana et al., 2024), QR Code-assisted tactile books (Dwiasnati et al., 2025), Smart Box (Khairunnisa & Andini, 2025), Interactive PowerPoint (Ramandha, Muharromah, & Novitasari, 2025), AR-integrated learning kits (Fitri & Amiruddin, 2025), and various Augmented Reality applications (Hidayah & Budijanto, 2003; Mulyahati et al., 2025). In comparison, fewer studies employed experimental, mixed-methods, or case study approaches, while several studies synthesized existing evidence through literature reviews, systematic reviews, and bibliometric analyses. This distribution suggests that current research has largely emphasized developing innovative learning media rather than conducting large-scale empirical evaluations of their long-term effectiveness.

The reviewed studies also demonstrate considerable diversity in the types of technology-based learning media employed. The most frequently investigated technologies included interactive multimedia, augmented reality (AR), assistive

technology, virtual manipulatives, digital learning platforms, QR Code-based media, Smart Box, educational robotics, game-based learning technologies, digital storytelling, artificial intelligence, and interactive websites. Despite their technological differences, these learning media shared several common instructional characteristics, including interactivity, multisensory representation, immediate feedback, adaptive learning pathways, and learner-centered instructional design.

Analysis of the targeted numeracy competencies revealed that most studies focused on basic numeracy skills, including number recognition, early numeracy, basic arithmetic, mathematical concepts, and mathematical communication. Fewer studies examined higher-order mathematical competencies, such as mathematical problem-solving, arithmetic reasoning, and mathematics achievement. This finding indicates that existing research has primarily concentrated on strengthening foundational numeracy competencies among students with special educational needs. At the same time, relatively fewer studies have investigated technology-supported interventions targeting higher-order mathematical thinking.

Across the reviewed literature, educational outcomes consistently indicate that technology-based learning media contribute positively to inclusive numeracy education. Interactive learning media generally improved students' conceptual understanding of mathematical concepts, increased learner motivation and classroom participation, strengthened early numeracy skills, enhanced mathematical communication, and improved accessibility for students with diverse educational needs. For example, Smart Box and Math Kids Game effectively supported number recognition, whereas Virtual Manipulatives and augmented reality applications facilitated conceptual understanding through interactive visualization. Similarly, assistive technologies, QR Code-assisted tactile learning media, and BISINDO-based interactive websites expanded learning accessibility by providing alternative modes of mathematical representation for students with visual and hearing impairments.

Although the reviewed studies consistently reported positive educational outcomes, they also showed variation in implementation contexts and instructional objectives. Technologies designed for students with visual impairments primarily emphasized accessibility through tactile, auditory, and assistive features. In contrast, interventions targeting students with intellectual disabilities and autism focused on visual representation, repetitive practice, and structured interactive activities. Furthermore, game-based learning, digital storytelling, and artificial intelligence were increasingly utilized to enhance learner engagement, personalize learning experiences, and promote active participation in inclusive mathematics instruction. These findings suggest that the effectiveness of technology-based learning media depends not only on technological innovation but also on their alignment with learner characteristics and instructional objectives.

Table 1. Characteristics of the Included Studies

No	Author(s)	Participants / Target Learners	Research Design	Technology-Based Learning Media	Numeracy Competency	Main Findings
1.	Astutik	Inclusive elementary school students	Research and Development (R&D)	STEM-Based Learning Media	Mathematical communication	STEM-based learning media improved students' mathematical communication skills and supported active mathematics learning.
2.	Rustandar & Widinarsih	Students with Autism Spectrum Disorder	Literature Review	Visual and Interactive Learning Media	Basic numeracy	Visual and interactive media facilitated individualized numeracy instruction for students with autism.
3.	Suarjana et al.	Elementary school students	Research and Development (R&D)	Virtual Manipulatives	Number concepts	Virtual manipulatives enhanced conceptual understanding of number concepts through interactive visualization.
4.	Azzahra et al.	Inclusive elementary school teachers	Needs Analysis	Digital Learning Media	Early numeracy	Adaptive digital media were identified as essential for supporting inclusive numeracy learning.
5.	Dhuha & Astutik	Students with special educational needs	Literature Review	Technology-Based Learning Media	Numeracy learning	Digital learning media improved accessibility and learner engagement in inclusive classrooms.

Continued Table 1.

