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A systematic review of the utility of assistive technologies for SEND students in schools

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The systematic review investigates the effect of various educational technologies on the learning outcomes of diverse student populations, particularly focusing on assistive technology interventions for students with disabilities. The comprehensive analysis covers literature from 2012 to 2023. The study highlights the potential of AR and assistive technologies in fostering inclusive and engaging learning environments. Despite positive findings, the review emphasizes the imperative for further research to refine the implementation of these technologies and enhance their effectiveness. The systematic review of five databases provides crucial insights into the effectiveness of various assistive technologies. Mobile devices, iPads, and AR interventions emerge as frequently utilized tools. Research activity peaked in 2013 and 2018 and subsequently declined. Twelve studies focus on Autism Spectrum Disorder and emphasize the prioritization of ASD in assistive technology interventions. The research highlights the importance of adopting a holistic perspective on educational inclusion, emphasizing collaborative efforts among teachers, diverse teaching methods, and technology integration. Despite the promise shown by assistive technologies, the review acknowledges their limitations and advocates for ongoing research and innovation to refine their application across diverse educational contexts. The findings stress the importance of a nuanced interpretation of evidence, considering the challenges posed by the limited number of eligible studies. The review calls for careful consideration of future research directions to bolster the comprehensiveness and reliability of evidence synthesis in assistive technology interventions for students with disabilities.

KEYWORDS

assistive technologies, students with disabilities, augmented reality, inclusive education, autism spectrum disorder, special educational needs and disabilities

1 Introduction

Modern educators face the challenge of adapting to the digital experiences of today's students and addressing the diverse educational needs arising from these experiences. Current students, having grown up with interactive games, expect similar engaging experiences from their educational tools (Squire et al., 2005). Literacy is no longer confined to a single medium (Mackey, 2003). Students now use a variety of modes of communication, a concept referred to as multimodality. Multimodality encompasses diverse interactions, extending beyond traditional scripts to include video, internet, music, and other modes of expression

(Heron-Hruby et al., 2008). This approach is situated within a participatory culture created by new media, reshaping learning for 21st-century students (Jenkins, 2009). Modern classrooms are diverse and require that educators understand the specific requirements and respond inclusively (Cope and Kalantzis, 2015; Serafini and Gee, 2017; The New London Group, 1996; Tyler, 2019; Zembylas, 2019).

Contrary to the prevailing preference for traditional face-to-face classes among the general student population, students with disabilities prefer online learning (Ilgaz and Gulbahar, 2017; Kent et al., 2018). This peculiarity prompts a nuanced exploration of the factors influencing the educational preferences of individuals with disabilities, warranting further investigation into the dynamics shaping their learning preferences. Nevertheless, comprehensive international analyses scrutinizing the overall accessibility landscape of online learning reveal pervasive shortcomings in learning materials and platforms (Alsalem and Doush, 2018; Boateng, 2016; Carvajal et al., 2018; Massengale and Vasquez, 2016). This collective inadequacy underscores the imperative for a systemic overhaul to rectify these deficiencies and enhance the inclusivity of digital educational resources.

Establishing an inclusive learning environment that accommodates individuals with diverse needs represents the core responsibilities of education providers. Disabled students face numerous challenges and barriers in science and medicine laboratories (Hackl and Ermolina, 2019). Researchers suggest that enhancing the accessibility of printed materials and video files, reliance on multiple teaching techniques, and assistive technologies fosters an inclusive learning environment.

The term "inclusive learning environment" denotes the integration of students with special educational needs and disabilities or SEND into routine school activities. Thereby, inclusive design signifies the creation of typical educational services and products that are usable and accessible by the largest possible spectrum of individuals without requiring special adaptations (Persson et al., 2015). Hockings refines the discourse by defining inclusive learning and teaching as the strategic alignment of curriculum, teaching and evaluation to engage students in educational experiences that are productive, appropriate and universally accessible (Hockings, 2010). An inclusive learning environment is pivotal in supporting disabled students in acquiring education. This underscores the duty of education providers in creating inclusive environments and facilitating individual adjustments. Recent reviews have emphasized the need for institutional commitment to inclusive teaching and learning, with a particular emphasis on designing curriculum, delivering content to students, and evaluating progress (Gibson, 2015; Lawrie et al., 2017; Penner, 2018). These efforts collectively underscore the imperative of fostering inclusivity within the education landscape.

2 Literature review

Assistive technologies (ATs) have emerged as highly efficacious resources for educators, particularly in enhancing student's academic capabilities, including those with various disabilities. Pioneering research during the initial integration of computer technologies into schools globally revealed that assistive technology tools significantly improve the communication and reading of students with disabilities, including those with ASD (Autism Spectrum Disorder) (Heimann et al., 1995). The Franklin Language Master and PowerPoint represented the forefront of assistive technologies in pedagogy. These innovative resources played a pivotal role in developing traditional reading and writing skills (Vacca et al., 2011). Educators could establish dynamic instructional environments that leverage engaging visual and auditory cues by integrating new literacies and best teaching practices. This approach allowed students to experience reading material interactively and express their personalized understanding of readings in novel and individualized ways (Gentry, 2005; Lindsey-Glenn and Gentry, 2008).

The integration of ATs has been validated through engaging research-backed practices. These devices offer novel opportunities for textual reading and enable educators to use direct and logical commands to direct student's attention to on-screen words or phrases. The convergence of student attention on specific words or particular phrases aids in the comprehension of contextual meanings within the story (Lindsey-Glenn and Gentry, 2008). ATs are transformative tools that empower educators to create rich and immersive learning environments, foster enhanced literacy skills, and cultivate meaningful engagement among diverse student populations.

Students with ASD face considerable challenges that may impede their success in inclusive educational settings. Difficulties in interacting and communicating with classmates and teachers and active participation in classroom activities arise from social communication deficits central to the disorder's diagnostic criteria. The manifestation of restricted and repetitive interests or behaviors in students with ASD can adversely impact both academic achievements and social relationships (Lanovaz et al., 2013). Furthermore, the prevalence of challenging behaviors among students with ASD may act as a barrier to their successful inclusion in general education classrooms (Crosland and Dunlap, 2012; Dunlap et al., 2010; Emerson et al., 2001). An examination into the effectiveness of collaborative group work, facilitated by ICT, for cultivating appropriate task-related interactions among primary school children diagnosed with ASD demonstrated positive results. The male adolescent reported moderate improvement and proficiency in engaging with peers. These improvements were evident in both social interactions and those related to specific tasks. Additionally, the study observed an elevated social standing for the child among his classmates (Lewis et al., 2005).

