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OBM Neurobiology

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Review

A Systematic Literature Review on the Efficacy of Emerging Computer Technologies in Inclusive Education for Students with Autism Spectrum Disorder

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Academic Editor: Fabrizio Stasolla

Special Issue: New Technologies of Assessment and Interventions for Neurodevelopmental Diseases

OBM Neurobiology
2023, volume 7, issue 2
doi:10.21926/obm.neurobiol.2302172

Received: March 05, 2023
Accepted: May 28, 2023
Published: June 05, 2023

Abstract

Including learners with autism spectrum disorder (ASD) in mainstream classrooms is associated with challenges that could impede their academic participation. However, studies have shown the value of inclusive education, especially when supported with computer technologies, learners with ASD can effectively learn alongside their non-autistic peers.

Despite that, there has been minimal research on ASD inclusion with emerging computer technologies. This paper presents a systematic review of the literature on the application of emerging computer technologies in supporting the inclusion of learners with ASD. By analyzing a wide range of scholarly articles, this research goes beyond the existing literature by thoroughly examining the unique contributions and advancements made in this field. The study findings revealed valuable strategies and technologies for ASD-inclusive education that could be utilized by educationists, researchers, and relevant stakeholders. Moreover, this research bridges the knowledge gap and provides a foundation for future investigations into effective and sustainable technological interventions for ASD-inclusive education.

Keywords
Autism spectrum disorder; inclusive education; technological intervention; virtual reality; augmented reality; educational robot; video modeling; web application; learners with autism; systematic literature review

1. Introduction

Autism spectrum disorder (ASD) is a complex neurodevelopmental disorder that affects communication and social interaction [1]. The exact cause of ASD is not fully understood, but it is thought to be caused by a combination of genetic and environmental factors [2]. There is no cure for ASD, but early diagnosis and intervention can significantly improve the long-term condition of individuals with the disorder [3]. Inclusive education is an approach that involves providing support and accommodations to learners with disabilities, including learners with ASD, in regular classrooms alongside their non-disabled peers; it aims to create a welcoming and supportive learning environment for all students, regardless of their disabilities or needs [4, 5]. Studies have shown the value of inclusive education for learners with ASD over special education classrooms in terms of improved communication, social and cognitive skills, among others [4, 6-9]. Accordingly, notable strategies to support learners with ASD in an inclusive educational setting emphasize providing consistent and predictable routines using assistive technologies, communication, and visual support tools [9-14].

However, despite the rising prevalence of the disorder, there is limited research on which technologies are the most effective and could be leveraged to support the most notable inclusion strategies. Accordingly, there is a need to explore and analyze existing studies that proposed various technological modalities that have the potential to provide learners with ASD in inclusive settings with additional support and guidance, helping them to succeed in their educational goals. Particularly, emerging computer technologies have potential benefits for students with ASD in inclusive learning environments. For instance, exemplary studies have shown how virtual reality (VR) may create immersive and engaging learning experiences for enhancing social skills, communication, and emotional regulation [15-17], and augmented reality (AR) can assist students with autism in understanding and interacting with their environment [18-20]. Adaptive learning experience, feedback, and practice for learning new skills are all possible with robotic assistants [8, 21-24]. In addition, gamified applications [25, 26], mobile apps [7, 10, 12, 27-31], online apps [32, 33], and

multimedia instructional content [34-36] can offer interesting and individualized learning opportunities. Video modeling techniques are valuable in demonstrating how to accomplish particular tasks to learners with ASD using visual and audio representation [37-40]. Real-time feedback and hands-on learning opportunities suited to the interests and skills of students with ASD can be offered by wearable technology and maker programs [14, 41, 42].

The current study aims to analyze published articles on utilizing emerging computer technologies for an inclusive educational practice involving learners with ASD. Accordingly, we explored the literature that allowed us to understand vital, relevant parameters, including how the various technologies were utilized during the inclusion of learners with ASD and the various educational activities supported by the technologies. Consequently, the synthesized literature explains past successful practices and possible future discussions. Thus, paving the way for future research agenda on identifying, assessing, and disseminating various technological interventions for effective and sustainable ASD-inclusive education.

The subsequent sections of this paper are organized as follows: Section 2 provides an overview of the methodology employed in conducting the systematic literature review. Section 3 presents the findings on the strategies and technologies identified in the literature. Section 4 discusses the implications for educators, researchers, and stakeholders. Finally, Section 5 offers concluding remarks and outlines future research directions in ASD-inclusive education supported by emerging computer technologies.

2. Methodology

2.1 Search Strategy

The systematic search conducted in the present study took place in June 2022 to identify the most relevant studies that could help in addressing the research question. The authors carefully approached and planned the data collection, reading, and literature synthesis tasks modularly. The systematic literature search focused on the most popular and reputable scientific databases on the study topic: Web of Science, EbscoHost, IEEE Xplore, and Scopus. Specifically, the search terms used were (“autism spectrum disorder” OR “autism” OR “autistic”) AND (“inclusion” OR “inclusive” OR “inclusive education” OR “inclusive classroom”) AND (“computer” OR “technologies” OR “technology” OR “information and communication technologies” OR “technological intervention”). In addition, the search filters utilized were constrained to articles published in English and after 2012.

2.2 Selection Criteria

PRISMA systematic review procedure was utilized to select the most relevant articles to be included in the study [43]. Relevant studies from Education [44] and Autism Research [45, 46] have utilized PRISMA to critically appraise assorted literature. The criterion for inclusion in the present study covered any published full-text journal article, book chapter, or conference paper, from the indicated databases, on emerging computer technologies in ASD-inclusive education. At the beginning of data screening, duplicate articles retrieved from multiple databases were eliminated using the duplicate-removal function of Microsoft Excel. Then, the authors advanced the inclusion criteria by scrutinizing worthy papers to be synthesized in the systematic literature review. The decisions for inclusion/exclusion of the unique records were recorded in a separate column within

the combined Excel sheet imported from the multiple databases. Thus, for documents whose titles and corresponding abstracts aligned with the preset inclusion criteria, full-text articles of the studies were retrieved for the subsequent screening stage. In the next PRISMA screening stage, all the downloaded papers were reviewed to ascertain their relevance with the search query and the preset research question.