No	Author(s)	Participants / Target Learners	Research Design	Technology-Based Learning Media	Numeracy Competency	Main Findings
6.	Dwiasnati et al.	Students with visual impairment	Research and Development (R&D)	QR Code Audio Book	Mathematical concepts	QR Code-assisted tactile learning promoted interactive understanding of mathematical concepts.
7.	Erliani et al.	Inclusive elementary students	Implementation Study	Interactive Multimedia	Early numeracy	Interactive multimedia increased learner participation and strengthened early numeracy skills.
8.	Febrianti et al.	Deaf students	Development Study	Interactive Website (BISINDO)	Numeracy support	The website improved accessibility and supported inclusive mathematics learning.
9.	Khairunnisa & Andini	Elementary school students	Experimental Study	Smart Box	Number recognition	Smart Box significantly improved students' number recognition abilities.
10.	Sekar	Students with special educational needs	Literature Review	Digital Learning Media	Numeracy learning	Digital media enhanced accessibility and learning effectiveness in inclusive education.
11.	Sofiana et al.	Students with visual impairment	Experimental Study	Audio-Tactile Learning Media	Early numeracy	Audio-tactile media improved engagement through multisensory mathematics instruction.

Continued Table 1.

No	Author(s)	Participants / Target Learners	Research Design	Technology-Based Learning Media	Numeracy Competency	Main Findings
12.	Zahroh et al.	Inclusive education students	Literature Review	Adaptive Digital Learning Media	Numeracy learning	Adaptive digital media demonstrated strong potential for technology-supported inclusive mathematics learning.
13.	Hidayah & Budijanto et al.	Inclusive school students	Development Research	AR-Integrated OXYTECH Learning Kit	Science-integrated numeracy	AR-supported learning improved conceptual understanding through interactive activities.
14.	Hidayah & Budijanto	Students with disabilities (SLB)	Development Research	Augmented Reality (Assemblr)	Basic numeracy	Assemblr-based AR increased students' motivation and mathematical understanding.
15.	Indriani & Aminullah	Students with special educational needs	Development Study	Assistive Technology	Basic numeracy	Assistive technology facilitated individualized mathematics instruction.
16.	Mulyahati et al.	Inclusive education students	Development Research	Augmented Reality	Number concepts	AR improved students' understanding of mathematical concepts through interactive visualization.
17.	Lestari et al.	Inclusive elementary students	Development Research	Assistive Technology	Basic numeracy	Assistive technology enhanced accessibility and individualized mathematics learning.

Continued Table 1.

No	Author(s)	Participants / Target Learners	Research Design	Technology-Based Learning Media	Numeracy Competency	Main Findings
18.	Stasolla et al.	Students with dyscalculia	Systematic Review	Educational Robotics & Game-Based Learning	Arithmetic skills	Robotics and game-based interventions improved arithmetic performance among learners with dyscalculia.
19.	Chandra et al.	Students with disabilities	Literature Review	Augmented Reality	Mathematical concepts	AR promoted inclusive learning through visualization and learner engagement.
20.	Ferawati et al.	Students with special educational needs	Experimental Study	AR-Math	Numeracy skills	AR-based assistive learning significantly improved numeracy performance.
21.	Ali	Rural inclusive school students	Mixed Methods	Digital Mathematics Learning Platform	Mathematics achievement	Technology-supported instruction improved mathematics achievement in rural inclusive settings.
22.	Ali et al.	Students with learning difficulties	Case Study	Assistive Technology	Mathematics learning	Assistive technology supported differentiated mathematics instruction.
23.	Gallud et al.	Children with special educational needs	Systematic Mapping Study	Game-Based Learning Technologies	Numeracy learning	Game-based learning consistently enhanced motivation and engagement in mathematics.
24.	Shoaib et al.	Students with visual impairment	Literature Review	Assistive Technology	Mathematical concepts	Assistive technology improved accessibility in mathematics learning.

Continued Table 1.