Students with visual impairments encounter challenges in accessing Online Courses, virtual reality applications and other Information Communication Technology (ICT) supports (Eligi and Mwantimwa, 2017; Lannan, 2019; Park et al., 2019). These impediments underscore the pressing need for enhanced accessibility measures in digital learning environments catering to individuals with visual impairments. Likewise, deaf or hard-of-hearing individuals confront accessibility issues in acquiring education (Batanero et al., 2019; Lago and Acedo, 2017). The reported challenges underscore the importance of addressing auditory accessibility in educational platforms to ensure an inclusive educational experience for students with disabilities.

The research underscores the pervasive use of assistive technologies supported by mobile devices for orientation of and interaction with SEND students (Pellerin, 2013; Dionne, 2013; Terrer-Perez, 2013). Mobile devices enhance accessibility and play a supportive role in improving educational outcomes for students with visual impairment (Hayhoe, 2012). Moreover, the use of assistive mobile technologies in students with ASD leads to improvements in communication, interpersonal and organizational skills (Sultana and Hayhoe, 2013).

Digital reading practices and technologies help augment SEND student's written text understanding (Hutchison et al., 2012). Features such as audio support, word-by-word reading capabilities, and visual animations facilitate alternative forms of engagement and motivate reading activities in students with visual disabilities.

However, the favorable outcomes resulting from the interplay of mobile devices and SEND students depend upon the accessibility of technological interfaces and several other factors (Fernández-López et al., 2013). Firstly, the user interface must be facile and intuitive for ease of use and access. Secondly, it must allow for the customization of interface and educational content to attract and maintain student interest. Thirdly, there must be multi-modal accessibility features for engaging students with diverse needs. Finally, there is a need for proactive interactions designed to foster communication between students and teachers. These factors will collectively contribute to the efficacy and inclusivity of mobile technology interfaces in catering to the educational requirements of students with diverse needs.

A systematic review published in 2019 explored the utility of Augmented Reality (AR) as an educational and pedagogical technology for catering to all student's needs, particularly SEND students (Quintero et al., 2019). The systematic review examined 50 studies conducted between 2008 and 2018 across three databases. The systematic review also included conference papers. Twenty per cent of the studies in the disability category dealt with Deaf or Hard of Hearing (DHH). Research showed that AR works well with mobile devices, and people with hearing impairments often prefer using the visual channel for understanding information (Parton et al., 2010). The greater reliance on the visual medium lends greater importance to visual tools, including interactive multimedia and videos. The research also encourages using special glasses for reading and decoding accessibility features such as QR and AR codes (Parton, 2017).

Furthermore, 18 % of the studies investigated the utility of assistive mobile technology in addressing the needs of individuals with ASD. AR offers promising results in designing applications that facilitate the recognition of facial emotions, which is a primary challenge for individuals with ASD (Chen et al., 2015). This reduced the teacher's workload by evoking a recognition of emotions in autistic children, promoting self-regulation, and increasing student concentration and motivation to participate in social situations (Escobedo and Tentori, 2014). Fourteen per cent of the research concentrated on individuals with intellectual disabilities. The low-cost integration of gamification through AR has impacted the approach to treatment in this area (Colpani and Homem, 2015). Interactive textbooks incorporating AR, videos, and images are effective for children with learning disabilities (Vinumol et al., 2013). Other studies have explored the impact of augmented reality in improving the understanding of primary elementary geometry and developing decision-making skills in students with Autism and other intellectual disabilities (Lin et al., 2016a; Lin et al., 2016b; McMahon et al., 2015; McMahon et al., 2016). Numerous studies emphasize the utility of assistive technology tools for promoting the participation and inclusion of SEND students (Fernández-Batanero et al., 2022; Zubillaga del Rio et al., 2013).

Our examination of current research on using AR for SEND students points out its utility for improving education outcomes for students with disabilities. These advantages include aiding in self-initiation and self-management, providing guidance in resolving complex tasks through self-instruction, and offering assistance in location and navigation in various environments (Gómez-Puerta et al., 2019). Moreover, AR technology provides advantages to individuals with physical and mental disabilities, enabling them to enjoy normal activities and participate in their hobbies (Alshafeey et al., 2019).

Researchers have investigated the use of AR applications to enhance the learning outcomes of SEND students (Sirakaya and Alsancak Sirakaya, 2018; Yuliono and Rintayati, 2018). Meta-analysis confirms the utility of technology-assisted education practices for the successful community integration of ASD students (Barton et al., 2017). A rigorous analysis with very narrow parameters confirms the utility of technological interventions for imparting social skills to autistic students. The results are even favorable for subjects with acute manifestations of Autism (Sansosti et al., 2015). Another review of assistive technologies in special education settings found minor evidence of their positive effects (Garzón et al., 2019). However, the research merely investigates the potential impact of assistive technologies and does not measure the effect size. Furthermore, research does not clearly define the disabilities under investigation, nor the skills imparted to individuals under study (Barton et al., 2017). AR technologies and their impact on SEND student's educational outcomes are novel research areas as the pool of published studies in this domain is relatively small (Lorenzo et al., 2019). However, the pervasiveness of digital technologies demands a greater interest in exploring augmented reality's utility in teaching SEND students' different skills. AR serves as an indispensable pedagogical tool, transcending conventional instructional paradigms by adeptly emulating the intricacies of scientific apparatus within a virtual domain seamlessly superimposed upon real-world objects. This educational framework distinguishes itself by its capacity to dynamically enhance operational principles during user interaction, a feature notably absent in traditional real-world pedagogy (Wu et al., 2013).

The substantial merit of AR games is underscored by their facility to append supplementary multimedia components and interactive elements, thereby providing real-time accessibility and comprehension of complex phenomena and mechanisms (Sahin and Yilmaz, 2020). This augmentation is critical in explicating imperceptible concepts, elucidating laboratory safety protocols, and substantiating abstract notions (Walczak et al., 2006). AR spans two-dimensional and three-dimensional representations of objects, facilitating a nuanced visual exposition of real-world items. The interactional facet of augmented reality amplifies user engagement and cultivates a heightened spatial and logical understanding of otherwise concealed scientific, biological, or mechanical processes (Kurniawan et al., 2018; Rohendi et al., 2018). Therefore, disciplines necessitating acute spatial awareness, inclusive of geometry, mathematics, chemistry, mechanics, anatomy, and astronomy, stand poised to accrue substantial benefits from the transformative potential of AR (Kadry and Ghazal, 2019; Layona et al., 2018; Radu, 2012; Rashevska et al., 2020).

Augmented reality applications and alternate reality games (ARG) present opportunities for creating engaging learning environments. Incorporating AR and ARG into educational frameworks should consider individual differences between students. Universal Design for Learning (UDL) provides a framework based on action, engagement, and representation for accommodating students with diverse learning needs. The affordability and accessibility of

Augmented Reality Applications and Games provide multiple avenues for action, engagement, and representation. The blend of AR and UDL curates an inclusive and dynamic learning environment for students.