Specifically, nine hundred and fifty-four records were carefully assessed for eligibility. Five hundred and five unique papers remained after duplicate removal. Two hundred and nineteen records were eliminated due to the following reasons: Editorial materials (n = 41), not written in English (n = 29), Full text not available (n = 52), and Short Reviews (n = 97). The remaining two hundred and eighty-six studies were further assessed; one hundred and eighty-five records were eliminated because they were not related to the present study despite having some of the search keywords (n = 103) and relevant to the present study but did not focus on technological interventions (n = 82). Consequently, one hundred and one full-text articles were retrieved, read, and qualitatively assessed. Nonetheless, the exclusion criteria catch additional relevant studies with a lot of ambiguities (n = 25), with significant deviation from the research aim (n = 33), and with a greater focus on research data collection with emerging technologies rather than educational intervention (n = 7). Finally, thirty-six studies met the inclusion criteria. The PRISMA flow diagram (Figure 1) summarized the abovementioned systematic literature review process.

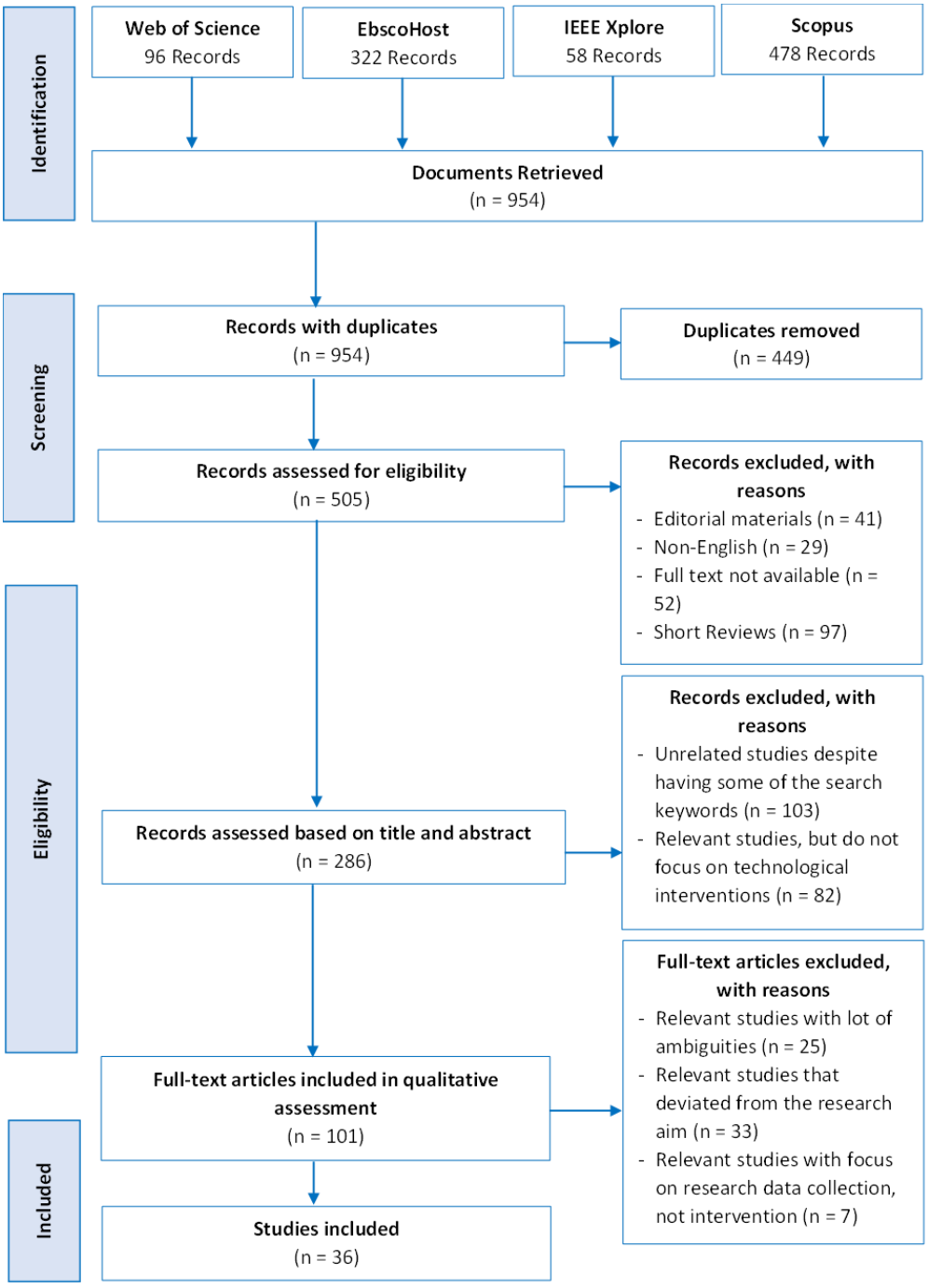

Figure 1 PRISMA flow diagram of the search results.

2.3 Quality Assessment

The authors carefully adhered to the planned, systematic literature review process to maintain the quality of the study. Notably, the authors ensured careful adherence to the adopted research framework at every phase of the systematic literature review. Furthermore, all the downloaded articles were uploaded to an online Mendeley repository to keep track of the appropriate citations to the literature and aid in information sharing, data extraction, and classification stages. Nevertheless, unbiased and constructive assessments of the systematic approach used in this study

were sought from external professionals on educational intervention for learners with disability and with expertise in systematic literature reviews.

2.4 Data Extraction

In the final stage of the study's PRISMA, the data extraction stage, 36 articles were appraised critically, and the following information was extracted from the studies:

- Reference and year of publication
- Number of citations
- Source title and publisher
- The research aims and research method
- Technological intervention
- Participants and country of research
- Article type
- Key Finding(s)

3. Results

3.1 Descriptive Analysis of the Literature

Based on the exported data, the trend of studies on emerging computer technologies in ASD-inclusive education showed the most researched technologies and study design, most cited references, sources, the country of research, and citation and publication frequencies over the years.