No	Author(s)	Participants / Target Learners	Research Design	Technology-Based Learning Media	Numeracy Competency	Main Findings
25.	Ramandha et al.	Children with Down syndrome	Development Research	Interactive PowerPoint	Numerical skills	Interactive PPT significantly improved numerical skills among children with Down syndrome.
26.	Kumaş	Early childhood learners	Experimental Study	Digital Storytelling	Early numeracy	Digital storytelling strengthened children's early numeracy understanding.
27.	Purwasih	Elementary school students	Research and Development (R&D)	Math Kids Game	Number recognition	Educational games effectively improved early numeracy achievement.
28.	Khuzaini et al.	Studies on special education	Bibliometric Analysis	Mathematics Learning Media	Mathematics learning	The study identified emerging trends and research gaps in technology-supported mathematics learning media.
29.	Pilco et al.	Minority students with special educational needs	Literature Review	Artificial Intelligence	Mathematics support	AI technologies demonstrated potential to personalize inclusive learning experiences.
30.	Rahmah et al.	Blind student	ADDIE Development Research	Inclusive Digital Numeracy Assessment	Numeracy assessment	The ADDIE-based assessment successfully measured numeracy competencies for visually impaired learners.
31.	Hidayah & Budijanto	Students with disabilities	Development Research	Augmented Reality Learning Media	Basic numeracy	AR learning media improved conceptual understanding and learner motivation.

Overall based on the Table 1, the synthesis of the included studies shows that technology-based learning media have evolved from simple digital instructional tools into adaptive learning environments that support diverse numeracy competencies in inclusive education. Rather than emphasizing technological sophistication alone, the reviewed studies consistently highlight accessibility, interactivity, adaptability, and learner-centered instructional design as key characteristics that contribute to successful technology-supported numeracy learning. These recurring patterns provide the empirical foundation for the conceptual framework proposed in this review and illustrate the current direction of research on technology-based interactive numeracy learning media in inclusive educational settings.

Table 2. Distribution of Technology-Based Learning Media in the Included Studies

Technology-Based Learning Media	Frequency	Percentage
Interactive Multimedia	5	16.1%
Augmented Reality (AR)	5	16.1%
Assistive Technology	4	12.9%
Digital Learning Media	4	12.9%
Virtual Manipulatives	2	6.5%
Interactive Website	2	6.5%
Smart Box	2	6.5%
Game-Based Learning Media	2	6.5%
QR Code-Based Media	1	3.2%
Audio-Tactile Media	1	3.2%
Digital Storytelling	1	3.2%
STEM-Based Learning Media	1	3.2%
Interactive PowerPoint	1	3.2%
Video-Based Learning	1	3.2%
Total	31	100%

Table 2 presents the distribution of technology-based learning media employed in the included studies. Augmented Reality (AR) and Interactive Multimedia were the most frequently investigated technologies, each appearing in five studies (16.1%). Assistive Technology and Digital Learning Media were also commonly implemented, each appearing in four studies (12.9%). Other technology-based media included Virtual Manipulatives, Interactive Websites, Smart Box, and Game-Based Learning Media (6.5%

each). Less frequently investigated technologies included QR Code-Based Media, Audio-Tactile Media, Digital Storytelling, STEM-Based Learning Media, Interactive PowerPoint, and Video-Based Learning (3.2% each). These findings indicate that recent research has increasingly emphasized interactive and adaptive digital technologies to improve accessibility, engagement, and numeracy learning outcomes in inclusive educational settings.

Table 3. Distribution of Target Learners in the Included Studies

Target Learners	Frequency	Percentage
Mixed Special Educational Needs	10	32.3%
Students with Intellectual Disabilities	5	16.1%
Students with Visual Impairments	4	12.9%
Students with Autism	3	9.7%
Students with Hearing Impairments	2	6.5%
Students with Dyslexia	2	6.5%
Students with Down Syndrome	1	3.2%
Students with Dyscalculia	1	3.2%
Students with Learning Disabilities	2	6.5%
Teacher Participants (Inclusive/Special Education)	1	3.2%
Total	31	100%

Table 3 presents the distribution of target learners across the included studies. Mixed special educational needs (SEN) represented the largest participant group, accounting for 10 studies (32.3%). Students with intellectual disabilities were the second most frequently investigated population (16.1%), followed by students with visual impairments (12.9%) and students with autism (9.7%). Fewer studies focused specifically on students with hearing impairments, dyslexia, Down syndrome, or dyscalculia. Only one study targeted teachers through professional development activities. These findings indicate that current research predominantly investigates technology-based learning media for heterogeneous inclusive classrooms rather than focusing on specific disability categories. Moreover, learners with intellectual disabilities and visual impairments have received greater attention than other disability groups, highlighting opportunities for future research involving underrepresented populations such as students with hearing impairments, dyscalculia, and multiple disabilities.