3 Methodology

The current research centers around an exhaustive examination of articles elucidating the pedagogical utilization of Augmented Reality video games for imparting logical reasoning skills to school students with disabilities. This aligns with research identifying elementary, junior, and senior high school students as the most preferred participants (Akçayır and Akçayır, 2017). According to the dictates of cognitive development theory given by Piaget, students at these education levels are in the concrete operational stage. During this stage, students rely on their sight, hearing, or senses for understanding (Akçayır and Akçayır, 2017; Martin and Loomis, 2013). The strong visualization provided by AR becomes crucial for effective learning during this cognitive stage.

We canvassed five eminent databases of scholarly repute, namely Google Scholar, JSTOR, Science Direct (WoS), Pub Med, and IEEE XPLORE, to scrutinize publications spanning the chronological interval from 2010 to 2024. To minimize bias, we employed a comprehensive and standardized search strategy. Search terms were developed iteratively based on pilot searches to ensure inclusivity and relevance. We tailored search terminologies for each database, as documented in Table 1, to capture variations in indexing and terminologies used across platforms. Boolean operators (e.g., AND, OR) were applied to combine key terms effectively, ensuring the inclusion of diverse perspectives.

To reduce selection bias, inclusion and exclusion criteria were predefined (see Table 2). A dual-review process was implemented, where two independent reviewers screened articles by title and abstract, followed by full-text evaluation. Discrepancies were resolved through discussion with a third reviewer to ensure consistency. Additionally, we excluded conference papers to avoid data quality concerns related to limited peer review and reporting practices. Search results were meticulously catalogued and deduplicated using Zotero to ensure transparency.

Adjustments were made during the search process to address gaps identified in initial results. For example, search terms were expanded to include synonyms and related concepts (e.g., "inclusive learning" and "assistive technologies"), ensuring comprehensive coverage of relevant literature. Efforts were also made to include studies from a diverse range of geographical and cultural contexts to avoid overrepresentation of specific regions or biases in educational practices.

Our methodological framework rigorously adhered to the PRISMA guidelines for ensuring the validity and accuracy of our systematic review, as delineated in Figure 1. In order to forestall potential bias, a dualistic evaluation protocol was instituted, with two autonomous reviewers meticulously applying predefined inclusion and exclusion criteria, illustrated in Table 2, to all search results. The systematic exclusion of conference papers is predicated upon a purposeful consideration of various concerns, including but not limited to the constrained extent of peer review, inadequacies in reporting, restricted accessibility, potential proclivities towards publication bias, the importance accorded to high-quality evidence, and the inherent risk of unreliable data, all of which could collectively compromise the methodological robustness of a systematic review. The differences of opinion amongst the reviewers were resolved by recourse to an impartial third reviewer.

Ninety-eight articles were scrutinized based on stipulated exclusion and inclusion criteria. Therefore, 44 articles relevant to our study objectives were selected for detailed analysis. A rigorous perusal of complete texts excluded 39 studies considered peripheral to the primary research objectives. The references of the eligible studies were also scouted to identify relevant sources for the project. A total of 21 studies relevant to the research objectives were identified. Two researchers independently extracted data from the selected articles using Excel worksheets. The information extracted from the selected sources is presented in Table 3. The ensuing data analysis and synthesis phases were consummated through a collegial nexus, wherein all authors participated in the process through discussions and collaborative write-ups.

TABLE 1 Search queries used on various databases.

Keywords used	Database	Date	No. of Articles
"Technology" "Inclusive Learning" "School" "Education" "Hearing" after:2010 before:2024 filetype:pdf intitle:"journal" lang:en	Google Scholar	14/01/2024	11
("Technology" AND "Inclusive Learning" AND "School" AND "Education" AND "Hearing") AND (PubYear:[2010 TO 2023]) AND Item Type: "research article" AND Language: English	JSTOR	15/01/2024	7
TITLE-ABS-KEY("Technology" AND "Inclusive Learning" AND "School" AND "Education" AND "Hearing") AND PUBYEAR >2009 AND PUBYEAR <2024 AND (DOCTYPE(j) OR DOCTYPE(a)) AND (LANGUAGE(eng))	Science Direct	15/01/2024	37
("Technology" AND "Inclusive Learning" AND "School" AND "Education" AND "Hearing") AND ("2010/01/01"[Date - Publication]: "2023/12/31"[Date - Publication]) AND "Journal Article"[Publication Type] AND "English"[Language]	US National Library of Medicine (Pub Med)	15/01/2024	62
("Technology" AND "Inclusive Learning" AND "School" AND "Education" AND "Hearing") AND (Publication Year: 2010 TO 2023) AND Content Type: Journals AND Language: English	IEEE Xplore	15/01/2024	0

4 Results

Our review supports using assistive technology devices to address the educational, social and communication needs of students with disabilities. Mobile devices, particularly iPads and iPods, emerged as the most commonly employed category for TAII interventions, focusing on teaching socially significant skills. Tablets and iPads are prevalent among students with disabilities because of their intuitive touch interfaces, portability, and ability to host a wide range of assistive applications tailored to individual needs. These devices are user-friendly for both students and educators, and their versatility allows for customization of learning experiences, making them effective tools for enhancing engagement, communication, and skill development. Figure 2 reveals a varied utilization of devices in research studies, each contributing to exploring different aspects. iPads emerge as the most frequently employed device, featuring in seven studies. Following closely are Mobile Tablets or Devices incorporated in five studies. Laptops and iPods are utilized in four and three studies, respectively, showcasing their relevance in research settings. One study employs computers, emphasizing their presence as a research tool.

Moreover, there are instances where researchers opted for other devices, totaling four studies, showcasing a diverse approach in technological choices. However, the device used in the two cases remains unclear, suggesting the need for improved reporting or standardization in research documentation. Overall, this analysis underscores the dynamic landscape of device usage in research studies, reflecting the adaptability and versatility of technology in diverse academic investigations. The supplementary devices employed in the studies encompass a spectrum of innovative technologies. These include an Electronic Interactive Whiteboard (IWB), providing an interactive platform for educational activities. Another distinctive device is a large-scale, interactive floor projection system featuring high-performance projectors and ceiling-mounted tracking cameras, facilitating the overlay of individual visual aids. Furthermore, the Franklin Language Master and modified multimedia PowerPoint 2007 contributed to the technological diversity, offering unique functionalities in educational settings. The Alpha Smart Neo keyboard for writing is also a specialized tool for addressing writing-related challenges. This assortment of devices highlights the ingenuity in incorporating advanced technologies to cater to diverse needs in

TABLE 2 Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Technology	Conference Papers
Inclusive Learning	University Students
School	Nursing / Pharmacy Students
Education	Teacher Centred Research
Hearing	Curriculum Centred Research
ASD	Institute Centred Research
Learning Disabilities	