With the rising prevalence of ASD coupled with the increasing popularity of emerging computer technologies for educational practice, there will be growing demand for sustainable strategies for ASD inclusion using the technologies. Notably, as shown in Figure 2, from 2013 to 2018, not many studies cared about the subject area. However, with the recently increased patronage of various technologies in supporting different educational strategies, there is the possibility of more future studies on technological interventions for ASD inclusion. Obviously, in the future, it can be said that the trend will go on.

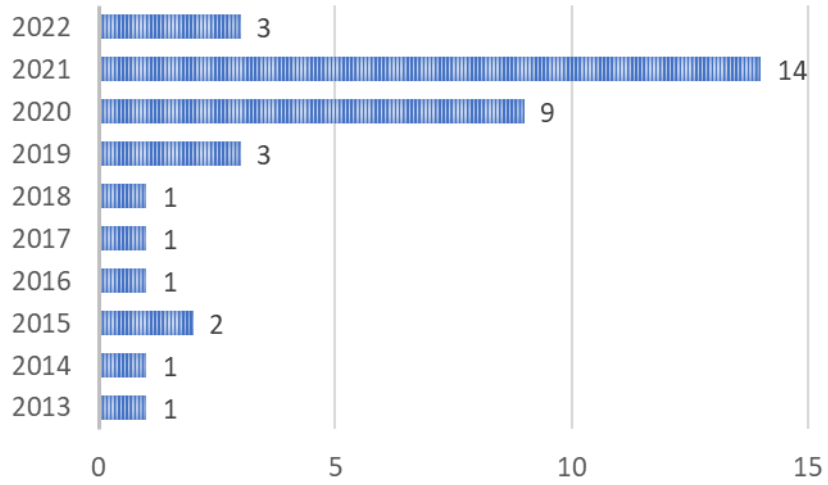

Figure 2 Number of publications across years.

From Figure 3, most of the articles contributing to the area were published in the *Journal of Autism and Developmental Disorders* (n = 4), followed by the *Journal of Special Education Technology, Journal of Behavioral Education,* and *Focus on Autism and Other Developmental Disabilities* (n = 2, each). Others were conference papers (n = 8) and book chapters (n = 6), while each of the remaining twelve journals featured in the inclusion list published one article. In addition, Springer published most of the study area articles (n = 14), as shown in Figure 4.

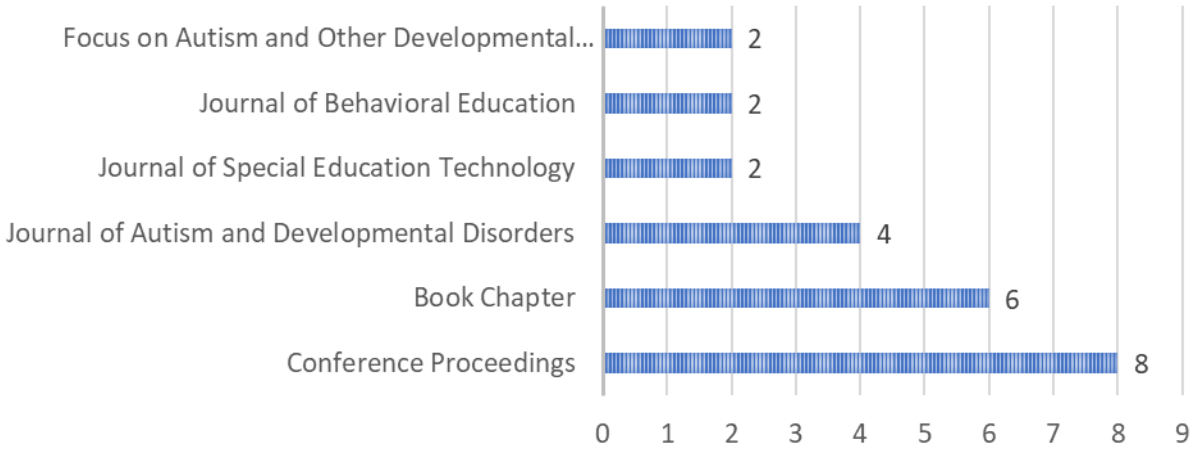

Figure 3 Most frequent sources.

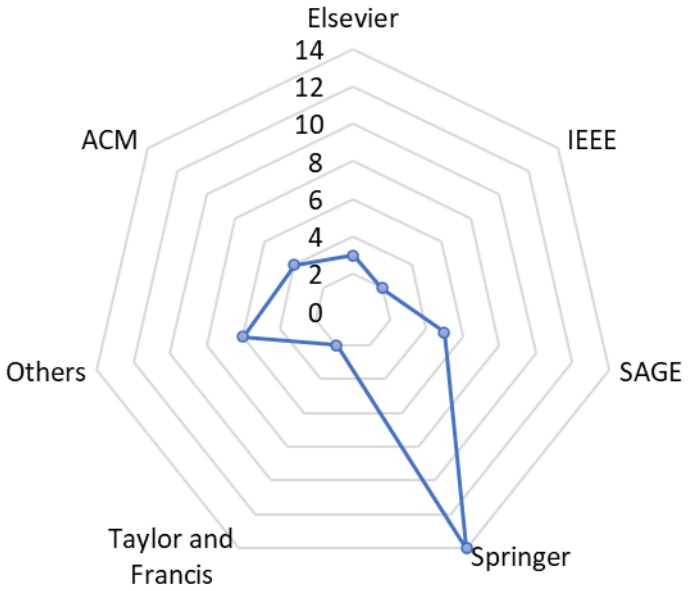

Figure 4 Number of articles based on publishers.

Based on the citation data analysed in the present study, the most cited references are Smith et al. [34] (n = 115), Rosenbloom et al. [12] (n = 35), and Knight et al. [35] (n = 32). These references contributed the most citations in the past, as shown in Figure 5, as they were published in Research in Autism Spectrum Disorders, Assistive Technology, Journal of Autism and Developmental Disorders, respectively.