Table 4 summarizes the numeracy competencies investigated across the included studies. Number recognition was the most frequently addressed competency, representing 25.8% of the reviewed studies. This was followed by counting skills (19.4%) and mathematical concepts (16.1%), indicating that most technology-based learning media

were designed to strengthen foundational numeracy skills in inclusive educational settings. Problem-solving (12.9%) and arithmetic operations (9.7%) were investigated less frequently, while number sequencing, quantity comparison, mathematical communication, and numeracy assessment received comparatively limited attention. These findings suggest that current research largely emphasizes basic numeracy competencies. Meanwhile, higher-order mathematical reasoning and broader quantitative skills remain underexplored, creating opportunities for future research and instructional media development.

Table 4. Distribution of Numeracy Competencies Investigated in the Included Studies

Numeracy Competency	Frequency	Percentage
Number Recognition	8	25.8%
Counting Skills	6	19.4%
Mathematical Concepts	5	16.1%
Problem Solving	4	12.9%
Arithmetic Operations	3	9.7%
Number Sequencing	2	6.5%
Quantity Comparison	1	3.2%
Mathematical Communication	1	3.2%
Numeracy Assessment	1	3.2%
Total	31	100%

Discussion

Research Trends in Technology-Based Interactive Numeracy Learning Media

The findings of this systematic literature review indicate a substantial increase in research on technology-based interactive numeracy learning media in inclusive education during 2020–2025. The distribution of the reviewed studies shows that research has shifted from conventional discussions of inclusive education toward developing and implementing digital learning media that support students with diverse educational needs. This trend reflects not only the rapid advancement of educational technology but also the growing recognition that inclusive education requires instructional innovations that address learner diversity through accessible, flexible, and learner-centered approaches (Azizah et al., 2024; Pratiwi & Sukartono, 2025).

The analysis of research designs further reveals that Research and Development (R&D) was the dominant methodological approach among the reviewed studies. This finding suggests that current research has primarily focused on designing and validating innovative technology-based learning media rather than conducting large-scale evaluations of their long-term effectiveness. Examples include the development of STEM-based learning media (Astutik, 2020), Smart Box learning media (Khairunnisa & Andini, 2025), augmented reality applications (Hidayah & Budijanto, 2003; Mulyahati et al., 2025), QR Code-integrated tactile books (Dwiasnati et al., 2025), and virtual manipulatives for mathematics learning (Suarjana et al., 2024). Collectively, these studies

demonstrate that researchers are increasingly attempting to bridge the gap between technological innovation and the instructional needs of students with special educational needs. However, the relatively limited number of experimental and longitudinal studies indicates that stronger empirical evidence regarding the sustained educational impact of these learning media is still required.

Another notable trend concerns the types of technology adopted in inclusive numeracy learning. The synthesis shows that recent studies increasingly employ interactive multimedia, augmented reality, assistive technologies, digital learning platforms, and game-based learning media. This transition indicates a shift from technology as a tool for presenting information to technology as an interactive learning environment that promotes active participation, immediate feedback, and individualized learning experiences. Such findings are consistent with Karwanto (2023), who argues that educational technology should function as an instructional facilitator that enables meaningful learning experiences rather than simply digitizing conventional teaching materials.

Earlier studies tended to emphasize the development of technological products, whereas more recent investigations increasingly consider pedagogical aspects such as learner engagement, accessibility, adaptability, and differentiated instruction. This evolution suggests that the effectiveness of technology-based learning media is no longer evaluated solely by technological sophistication but by their capacity to reduce learning barriers and facilitate meaningful participation among students with diverse abilities. Such an orientation aligns with the principles of inclusive education, which emphasize equitable learning opportunities through flexible instructional design rather than standardized instructional practices (Maslahah, Tiyas, Chozin, Juminarsih, & Trijoko, 2024).

Despite these encouraging developments, several gaps remain evident. Most studies focused on short-term implementation involving relatively small participant groups, while only a limited number investigated long-term classroom implementation, scalability, or cross-context comparisons. Furthermore, research still focuses mainly on developing individual learning media rather than examining how different technological approaches can be integrated into comprehensive instructional ecosystems. These findings indicate that future research should move beyond product development by conducting longitudinal, comparative, and large-scale studies that generate stronger evidence on the sustainability and broader educational impact of technology-based interactive numeracy learning media in inclusive education.