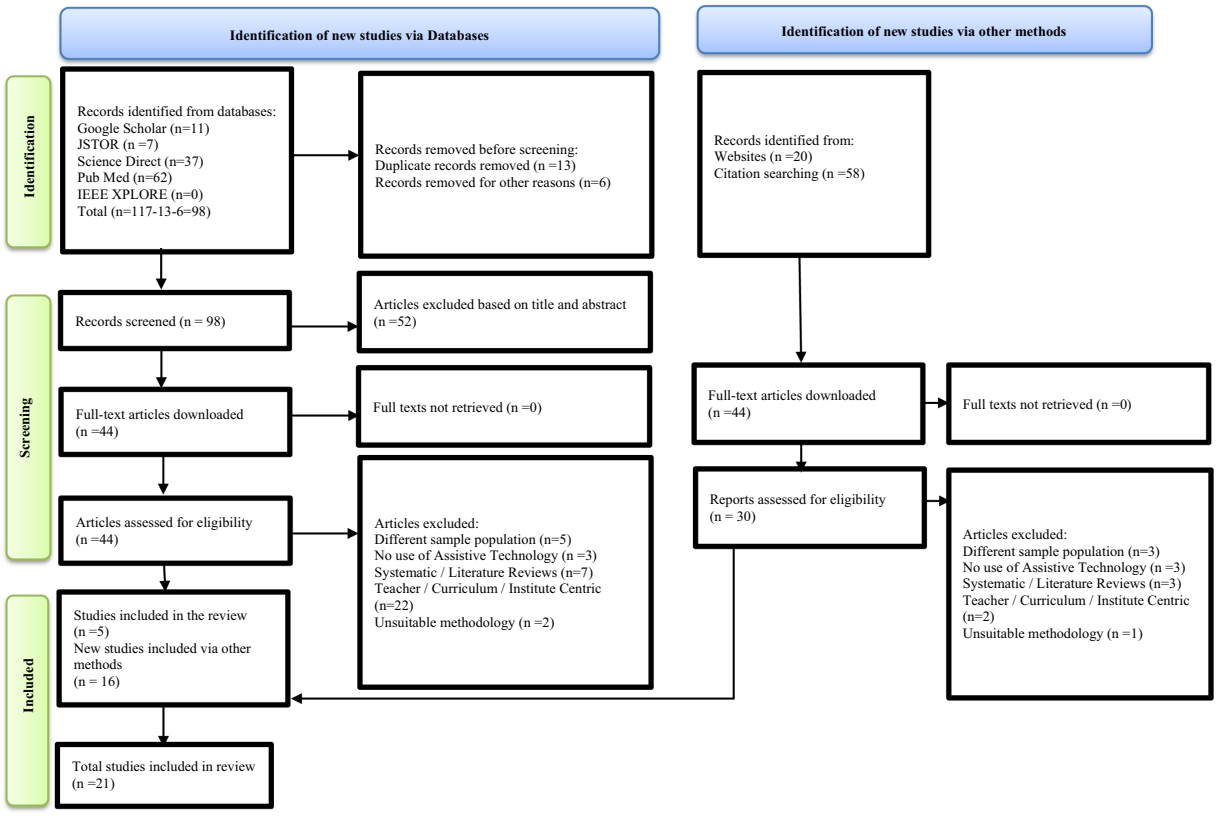

FIGURE 1
PRISMA guideline flowchart.

TABLE 3 Summary of studies included in the review.

Source	Methodology				Remarks	Outcome
	Sample size	Instruments	Assessment style	Assistive technology used		
Pellerin (2013)	Twelve EFI (Early French Immersion) teachers and their students (Grades 1 to 4) from two Canadian elementary schools, including one with fine motor difficulties	Focus groups with teachers, Audio-Video recordings of students, and classroom observations.	Collaborative action research	iPods, iPads and Laptops for Voice recording and other activities	Learning occurs through the harmonious interaction of inclusive practices, the learning environment, and the teacher for supporting and structuring the learning process.	Leveraging digital technologies facilitated diverse avenues for presenting information, taking action, expressing thoughts, and fostering engagement.
Fernández-López et al. (2013)	39 SEND students from elementary schools in Spain	Pre-experimental study, pre- and post-activity assessments	Quantitative Research	Mobile platform Picaa on iPod and iPad devices	The use of mobile platforms is associated with greater student interest in and attention to learning.	The study reports enhancements in fundamental skills, including autonomy, environmental awareness, language acquisition and social skills.
Chen et al. (2015)	Three adolescents with ASD from Taiwan	Pre, Post and Intervention Sessions with subjects	Multiple baseline design	AR-based self-facial modelling on a Laptop	The ARSFM learning system was facilitative in teaching social skills to children with ASD.	AR interventions enhance the accurate recognition and appropriate response to facial expressions.
Stylianidou et al. (2020)	• Thirteen boys and eleven second-grade girls from Greece. • Ten students are bilingual, and four experience learning disabilities.	Focus group discussions and Classroom observations	Qualitative Research	AR – Zapworks, Windows Movie Maker and Story Jumber Device: Mobile Tablet Other: Cards and Puzzles	No quantitative assessment of academic achievement or learning outcomes was conducted.	Learning environment with Universal Design and augmented reality games enhances engagement and participation among all students, including those with learning disabilities.
Intarapreecha and Sangsawang (2023)	Nine students from primary 4 with learning disabilities in Thailand	Pre and Post Test Assessment form to gauge student satisfaction	Quantitative	AR application for teaching Maths	An augmented reality game activity in mathematics was used to teach addition and subtraction.	Students expressed considerable satisfaction with the device, and results show improvements in student's spatial orientation skills.
Sun et al. (2022)	Fifty-five students from kindergarten aged 4 to 6 years in China. Group A – 22 hearing-impaired children, including 10 females and 12 males. Group B – 33 hearing children, including 17 females and 16 males.	Direct observation and interview	Mixed Method	AR representation of sequential time through a mobile device	The experiment was designed to measure understanding of sequential time in Mathematics.	AR in preschool education can offer comprehensive information, boost cognitive understanding, and foster active learning.