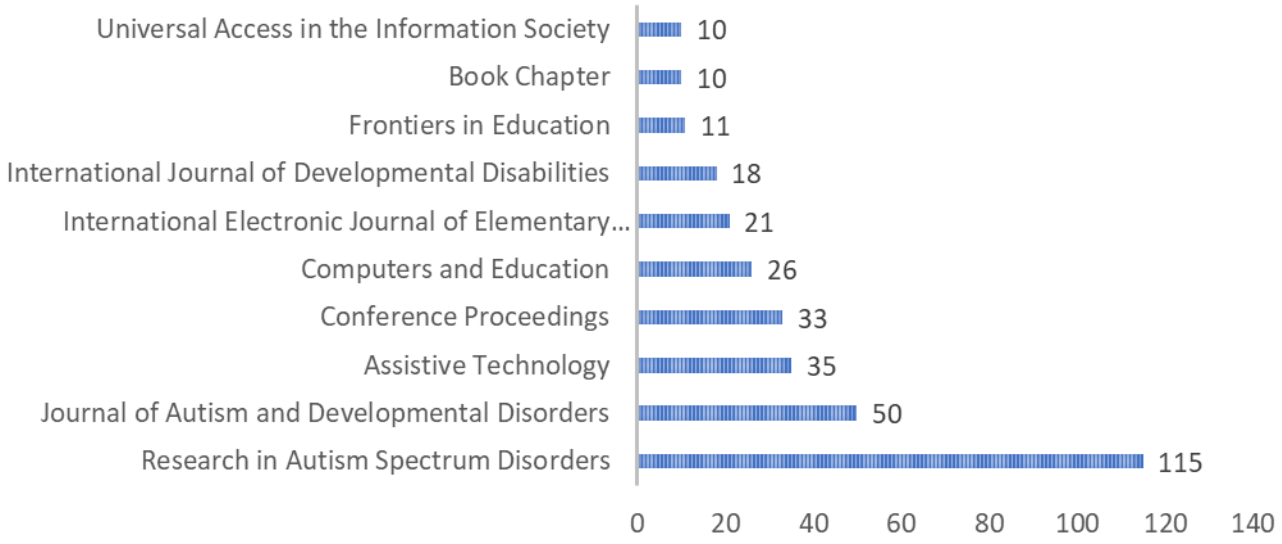

Figure 5 Most frequent citations based on sources.

The citation distribution across years, as shown in Figure 6, indicated the relevance of the past publications on the research topic by attaining high citation counts.

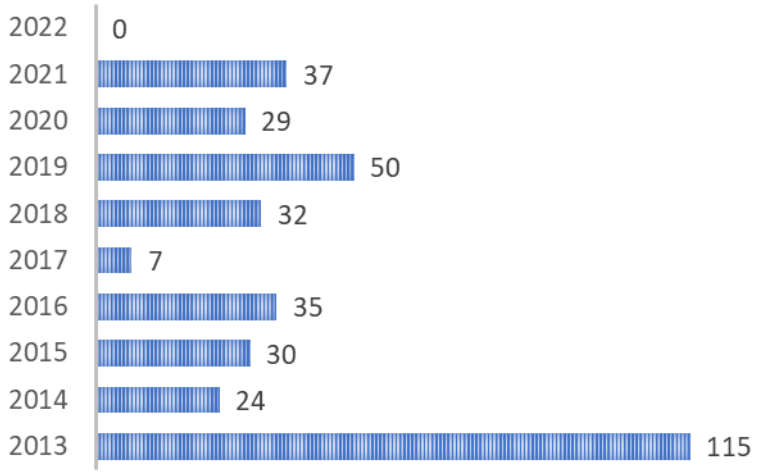

Figure 6 Number of citations across years.

From Figure 7, the included studies were predominantly conducted in the USA (n = 13) and a few from Ecuador (n = 3), France (n = 2), and Italy (n = 2). Thus, out of the 36 articles included in the study, the countries mentioned above contributed more to the research area, followed by other countries depicted in the figure that contributed single articles each and one multinational study conducted in Russia and Brazil [20].

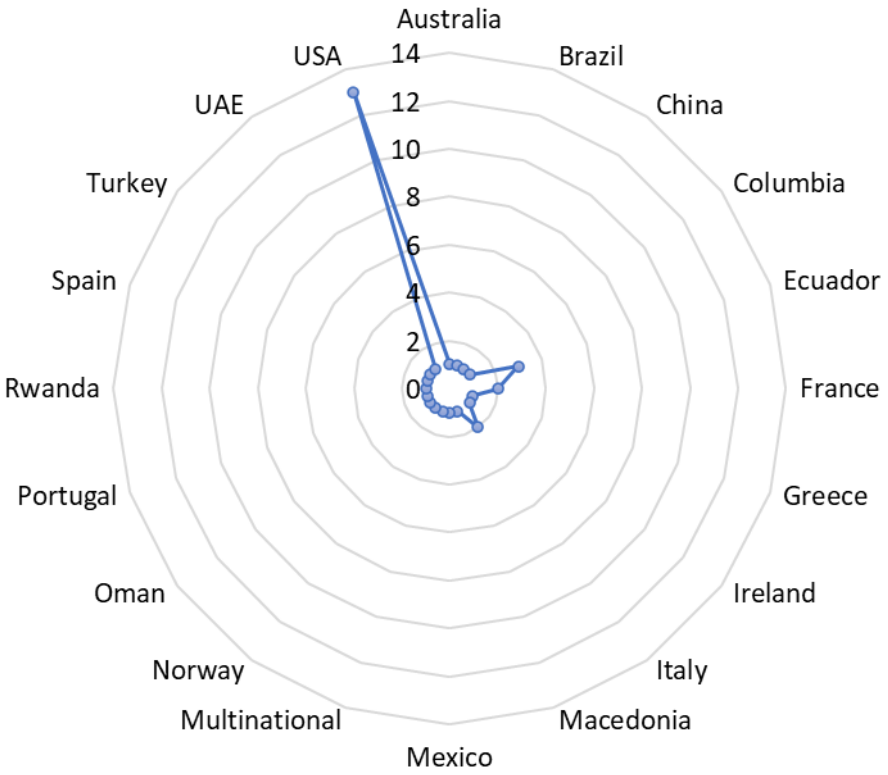

Figure 7 Number of articles based on country of research.