Characteristics of Effective Technology-Based Learning Media

The synthesis of the 31 included studies shows that the effectiveness of technology-based learning media in inclusive numeracy education depends not on technological sophistication alone but on integrating pedagogical, technological, and accessibility principles that accommodate the diverse characteristics of learners with special educational needs. Across the reviewed studies, several instructional characteristics recurred, including interactivity, multisensory representation, adaptability, immediate

feedback, and learner engagement. These characteristics were identified across various forms of technology-based learning media, including interactive multimedia, augmented reality (AR), virtual manipulatives, assistive technologies, QR Code-based media, Smart Box, digital storytelling, and interactive websites. Rather than functioning independently, these instructional characteristics complement one another to create meaningful and inclusive numeracy learning experiences.

One of the most prominent characteristics identified in this review is interactivity. Most reviewed studies indicate that technology-based learning media become more effective when learners actively manipulate objects, respond to learning tasks, receive immediate feedback, and participate directly in constructing mathematical understanding. For example, virtual manipulatives let students explore mathematical concepts through digital representations they can manipulate repeatedly, supporting conceptual understanding of numbers and mathematical relationships (Suarjana et al., 2024). Similarly, Smart Box media allow students with intellectual disabilities to recognize numbers through interactive activities involving visual objects and immediate feedback, resulting in significant improvements in early numeracy skills (Khairunnisa & Andini, 2025). These findings suggest that interactive learning environments encourage students to become active participants rather than passive recipients of information.

These findings are consistent with Constructivist Learning Theory, which argues that knowledge is actively constructed through learners' interaction with their environment rather than transmitted directly from teachers to students (Piaget, 1971). Technology-based learning media facilitate this process by allowing learners to manipulate digital objects, solve mathematical problems, receive immediate feedback, and revise their understanding based on learning experiences. Consequently, technology functions not merely as a presentation medium but as a cognitive tool that supports the active construction of mathematical knowledge. This interpretation also explains why studies using highly interactive learning environments generally reported greater improvements in numeracy learning than studies that used technology only for information delivery.

Another recurring characteristic is multisensory representation. Students with diverse educational needs often require multiple forms of information presentation to understand abstract mathematical concepts. Across the reviewed studies, learning media integrating text, images, audio, animation, tactile components, sign language, and visual simulations consistently reported positive educational outcomes. For example, QR Code-based tactile books combined audio instructions with tactile materials to support students with visual impairments (Dwiasnati et al., 2025), whereas BISINDO-based interactive websites facilitated communication accessibility for students with hearing impairments through visual language representation (Febrianti et al., 2025). Likewise, audio-tactile media provided alternative sensory pathways for students with visual impairments to understand scientific and mathematical concepts (Sofiana, Aslamiah, & Amini, 2025). These findings indicate that multisensory learning environments reduce cognitive barriers by presenting information through multiple complementary modalities.

The review also shows that adaptability is another essential characteristic of effective technology-based learning media. Unlike conventional instructional media designed for homogeneous classrooms, technology-based media developed for inclusive education frequently incorporate flexible learning pathways that accommodate different learner characteristics. Assistive technologies, adaptive digital media, and individualized learning platforms allow educators to adjust instructional content to students' cognitive abilities, sensory needs, and learning pace (Lestari et al., 2025; Zahroh et al., 2025). Such flexibility is particularly important because inclusive classrooms include students with heterogeneous educational needs, including autism, hearing impairments, visual impairments, intellectual disabilities, and learning difficulties, each requiring different instructional supports.

These findings align closely with the principles of Universal Design for Learning (UDL), which emphasize providing multiple means of representation, engagement, and action and expression to accommodate learner variability. The reviewed studies demonstrate that adaptive digital learning environments improve accessibility by enabling learners to engage with mathematical concepts using instructional approaches appropriate to their individual characteristics. Maslahah et al. (Maslahah et al., 2024) reported similar conclusions, emphasizing that UDL-based instructional design creates more inclusive learning environments by reducing instructional barriers and increasing learner participation. Therefore, adaptability should be viewed as a fundamental pedagogical requirement rather than merely an additional technological feature.

Another recurring finding concerns the importance of immediate feedback. Interactive learning media often provided automated responses that helped students recognize errors, monitor progress, and correct misconceptions during learning. This feature was evident in Smart Box media (Khairunnisa & Andini, 2025), interactive multimedia (Erliani et al., 2025), and game-based applications, where immediate responses encouraged continuous learner engagement while reinforcing mathematical understanding. Such findings suggest that feedback functions not only as an assessment mechanism but also as an instructional strategy that supports self-regulated learning and conceptual development.