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TABLE 3 (Continued)

Source	Methodology				Remarks	Outcome
	Sample size	Instruments	Assessment style	Assistive technology used		
Pitchford et al. (2018)	33 Special Educational Needs and Disabilities students, including 21 males and 12 females from Malawi	Interviews with teachers and video recordings of students while interacting with the technology. Topics passed / time spent data recorded by the App. Pre- and post-intervention evaluation of Maths skills.	Subjective and Quantitative assessment	Maths applications on iPad at the Learning Centre	SEND students utilised the technology without needing additional assistive technology devices.	Students with SEND can acquire fundamental mathematical skills using this technology; however, their advancement is only half as fast as their peers in mainstream education.
Breivik and Hemmingsson (2013)	Four boys and one girl aged 11–16 with ASD from Sweden	Interviews and participant ratings through the Canadian Occupational Performance Measure	Qualitative Approach	Alpha Smart Neo keyboard for writing	The Assistive Technology Device (ATD) employed in the present study is distinguished by its cost-effectiveness and ease of mobility and handling.	ATD proved helpful in alleviating motor-related impediments, enhancing writing proficiency, and facilitating seamless engagement in academic activities.
Lindsey (2012)	One 7-year-old boy with high-functioning ASD in the US	Formative assessment, descriptive statistics, gain/loss scores analysis, field notes, and photographs	Action Research Framework with Case Study Methodology	The Franklin Language Master and multimedia modified PowerPoint 2007	The utility was maximum when these students comprehended the purpose and utility of the incorporated technology.	The amalgamation of technology with optimal real reading practices significantly augmented the reading instructional capabilities of autistic students.
Oakley et al. (2013)	Case 1: A five-year-old boy with High Functioning ASD in the Pre-primary/Year One classroom of an Australian school Case 2: A boy who displayed anxiety towards schoolwork in a Year 2 classroom of an Australian school	Case 1: Diagnostic and Summative Assessments through Diana Rigg Early Literacy Screening Test Case 2: Diagnostic and Summative Assessments through a modified McKenna and Kear Elementary Attitude to Reading Test	Two case studies of classroom-based teaching interventions	Case 1: iPad with a flashcard app for letters Case 2: eBooks on PowerPoint to develop multimodal non-fiction texts	Integrating Information and Communication Technologies (ICTs) played a transformative role in shaping teaching and learning tasks.	Every intervention demonstrated efficacy in enhancing the literacy achievement and engagement of the involved child.
Santarosa and Conforto (2016)	Three research subjects with ASD enrolled in a Brazilian elementary school.	Direct observation, document analysis, interviews and focus groups	Qualitative Research	Mobile devices vs. Laptops	Laptops are not user-friendly due to their complexity.	The touchscreen interface and versatility of use make tablets more approachable and provide an intuitively navigable user experience.

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TABLE 3 (Continued)

Source	Methodology				Remarks	Outcome
	Sample size	Instruments	Assessment style	Assistive technology used		
Chen et al. (2016)	Six adolescents with ASD (5 boys and one girl) from Taiwan	Pre, Post and Intervention Sessions with subjects	Multiple baseline design	AR-based video Modelling of a storybook on a Tablet device	ARVMS intervention introduced an enhanced visual cue for capturing and sustaining the attention of children with ASD.	The intervention aided the adolescent's comprehension of the facial expressions and emotions displayed by storybook characters.
Lee et al. (2018a)	Three children (1 girl and two boys) with ASD from Taiwan	Pre, Post and Intervention Sessions with subjects	Multiple baseline design	AR combined with concept map (CM) on Tablet device	The combination of AR with CM assisted therapists in educating children with ASD on grasping social relations through concept visualization.	AR with CM intervention proved moderately effective in instructing children with ASD to generate appropriate greeting responses.
Lee et al. (2018b)	Three children (1 girl and two boys) with ASD from Taiwan	Pre, Post and Intervention Sessions with subjects	Multiple baseline design	AR with tabletop role-playing game (AR-RPG) using Desktop Computer and storyboard	AR-RPG directs attention towards comprehending the meaning and social significance of greeting behaviors in specific social contexts.	Using AR-RPG improves the interaction and social skills of autistic children.
Cihak et al. (2016)	Three male elementary students with ASD and Learning Disabilities in the US	Baseline, augmented reality, and maintenance phases	Multiple probes across subjects	AR-based video Modeling on an iPod with visual markers	Augmented reality is an effective tool for teaching chain tasks to students with ASD.	All students acquired the ability to brush their teeth independently.
Lin and Chang (2015)	Three children with developmental difficulties in Taiwan	ABAB	Descriptive and qualitative analysis	AR function to perform physical activities by using a webcam attached to a laptop	It is cost-effective, as only a webcam is required to expand children's activities with diverse needs.	The findings demonstrated a notable and positive impact on children's physical activity.
Takahashi et al. (2018)	Sixty-six students from preschool to high school at the Special Needs School at Otsuka (SNSO) in Tokyo, Japan	Viability tests	Descriptive and qualitative analysis	A large-scale, interactive floor projection system with high-performance projectors and ceiling-mounted tracking cameras for overlay of individual visual aids	It shows potential for assisting children in paying attention to others, which is crucial for effective interpersonal interactions.	The visual aid can modify student's running behaviour.
Lorah et al. (2014)	Two male and one female child with developmental disabilities in the US	Sessions and Trials	Multiple baseline design	iPad as a Speech Generating Device (SGD)	iPad proved effective in speech generation.	The participants achieved mastery in trials and learned to distinguish sentence formations.

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TABLE 3 (Continued)

Source	Methodology			Assistive technology used	Remarks	Outcome
	Sample size	Instruments	Assessment style			
Neely et al. (2013)	Two school-aged children with ASD in the US	ABAB reversal design	Multiple baseline design	iPad as an academic instruction delivering device	Employing an iPad for instructional delivery may mitigate escape-maintained behaviour in certain children with autism.	Both participants exhibited reduced levels of challenging behaviour and increased academic engagement when using the iPad.
van der Meer et al. (2013)	Two school-aged children with ASD in the US	AB design	Alternating-treatments design	iPad as a Speech Generating Device (SGD)	One participant preferred using the Speech Generating Device (SGD), while the other favoured Picture Exchange (PE).	Both participants acquired proficiency in the target responses, including two- and three-step requesting responses, greetings, answering questions, and social etiquette responses.
Yakubova and Taber-Doughty (2013)	Two autistic and one moderately intellectually disabled students in the US secondary classroom	Baseline and intervention sessions	Multi-probe across students	An electronic interactive whiteboard (IWB)	The interactive and self-operated device promotes active student participation in the learning process.	The Interactive Whiteboard (IWB) underscores the effectiveness of a multicomponent intervention in enhancing student's skill acquisition.

educational and research contexts. The varied devices showcase the flexibility of technology in enhancing learning experiences and addressing specific requirements across different studies.

Figure 3 highlights a diverse international representation in studies analyzing assistive technology interventions for students with disabilities. The United States has the highest number of studies, totaling six, showcasing a significant research focus. Taiwan follows closely with five studies, indicating a notable contribution to exploring assistive technology for students with disabilities. Other countries demonstrate a more limited but valuable presence in this research domain, each contributing one study. Australia, Brazil, Canada, China, Greece, Japan, Malawi, Spain, Sweden, and Thailand collectively represent a global effort to investigate the effect of assistive technology interventions on students with disabilities.