Descriptive findings that are of the essence to ASD-inclusive education and research are the most popular technologies utilized in the study area, as well as the frequently used research designs. As shown in Figure 8, most studies utilized a mixed study design (n = 17) to understand the efficacy of emerging computer technologies in supporting ASD-inclusive education. Other studies were case studies (n = 3), experimental (n = 6), and implementation (n = 7) studies that developed and evaluated various technologies for ASD-inclusive education.

Figure 8 Commonly used research methods.

The most notable technologies involved in the study area, as highlighted with the help of Figure 9, include mobile applications (n = 7), educational robots (n = 6), gamified applications (n = 4), video modeling (n = 4), augmented reality (n = 3), virtual reality (n = 3), educational multimedia (n = 3), maker program (n = 2), wearable devices (n = 2), web application (n = 2).

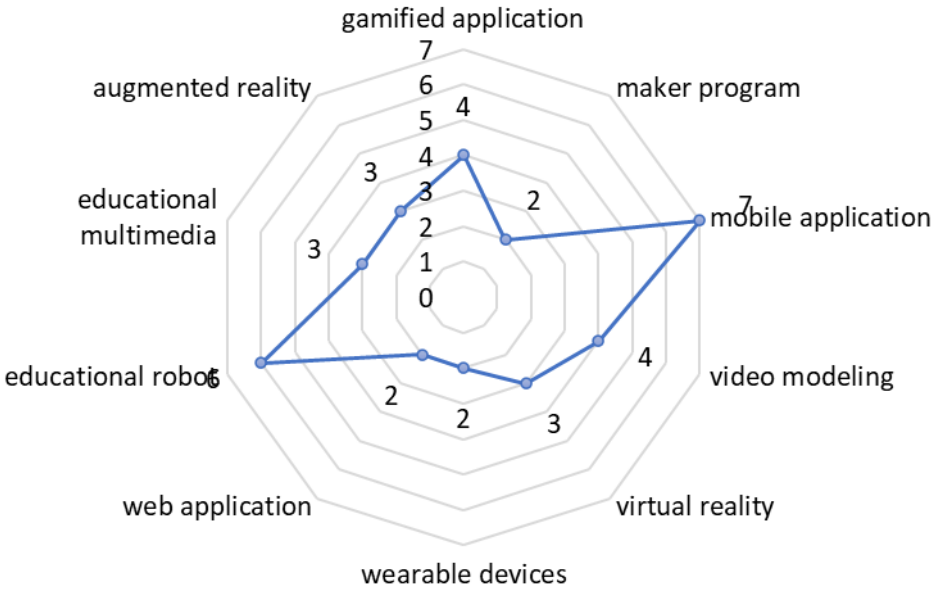

Figure 9 Commonly used technological interventions.

3.2 Analysis of the Commonly Used Research Methodologies

The most prominent research designs utilized by previous studies to demonstrate the efficacy of various computer technologies in supporting ASD-inclusive education include case studies [25, 26, 37], experimental designs [8, 10, 12, 16, 20, 38], systems developments and implementations [15, 17, 21, 29, 30, 32, 47, 48], mixed study designs [19, 22-24, 27, 28, 33-36, 39-42, 49-51], observation [18] and quantitative research methodologies [7, 52]. Furthermore, the research methodologies were limited by small sample sizes and were mainly conducted in the US [7, 12, 25, 34, 35, 38-42, 50-52], and European countries [10, 15, 17, 26, 27, 32, 37]. Noteworthy, many relevant studies utilized small sample sizes, lacking long-term data and evidence of consensus with best ASD-inclusive practices. This could imply limited generalizability, lack of sustainability, and practical evidence. Therefore, apart from privacy and data security issues, future studies should propose cost-effective solutions, as some emerging technologies, such as VR and AR systems, could be expensive to implement in low- and middle-income countries and large educational settings.

3.3 Analysis of the Frequently Used Technological Interventions

The systematic literature search of the present study identified the most frequently employed emerging computer technologies for ASD-inclusive education, as shown with the help of Figure 9 and Table 1. Several studies aimed at supporting learners with ASD in inclusive settings using various technologies including mobile applications [7, 10, 12, 27-30], educational robots [8, 21-24, 49], gamified applications [25, 26, 48, 52], video modeling [37-40], augmented reality [18-20], virtual reality [15-17], educational multimedia [34-36], maker program [50, 51], wearable devices [41, 42],

and web applications [32, 33]. Future studies must revisit the efficacy of the existing technological interventions and propose practical enhancements to provide sustainable strategies for ASD-inclusive education in evolving societies.

Table 1 Information extracted from the articles.

Reference	Cite Count	Country	Research aim	Research Method	Technological Intervention	Participants	Key Finding(s)
[26]	10	Spain	Examine the effectiveness of videogames for improved communication, attention, and satisfaction	case study	gamified application	Four students between 5 and 10 years of age, five students between 14 to 18 years old	The intervention improves imitation, game attention, and social skills in children with ASD.
[25]	7	USA	Describe the variation in the communication patterns of a student with ASD under classroom and computer lab-inclusive settings featuring block-based coding	case study	gamified application	1 ASD and one non-ASD	Unlike the non-ASD, increased activity was observed in the student with ASD in the computer lab setting based on an analysis of video data.
[37]	21	Norway	Employ VM for learning social communication skills	case study	video modeling	One child	Bilingual children with ASD can transfer the learned social communication skills and targeted behaviors in a second language to the first language milieu.
[20]	0	Russia	Demonstrate the merit of AR and VR-based training book on educational outcome	experimental	augmented reality	30 students with ASD	Studying the book showed an increase in motivation and efficiency in mastering the proposed topic among students and a high level of interest among teachers using such technologies
[8]	0	Macedonia	Identify the possibility of reduced educational outcomes in non-ASD or	experimental	educational robot	3 ASD and three non-ASD children	Neither misbehavior nor issues were observed to suggest that the education and training of the non-