The review also highlights the growing integration of gamification within technology-based numeracy learning media. Several studies incorporated educational games, challenges, rewards, visual progress indicators, and interactive storytelling to increase learner motivation and persistence during mathematical learning activities. For example, Smart Apps Creator-based educational games (Munasaroh & Mizan, 2025) and interactive game-based media increased students' motivation while encouraging repeated mathematical practice. These findings suggest that gamification boosts engagement by turning repetitive mathematical exercises into meaningful, enjoyable learning experiences. Nevertheless, gamification appears most effective when carefully aligned with instructional objectives rather than implemented solely to increase learner enjoyment.

The review also indicates that the effectiveness of technology-based learning media depends on instructional design quality rather than technological complexity (Gallud et al., 2023; Khuzaini, Nasrullah, & Fariha, 2025; Kumaş, 2024; Purwasih, 2022; Salaspilco, Xiao, & Oshima, 2022; Shoaib, Fitzpatrick, & Pitt, 2023). Several studies reported that learning media containing excessive visual effects, complicated navigation, or unnecessary multimedia elements could reduce learning effectiveness by distracting students from mathematical content (Sintawati & Abdurrahman, 2020). Accordingly, effective technology-based learning media should balance multimedia richness with instructional simplicity to ensure that technological features facilitate rather than hinder mathematical learning.

Overall, this review's findings show that effective technology-based numeracy learning media share common pedagogical characteristics, regardless of the specific technology used. Interactivity, multisensory representation, adaptability, immediate feedback, and gamification collectively help create accessible, engaging, and learner-centered instructional environments. Therefore, the effectiveness of technology-based learning media should be understood not as the result of technological innovation alone but as the consequence of integrating sound pedagogical principles with inclusive instructional design. This synthesis extends previous studies by demonstrating that successful technology-enhanced numeracy learning emerges from the interaction among learner characteristics, instructional strategies, and technological affordances, providing a stronger conceptual foundation for developing future inclusive learning media.

Theoretical Contribution of the Conceptual Framework

A major contribution of this systematic literature review is an integrated conceptual framework that explains the relationships among learner characteristics, numeracy competencies, technology-based learning media, instructional processes, and learning outcomes in inclusive education. Unlike previous studies that mainly examined individual technologies, this framework demonstrates that effective technology-based numeracy learning results from the interaction of pedagogical design, learner needs, and technological affordances rather than from technology alone (Dwiasnati et al., 2025; Khairunnisa & Andini, 2025; Suarjana et al., 2024).

The framework reinforces Universal Design for Learning (UDL) principles by emphasizing learner diversity as the foundation of instructional design. The reviewed studies consistently show that adaptive technologies, assistive media, sign language-based multimedia, and interactive digital platforms improve learning accessibility by providing multiple ways for students to engage with mathematical concepts (Dhuha & Astutik, 2025; Febrianti et al., 2025; Lestari et al., 2025). These findings demonstrate how technology operationalizes inclusive instructional principles in numeracy learning.

The framework also supports Constructivist Learning Theory, which argues that learners actively construct knowledge through experience. Interactive media such as Virtual Manipulatives, Smart Box, and Augmented Reality encourage learners to explore mathematical concepts, solve problems, and receive immediate feedback, thereby promoting deeper conceptual understanding (Astutik, 2020; Khairunnisa & Andini, 2025;

Suarjana et al., 2024). Likewise, the findings extend Multimedia Learning Theory by showing that combining visual, auditory, and interactive elements enhances engagement and facilitates the understanding of abstract mathematical concepts, particularly for students with special educational needs (Dwiasnati et al., 2025; Erliani et al., 2025; Febrianti et al., 2025).

Furthermore, the review broadens the perspective of Assistive Technology by positioning digital technologies not merely as compensatory tools but as instructional resources that enhance participation, accessibility, and learner independence (Lestari et al., 2025; Zahroh et al., 2025). Overall, the proposed framework addresses the fragmented nature of previous research by integrating learner characteristics, instructional strategies, technology-based learning media, and educational outcomes into a unified explanatory model (Ali, Aftab, & Chaudhry, 2024; Chandra, Dwiana, & Muhajirin, 2025; Lin & Riccomini, 2025; Stasolla et al., 2025). Consequently, it provides a stronger theoretical foundation for future research and offers evidence-based guidance for designing more adaptive, interactive, and inclusive technology-based numeracy learning environments.