This distribution underscores the global interest and commitment to understanding and improving the utility of assistive technology interventions in diverse educational contexts. The collaborative nature of research across countries enriches the collective knowledge base. It highlights the universality of the challenges addressed by assistive technology in enhancing educational outcomes for students with disabilities.

The data in Figure 4 illustrates a temporal trend in the publication of studies analyzing assistive technology interventions for students with disabilities. Notably, 2013 and 2018 emerge as focal points, witnessing higher research activity with six and four studies, respectively. These peaks suggest concentrated efforts and heightened interest in understanding the impact of assistive technology during these periods. Following these peaks, the published studies show a discernible decline, particularly from 2020 onwards. This trend coincides with the global COVID-19 pandemic, indicating a potential shift in researcher priorities. The observed decrease in research output during and after 2020 suggests redirecting scholarly attention towards urgent issues posed by the pandemic, such as ensuring access to online education and addressing socio-economic factors influencing access to technology devices for remote learning. The evolving education landscape during the pandemic likely prompted researchers to explore innovative solutions and strategies for remote learning, specifically focusing on inclusivity for students with disabilities. The data hints at the adaptability of research priorities in response to external challenges, emphasizing the dynamic nature of educational research in the face of global events.

The data in Figure 5 highlights a significant focus on ASD within the research body. A notable concentration of 12 studies addresses the specific needs and challenges associated with ASD, indicating a substantial emphasis on understanding and enhancing interventions for this particular disability category. In contrast, other disability categories demonstrate a more limited presence in the research landscape. Developmental Difficulties, Fine Motor Difficulties, Hearing Impairment, Intellectual Disability, Learning Disabilities, and Special Educational Needs and Disabilities comprise fewer studies. While these categories contribute valuable insights, their relatively lower representation in the research corpus suggests that the scholarly community may be giving precedence to ASD in the context of assistive technology interventions.

This trend underscores the critical importance of addressing the multifaceted challenges associated with ASD through the lens of assistive technology. It also highlights a significant gap in research coverage for other disability categories, suggesting opportunities for

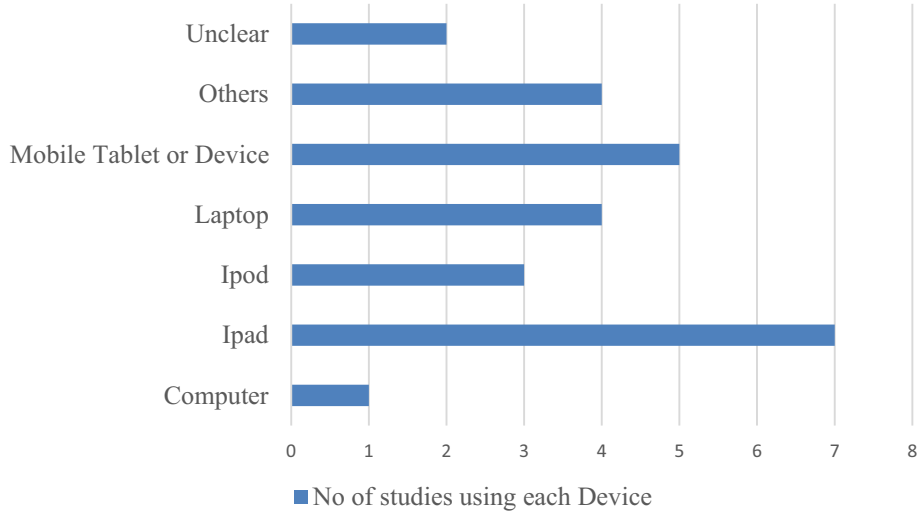

FIGURE 2
Number of studies using each device.

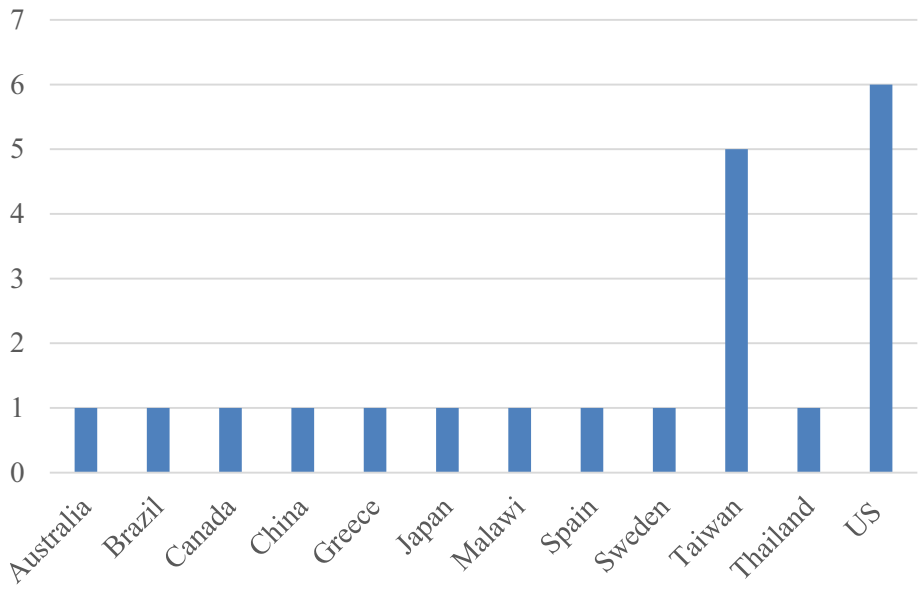

FIGURE 3
Number of studies from each country.

future investigations to explore the efficacy of assistive technologies in supporting diverse disabilities, such as physical, hearing, and intellectual impairments. Addressing these gaps could provide a more balanced and comprehensive understanding of how assistive technologies can promote inclusion. Researchers and policymakers should prioritize these trends when designing future studies and intervention strategies to ensure equitable and tailored support for students across a wide spectrum of needs.

The review identified communication, academic, and social skills as the most frequently targeted behaviors, reflecting the specific deficits observed in students with ASD. While emotion recognition has been a central focus of TAII, there remains a need to expand its application to teach a broader range of emotional comprehension, social interaction, and adaptive behaviors. Future research should explore innovative technologies, techniques, and devices while addressing underrepresented skills and disabilities. Additionally, longitudinal and experimental studies could evaluate the long-term impacts of these interventions, providing deeper insights into their potential to transform learning experiences and foster inclusive educational environments.