			adopting negative behaviors of children with disabilities				ASD were impeded after the interventions.
[38]	8	USA	Examine the effects of VM instructions on comprehension and problem-solving skills	experimental	video modeling	Three middle school students	Improved accuracy in mathematics skills, especially fraction problems.
[16]	18	China	Investigate the effectiveness of gesture-based instruction via VR in teaching matching skills	experimental	virtual reality	Three male first-grade students	High levels of correct responses, task engagement, and retention of the acquired skills were identified in the participants.
[12]	35	USA	Evaluate the relationship between the implementation of I-Connect SM with on-task and disruptive behaviors	experimental	mobile application	One child, nine years of age	With each introduction of I-Connect, there is an immediate increase in on-task behavior and a decrease in disruptive behaviors.
[48]	0	Mexico	Develop and evaluate a serious game as a support tool in the management of emotions	implementation	gamified application	A single child with ASD	Favorable results based on experts' evaluations were revealed.
[30]	7	UAE	Develop and implement a coordination mobile app	implementation	mobile application	50 participants (20 ASD)	Good usability and satisfaction scores were recorded based on SUS and learnability scores of 80.42 and 80.2, respectively.
[29]	6	Australia	Compare the quality and length of persuasive written text produced via handwriting and assistive technology	implementation	mobile application	Eight pupils between 9 – 11 years old for six weeks	There exist improved quality and length of written compositions and feelings of self-efficacy towards persuasive writing of students with ASD.
[17]	0	Italy	Develop drawing guidelines for the "autism-friendly" design of the VR	implementation	virtual reality	Group of autistic users	The concept is viable for inclusion and could enhance human abilities

							by improving knowledge for both ASD and non-ASD.
[21]	0	Columbia	Construct robots to establish a communication process with children at an educational level	implementation	educational robot	24 pupils with ASD	Compared with Software instructions, the participants showed greater difficulty when using textual instructions using multiple mechanisms.
[50]	11	USA	Develop and evaluate an inclusive maker program called IDEAS	mixed method	maker program	218 participants	Improved outcomes in STEM-related competencies were identified in the test group.
[32]	1	Italy	Develop web applications to help ASD and non-ASD users learn the basic concepts of music	implementation	web application	Teachers, caregivers, students	Preliminary results suggest a crucial role for technology in facilitating music teaching and supporting the learning process for students with autism.
[15]	9	Portugal	Promote the development of mathematical reasoning in students using a digital environment prototype	mixed method	virtual reality	Four professionals, two teachers, and 1 ASD	Respondents described the intervention as effective in providing autonomy and motivation and facilitating communication during students' teaching and learning processes.
[10]	24	France	Develop and evaluate a mobile app for activity schedules	experimental	mobile application	Ten children (5 test, five control)	Children reached steady, high, and autonomous intervention usage after the first month, with a considerable decrease in the third month.
[49]	0	Ecuador	Evaluate the management of SAR linked to educational video games for	mixed method	educational robot	11 children	The participants mastered the intervention efficiently, interacted, and attended the instructional game

			therapy and reinforcement in the teaching process				with a great attraction to the educational robot.
[36]	0	Rwanda	Examine the possibilities of re-creating and adapting digital content to improve the learning of numeracy	mixed method	educational multimedia	70 participants, 56 teachers (32 males, 24 females), 14 parents (6 males, eight females)	With awareness and careful application of evidence-based approaches, integrating multimedia content can increase focus and access to education for children with ASD and increase the acceptance of these children in mainstream schools.
[42]	0	USA	Evaluate sensor systems in measuring social proximity between students	mixed method	wearable devices	11 children (3 ASD and 8 TD)	Sensor and video-coded data analysis corresponded with an average accuracy of 83% for the eight dyads in the study.
[28]	1	Ireland	Compare a Computerized and Table Top Presentation in Reading Outcomes	mixed method	mobile application	31 participants (26 males, five females)	It was found that TTI was slightly more effective in teaching some core reading skills to participants with ASD.
[22]	0	Greece	Evaluate the impact of an educational robot intervention on the social status of students with autism	mixed method	educational robot	14 ASD and 214 non-ASD from 14 classes in 12 primary schools	Educational robot intervention positively impacts the social status of students with ASD in inclusive educational contexts.
[23]	0	Ecuador	Conduct a dialogue with the children, motivate them to carry out the exercises/rehabilitation activities, and motivate and engage them in the therapy sessions (for children with disabilities).	mixed method	educational robot	Seven children and 30 children 4 – 6 years (18 boys and 12 girls)	Robotic assistant (asiro-µ) produced a significant impact on children between 4 to 6 years old with and without disabilities, especially in verbal interactions as compared to manual signs.

[40]	0	USA	Examine the effectiveness of a packaged intervention consisting of VM in promoting extra-curricular activities	mixed method	gamified application	Six students; 3 ASD and 3 TD	The dyad showed a rapid increase in level and trend in response, with no overlap between baseline and intervention phases, when VM is used.
[51]	2	USA	Explore perceptions of students, teachers, and parents about ASD participation in the IDEAS Maker Program	mixed method	maker program	48 participants; 9 teachers, 26 students (17 ASD), and 13 parents	Students enjoyed the opportunity and flexibility and developed foundational and content-specific skills on projects that reflected their interests.
[39]	0	USA	Evaluate a social skills intervention, including behavioral skills training, VM, and self-monitoring on the acquisition of discrete vocational, social skills	mixed method	video modeling	8 participants	The intervention successfully improved the accuracy of steps in acquiring varied social skills, with at least two consecutive points between 80 and 100% accuracy for all skills among the participants.
[33]	4	Turkey	Examine the impact of e-coaching on the use of a simultaneous prompting (SP) procedure and its effects on teaching discrete skills	mixed method	web application	Four students between four and six years of age	E-coaching was effective in acquiring, maintaining, and generalizing preschool teachers' use of the SP procedure. In addition, the SP procedure was effective in teaching discrete skills to students with ASD.
[19]	2	Brazil	Offer new learning paths for children with ASD and spread an innovative way of learning for humbler areas with low-cost experience	mixed method	augmented reality	Children	In three years of the project, hundreds of ASD children across Rio de Janeiro learned how to read and write with the intervention.
[27]	26	France	Investigate whether supporting ER in mainstream classrooms can influence	mixed method	mobile application	50 students between the age of 12 and 17	The application showed promising rehabilitation effects for adolescents