Challenges in Implementing Technology-Based Interactive Numeracy Learning Media in Inclusive Education

Although the reviewed studies consistently reported positive effects of technology-based learning media on numeracy learning, several implementation challenges remain. The synthesis indicates that successful technology integration depends not only on the availability of digital media but also on infrastructure readiness, teacher competence, learner diversity, instructional design, and institutional sustainability.

A major challenge is the limited availability of technological infrastructure in inclusive schools. Several studies reported insufficient access to digital devices, internet connectivity, assistive technologies, and supporting facilities, particularly in schools outside urban areas (Adnyani & Pradnyana, 2025; Salma, Najibah, & Zulfadewina, 2025). Nevertheless, the review suggests that infrastructure alone does not determine success. Positive learning outcomes were also observed in resource-limited schools where teachers creatively adapted available technologies to meet students' learning needs (Rahmah, Rochyadi, Ufairah, Am, & Annisa, 2025; Sekar, 2025).

Teacher competence represents another critical challenge. Effective technology integration requires teachers to combine digital tools with differentiated instructional strategies that address diverse learner characteristics (Fitri & Amiruddin, 2025). However, many teachers still struggle to select appropriate learning media and adapt technology for students with special educational needs (Azizah et al., 2024; Pratiwi & Sukartono, 2025). Similarly, Erliani et al. (Erliani et al., 2025) emphasized that technology becomes more effective when teachers actively facilitate learning rather than relying solely on digital features.

Learner diversity also affects implementation. The reviewed studies demonstrate that different disabilities require different technological supports. For example, tactile and audio-based media were more appropriate for students with visual impairments (Dwiasnati et al., 2025; Sofiana et al., 2025), whereas sign language-supported

multimedia benefited students with hearing impairments (Febrianti et al., 2025). Meanwhile, Smart Box and Virtual Manipulatives were particularly effective for students with intellectual disabilities because they turned abstract mathematical concepts into concrete and interactive learning experiences (Khairunnisa & Andini, 2025; Suarjana et al., 2024). These findings highlight the need for flexible and adaptive learning media rather than standardized technological solutions.

The review further indicates that instructional design quality and long-term sustainability remain significant concerns. Learning media with simple navigation, clear visual representation, immediate feedback, and adaptive features consistently produced better learning outcomes than overly complex digital applications (D. Karwanto, 2023; Sekar, 2025). In addition, most studies evaluated technology over short intervention periods, providing limited evidence on long-term implementation and scalability (Indriani & Aminullah, 2024). Sustained integration therefore requires continuous teacher professional development, institutional support, and alignment between technology use, curriculum implementation, and individualized educational planning (Fitri & Amiruddin, 2025; Inayah & Prasetyo, 2025; Lestari et al., 2025).

D. Conclusion

This systematic literature review synthesizes current evidence on technology-based interactive numeracy learning media in inclusive education by examining research trends, instructional characteristics, and implementation challenges. The findings indicate that effective learning media consistently integrate interactivity, multisensory representation, adaptability, immediate feedback, and learner-centered instructional design. Their effectiveness depends not only on technological innovation but also on the alignment among learner characteristics, pedagogical strategies, and instructional design.

The review contributes theoretically by proposing an integrated conceptual framework that explains the relationships among learner characteristics, numeracy competencies, technology-based learning media, instructional processes, and learning outcomes. This framework advances previous research by demonstrating that successful technology integration is driven by the interaction of pedagogical, technological, and learner-related factors rather than by technology itself. Practically, the findings provide evidence-based guidance for educators, instructional designers, school leaders, and policymakers in designing more adaptive, accessible, and inclusive numeracy learning environments.

This review has several limitations. It included only studies published between 2020 and 2025 and was limited to publications indexed in Google Scholar, Crossref, DOAJ, and Garuda. In addition, most included studies adopted Research and Development (R&D) designs with relatively small samples and short implementation periods, limiting evidence regarding long-term effectiveness and scalability. Future research should prioritize longitudinal and experimental studies with larger and more diverse participant groups, as well as cross-country comparative research. Further empirical studies are also needed to validate and refine the proposed conceptual

framework and to examine how instructional design, learner diversity, and emerging technologies interact to support sustainable technology-based numeracy learning in inclusive education.

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