5 Discussion

The systematic review encompasses a comprehensive analysis of studies investigating assistive technology interventions for students with

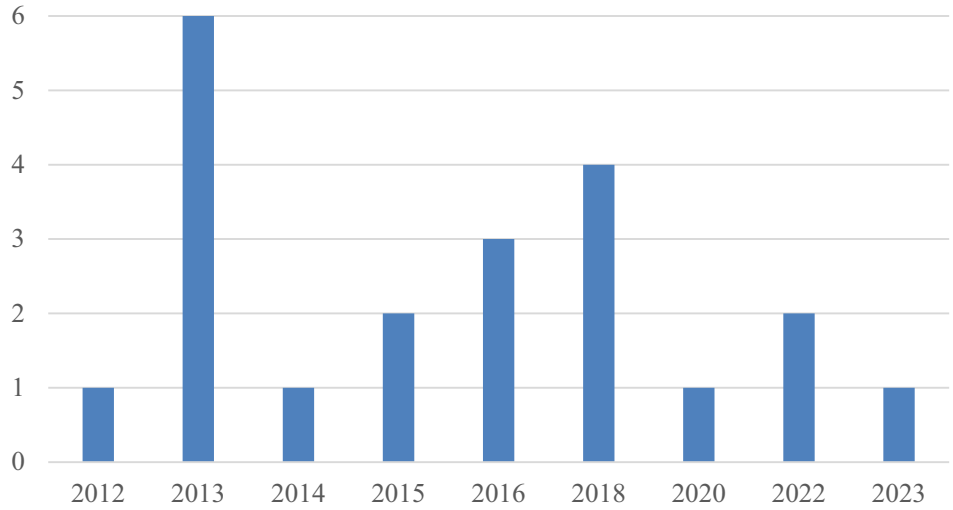

FIGURE 4
Number of studies published in each year.

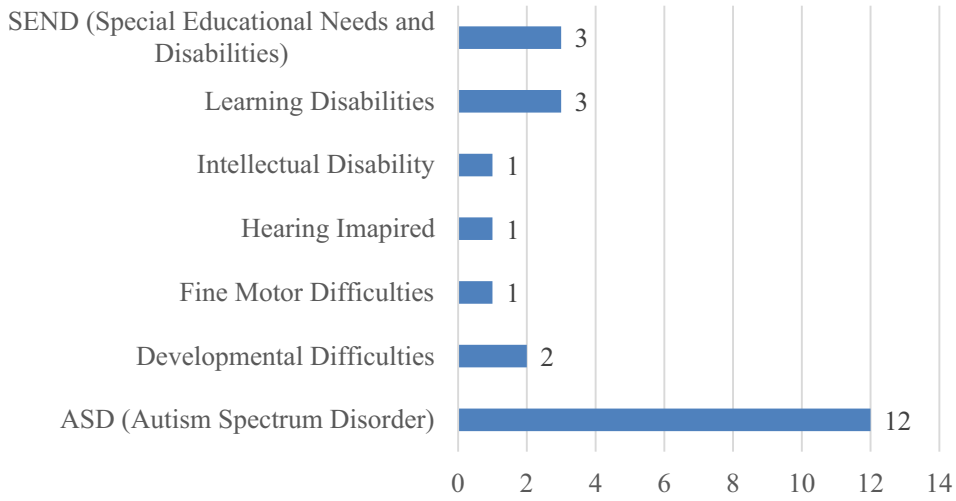

FIGURE 5
Number of studies dealing with each disability category.

disabilities. The diverse range of methodologies and technologies employed in these studies reveals key insights into the effectiveness of various assistive technologies in educational settings. Several studies focused on the integration of digital technologies in the learning environment. In the Canadian context, the collaborative action research by EFI (Early French Immersion) teachers and students utilizing iPods, iPads, and laptops demonstrated that leveraging digital technologies facilitated diverse avenues for presenting information, expressing thoughts, and fostering engagement (Pellerin, 2013). The findings aligned with the UDL framework, emphasizing the synergy between the learning environment, teachers, and inclusive practices. In Spain, a quantitative study involving SEND students highlighted the positive association between using a mobile platform and increased attention and interest in learning (Fernández-López et al., 2013). Fundamental skills, including autonomy, environmental awareness, language acquisition and social skills, showed improvement, underscoring the potential of mobile platforms in diverse skill development.

Studies from Taiwan investigated the impact of AR interventions on different aspects of learning for students with disabilities (Chen et al., 2015; Cihak et al., 2016; Lee et al., 2018a; Lee et al., 2018b; Lin and Chang, 2015; Takahashi et al., 2018). The AR-based self-facial modeling system on laptops facilitated social skills training for autistic children, enhancing their accurate emotional recognition and regulating their response to varied facial expressions (Chen et al., 2015; Lee et al., 2018a). These findings demonstrate how assistive technologies promote inclusion beyond academics by fostering critical emotional and interpersonal skills. Such tools empower students to build self-confidence, enhance social interactions, and participate more fully in inclusive learning environments, highlighting their broader role in holistic education. A qualitative study involving second-grade students in Greece utilized AR tools, cards, and puzzles (Lee et al., 2018a). While lacking quantitative assessment, the study highlighted the role of a learning environment with Universal Design. Augmented reality games enhance engagement and participation among all students, including those with learning disabilities.

Mathematics-focused interventions were prevalent, with studies from Thailand and China implementing AR applications for teaching. The AR game activity in mathematics in Thailand demonstrated high student satisfaction among those with learning disabilities (Intarapreecha and Sangsawang, 2023). In China, an experiment involving the AR representation of sequential time through a mobile device suggested that AR in preschool education could offer comprehensive information, boost cognitive understanding, and foster active learning (Pitchford et al., 2018). Research from Malawi focused on Special Educational Needs and Disabilities students utilizing Maths applications on iPads (Breivik and Hemmingsson, 2013). The findings indicated that while SEND students could acquire fundamental mathematical skills, their progress was slower than their peers in mainstream education.

Studies exploring specific assistive devices revealed notable outcomes. In Sweden, an Assistive Technology Device (ATD), specifically the Alpha Smart Neo keyboard, alleviated motor-related impediments and enhanced writing proficiency among students with ASD (Lindsey, 2012). Similarly, an investigation in the US involving an IWB emphasized its role as a self-operated and interactive device, enhancing student participation and skill acquisition (Yakubova and Taber-Doughty, 2013). Studies from Japan explored the viability of an interactive floor projection system, demonstrating its potential to modify student's running behavior and enhance attention and engagement among students with special needs (Lorah et al., 2014).

The study of an autistic seven-year-old boy in the United States assessed the impact of Franklin Language Master. It revealed that the utility of assistive technology was at its maximum when students comprehended the purpose and utility of the incorporated technology (Oakley et al., 2013). Integrating technology with optimal real reading practices played a crucial role in significantly augmenting the reading instructional capabilities of autistic students. This result underscores the importance of aligning assistive technology interventions with individual student's needs and understanding. It suggests that a tailored approach, considering the cognitive and instructional aspects of the technology, contributes to its effectiveness in enhancing learning outcomes for students with high-functioning ASD.