			self-regulation abilities and sociocognitive processes				with varying conditions, improving their self-regulation skills.
[41]	6	USA	Understand the effectiveness of WELI (Wearable Life) in communication between students and their assistants	mixed method	wearable devices	11 participants between 22 – 26 years old	Students and assistants found the application beneficial in facilitating teaching and learning activities with improved focus and reward features.
[35]	32	USA	Demonstrate a functional relation between a paraprofessional-delivered Video Prompting strategy to teach academics	mixed method	educational multimedia	3 ASD, three teachers, and one paraprofessional	There is a functional relation between the paraprofessional delivering video prompting and correct responding to academic tasks for students with ASD and ID.
[34]	115	USA	Investigate the efficacy of ICT-based explicit instruction in teaching science	mixed method	educational multimedia	3 ASD and 25 TD	The intervention was effective for ASD and TD with a functional relation to the assessment items answered correctly during science-based activities.
[24]	6	Ecuador	Test the efficacy of SAR and educational game in enhancing attention and motivation toward the teaching-learning process	mixed method	educational robot	Two children with ASD and 20 TD peers	Suggest ways of improving the robot design to incorporate the qualities of gamified learning and maximize benefits for inclusive education.
[7]	1	USA	Examine differences between story comprehension scores using paper and iPad books	qualitative	mobile application	30 participants (15 ASD and 15 TD)	There are promising results that extend to students with disabilities, including those with ASD, with some variance in using iPad books.
[18]	2	Oman	Help autistic children with independent learning and poster effective teaching in both Arabic and English at low cost	qualitative	augmented reality	6 participants (4 Boys and 2 Girls) 4 – 9	Improved knowledge, motivation, and social skills were observed among the participants during the Arabic-based learning activities.

[52]	5	USA	Compare the efficacy of the traditional GBG with technology-enhanced GBG variations	quantitative	gamified application	Six high school students (14–16 years)	Findings showed the efficacy of the technology-enhanced GBG variations through an effective decrease in disruptive behaviors despite individual preferences.

ASD, autism spectrum disorder; VM, video modeling; AR, augmented reality; VR, virtual reality; WELI, wearable life; ICT, information and communication technology; GBG, good-behavior-game; DSM, diagnostic and statistical manual; SP, simultaneous prompting; IDEA, individuals with disabilities education act; TD, typically developing; SAS, socially assistive robotic; TTI, tabletop instruction; ER, emergency room.

4. Discussions

The following subsections have thematically and chronologically highlighted the vital studies on the application of emerging technologies in supporting ASD-inclusive education.

4.1 Augmented Reality for ASD Inclusive Education

Augmented reality (AR) technology can be used in ASD-inclusive education to provide individuals with autism with additional information and support in the real world. Mainly, AR can be used to help individuals with autism understand and interact with their environment in a more meaningful way through visual cues and prompts for navigating new environments, such as a school or a public place, as well as real-time feedback that could help in understanding the emotions and intentions of others during social interactions [18-20]. For instance, Asif et al. [18] proposed Intelligent Education System primarily focused on providing interactive teaching and learning experience using AR and machine learning in both English and Arabic scribbles. The experimental setting of the study includes capturing and recognizing playable sand scribbles using Kinect 3D camera and classification models, respectively. Based on rigorous experimentation with a large dataset and use cases, the study findings indicated the efficiency of the intelligent system toward better learning. They observed facial expressions and emotions of learners with ASD. Similarly, Cirino et al. [19] developed an AR-based product to assist children with ASD in reading and writing skills. The study suggested the product's capability to overcome the digital and physical apart-feeling along its three functionalities of a puzzle, core AR, and construct-words structure. Thus, providing autonomy for children and teachers when elaborating on activities and evaluating students' performance in inclusive settings. Tokarskaya et al. [20] described the application of augmented and virtual reality in a training book describing "Space." Experimental findings of the study, based on two groups of 30 students with ASD from Russia and Brazil, showed an increase in the efficiency of mastering the proposed topic, motivation growth among students, and a high level of interest among teachers using the technologies.

4.2 Virtual Reality for ASD Inclusive Education

Virtual reality (VR) technology can be used in ASD-inclusive education to create immersive and interactive learning experiences for individuals with autism. VR can help individuals with autism improve their social skills, communication, and emotional regulation by providing personalized and engaging learning experiences [15-17]. For example, Santos et al. [15] presented a preliminary proposal for a VR environment to promote mathematical reasoning development in students with ASD. The study findings described the conceptual model of the study. They highlighted the need for dynamic adaptation processes and activities to address the diversity of ASD and align with numerous user profiles. Similarly, Hu and Han [16] investigated the effectiveness of gesture-based instruction via Leap Motion-aided VR to teach matching skills to students with ASD in China. The study involves multiple probe designs with three students with ASD in an inclusive setting. The study findings revealed positive results in acquiring and maintaining the targeted skills. Recently, Pecora et al. [17] described the relations between human factors and VR in spatial representation and its perceptual resonance in communication. The "autism-friendly" design guideline indicated user-centered

development to enhance the potential of VR as an inclusive education medium. In essence, VR can simulate real-life social situations and allow individuals with autism to practice responding and interacting in a safe and controlled environment. VR can also be used to teach specific skills, such as language and cognitive skills, in a way that is engaging and motivating for individuals with autism.