Using tablets, particularly iPads, was a common theme across multiple studies. From enhancing literacy achievement in Western Australian independent schools (Santarosa and Conforto, 2016) to improving user interaction in a Brazilian elementary school (Chen et al., 2016), tablets showcased their versatility and effectiveness in diverse educational contexts. However, the focus on Autism Spectrum Disorder (ASD) across most studies highlights a critical gap in research coverage for other disabilities. Students with physical, hearing, or intellectual impairments are underrepresented, limiting the generalizability of findings to these groups. Expanding research to include diverse disabilities would provide a more comprehensive understanding of how assistive technologies can support inclusion across various needs. Future research should also investigate technologies that address co-occurring disabilities, which present unique challenges requiring innovative approaches.

Overall, the systematic review indicates that various assistive technologies, including digital devices, AR interventions, and specific assistive devices, contribute positively to SEND student's learning outcomes and educational experiences. While the studies vary in methodologies and specific focuses, the collective findings underscore the potential of tailored assistive technology interventions in fostering inclusive and engaging educational environments for students with diverse learning needs.

6 Recommendations

Based on the findings of this systematic review, the following recommendations are proposed to enhance the implementation and impact of assistive technologies for students with disabilities:

1 For Educators and Schools:

- Integrate mobile devices, such as iPads and tablets, into daily classroom activities to promote inclusivity and engagement. Their intuitive interfaces and customization options make them particularly effective for teaching communication, academic, and social skills.
- Provide training programs for teachers to effectively use assistive technologies, emphasizing their application for diverse disabilities beyond ASD.

2 For Policymakers:

- Develop funding initiatives to ensure equitable access to assistive technologies in schools, particularly for underrepresented groups such as students with physical or hearing disabilities.
- Encourage the inclusion of assistive technologies in national education strategies, emphasizing their role in fostering inclusive learning environments.

3 For Researchers:

- Explore the application of assistive technologies for disabilities other than ASD, such as physical, hearing, and intellectual impairments, to address the identified research gaps.
- Conduct longitudinal and experimental studies to evaluate the long-term effects of assistive technologies on students' academic performance, social skills, and emotional development.
- Investigate the potential of emerging technologies, such as artificial intelligence and augmented reality, for teaching a broader range of skills, including emotional comprehension and adaptive behaviors.

7 Limitations

The meta-analysis concentrated exclusively on students with disabilities within school settings, omitting consideration for university students, adults, and those in vocational education settings. This decision aligns with existing research preferences, prioritizing students at the concrete operational stage of Piaget's cognitive development. However, this focus restricts the generalizability of the findings to broader educational contexts. Additionally, the absence of experimental or quasi-experimental studies among the reviewed literature limits the ability to draw causal inferences. Future research should prioritize such methodologies to provide stronger evidence of effectiveness.

A notable limitation arises from the preponderance of qualitative methodologies employed in most studies included in the meta-analysis. This prevalence raises concerns about the availability of quantitative data for comprehensive analysis. The qualitative nature of the research methods may limit the ability to conduct extensive quantitative synthesis, affecting the overall depth and breadth of the meta-analysis.

In adherence to PRISMA guidelines, the systematic review followed rigorous protocols for methodological transparency and thoroughness. Despite these efforts, the exploratory nature of the research domain resulted in a relatively limited pool of eligible studies. The small number of studies meeting the predefined inclusion criteria prompted the inclusion of additional studies obtained through the canvassing of citations and references, potentially introducing variability in study characteristics.

The inherent limitation of a small number of studies impacts the systematic review's conclusiveness, generalizability, and pattern recognition capabilities. The risk of bias and potential heterogeneity in study designs across a more extensive dataset can compromise the overall quality and robustness of the review. While the adherence to PRISMA guidelines reflects methodological rigor, the limited number of eligible studies necessitates a cautious interpretation of the findings.

Systematic reviews with few studies face challenges in achieving high conclusiveness and generalizability. The risk of bias and potential heterogeneity across studies may compromise the overall quality and robustness of the review. Adherence to PRISMA guidelines enhances methodological rigor, but the inherent limitation of a small number of eligible studies emphasizes the need for nuanced interpretation.

The findings underscore the need for further research into the efficacy of assistive technology interventions for students with disabilities. The limited experimental research data on assistive technology interventions makes it challenging to draw definitive conclusions about their overall potential in addressing the diverse challenges faced by students with disabilities. High-quality research and continuous innovation are necessary to widen the scope of assistive technology interventions for meeting the needs of diverse students, including those with disabilities. Researchers are encouraged to carefully assess the existing literature landscape and consider additional studies to strengthen the comprehensiveness and reliability of evidence synthesis, especially concerning the specific research question under consideration.

8 Conclusion

The diverse studies reviewed shed light on the varied applications of AR and Assistive Technologies in creating inclusive and engaging learning environments. While recognizing their potential, the nuanced effectiveness and considerations for diverse student populations underscore the need for further research. Controlled experimental designs are recommended to deepen our understanding and refine the implementation of these innovative educational approaches. The systematic review emphasizes the critical role of technology, particularly Assistive Technologies, in ensuring accessible education for all students, especially those with learning difficulties or disabilities. Integrating digital technologies is a powerful tool for supporting student's success in regular education, providing options, and removing barriers. Assistive Technology emerges as an empowering tool for inclusive education, addressing challenges related to cognitive abilities, knowledge acquisition, behavior, communication, and environmental interactions among students with special needs.

However, it is essential to recognize the limitations of technology as it cannot singularly address all learning difficulties or eliminate every barrier to learning. The systematic review emphasizes the importance of leveraging technology within effective teaching practices. Rather than relying solely on technology, the focus should shift towards the synergistic efforts of teachers, employing diverse teaching methods and integrating digital technologies. This collaborative approach is crucial in creating an empowering and inclusive learning environment for all students. The systematic review encourages a holistic perspective on educational inclusion, where technology is a complementary tool within a broader framework of effective teaching practices. The findings suggest that ongoing research and innovation are vital for refining the application of AR and educational technologies, ensuring their efficacy across diverse educational contexts and student populations.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

KM: Data curation, Investigation, Resources, Validation, Writing – original draft, Writing – review & editing. LS: Formal analysis, Funding acquisition, Methodology, Software, Writing – review & editing. AiT: Data curation, Methodology, Validation, Writing – original draft. NS: Formal analysis, Methodology, Writing – original draft. OS: Funding acquisition, Project administration, Supervision, Writing – original draft, Writing – review & editing. AsT: Supervision, Project administration, Funding acquisition, Writing – review & editing. RA: Data curation, Conceptualization, Investigation, Funding acquisition, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Generative AI was used in the creation of this manuscript.

Publisher's note

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