4.3 Robotic Assistants for ASD Inclusive Education

Robotic assistants could potentially be used to help learners with autism in inclusive education. For example, a robotic assistant could be programmed to provide visual and auditory individualized instruction and feedback to learners with autism, help them navigate their environment and interact with their peers, and learn and practice new skills [8, 21-24]. Pliasa et al. [8] utilized the Daisy robot as a technological intervention for including children with ASD to investigate the possibility of reduced educational outcomes in non-ASD or adopting negative behaviors of children with disabilities. The study finding revealed that the TD became more motivated to engage in actions under the robot's guidance, and their scores on almost all of the skills were perfected after the interventions. Most importantly, TD children's participation improved their development since no misbehaviors were observed to suggest impediments to their education and training. Lancheros-Cuesta et al. [21] developed an adaptive robotic platform to construct robots facilitating communication in ASD-inclusive educational settings. The study findings indicated that the participants showed more incredible difficulty using textual instructions at various levels than the technological intervention. Recently, Papazoglou et al. [22] evaluated the impact of an Educational Robotics intervention using Lego Wedo 2.0 on the social acceptance and status of students with ASD in primary education-inclusive contexts. The pre-post study design using a sociometric tool involved 14 students with autism and their 228 peers from 14 classes in 12 primary schools in Greece. Findings from the sociograms of the study indicated the value of technological intervention in improving the social status of learners with ASD in inclusive educational contexts. Andrade-Altamirano et al. [23] described the application of a multi-purpose robotic assistant named AsiRo-μ in motivating and mediating dialogue between children with ASD and their TD peers. The robot possesses various functionalities such as hand gesture recognition, automatic speech recognition, text-to-speech function through the IBM Watson Cloud services, and gesture imitation. Based on experts ' evaluations, findings from a pilot experiment with two groups of children indicated a favorable acceptance level among children with multiple disabilities, including ASD, and their TD peers. Paillacho Chiluiza et al. [24] and Solorzano Alcivar et al. [49] proposed and evaluated a prototype of a Socially Assistive Robotic (SAR) to support the learning process of children with ASD in an inclusive setting. The prototype possesses capabilities for mechanical movements, audio, and gestures connected to educational games. The results of the multifaceted evaluation in the studies suggest ways of improving the robot design to incorporate the qualities of gamified learning and maximize the benefits of inclusive education. In addition, Solorzano Alcivar et al. [49] identified that the participants mastered the intervention efficiently, interacted, and attended the instructional game with a great attraction to the educational robot.

4.4 Gamified Applications for ASD Inclusive Education

Game-based applications are modern mechanics for learning new skills and practicing existing ones with challenges and rewards that are valuable in providing engaging and motivating learning

experiences in ASD-inclusive education. For example, gamified applications could be used to teach learners with autism language and communication skills by providing them with a fun and interactive game to play [25, 26]. Gamified applications could also help learners with autism improve their social skills, providing them with simulations of real-life social situations and allowing them to practice responding and interacting in a safe and controlled environment [48, 52]. Notably, Gribble and Barbara [25] describe the communication patterns of pupils in classroom and computer lab ASD-inclusive settings. The participants were featured in a computer science curriculum involving block-based coding. Findings from the descriptive analysis of video data during the sessions indicated improved communication and interaction in the child with ASD in the computer lab setting. Baldassarri et al. [26] assessed the impact of two gamified applications on students' perceptions and learning processes in an inclusive setting. The study proposed technological interventions; an emotional trainer to depict the seven basic emotions (i.e., surprise, happiness, disgust, sadness, anger, fear, and neutral) and a tangible interactive tabletop to work out possible cognitive planning. The study findings revealed the usage of perception without prior cognitive planning among learners with ASD and with evidence showing that attention can be receptive or selective and can be improved with gamified applications. Nonetheless, Brown [52] compared the efficacy of the traditional good-behavior-game (GBG) with technology-enhanced GBG variations (ClassDoJo and ClassBadges) using a multielement design embedded within a reversal design with six male high school students diagnosed with ASD. The study results showed that all three GBG variations were similarly effective in decreasing disruptive behaviors with a repeated preference for technology-enhanced GBG under the ASD-inclusive setting. Carreno-Leon et al. [48] developed a serious game to support the management of emotions in children with ASD. The study integrated a gamified application with tangible user interfaces through an RFID communication board. Favorable results were obtained, based on experts' evaluation, of the effectiveness of the intervention.

4.5 Mobile Applications for ASD Inclusive Education

There are numerous studies on designing, developing, and evaluating various mobile applications for ASD-inclusive education. The findings of the studies indicated that mobile applications could help provide learners with a convenient and portable way to access educational resources. Particularly, learners with ASD can benefit from personalized instruction, interactive learning experiences, real-time feedback, and support from various mobile applications for smartphones, tablets, and similar handheld devices [7, 10, 12, 27-30]. For instance, Fage [10] assessed the efficiency of a tablet-based application in supporting inclusive activity schedules on verbal communications and classroom routines. Findings from the experimental study revealed that the children equipped with the intervention exhibited more classroom and communication routines when compared with the control group and the usage of the application became self-initiated within three months. Rosenbloom et al. [12] utilized the ABAB design in assessing the relationship of a self-monitoring application called I-Connect with the behavior and performance of an elementary student with ASD in a general education classroom. A functional relationship was found between the introduction of the intervention and an increase in on-task behavior with concurrent decreases in disruptive behavior, which suggest the value of the app's data monitoring, recording, and customizable prompts capabilities in supporting inclusive education. Charles et al. [27] experimented with emotion-regulation interventions virtualized as a tablet-based application to

help adolescents with ASD in inclusive classrooms. The test and control groups of the study comprise 14 and 15 adolescents with ASD, respectively. Findings from a comparative evaluation of the experimental groups with additional 19 adolescents with Intellectual Disabilities showed the excellent usability and effectiveness of the app in emotion regulation for adolescents with ASD. Another experimental study by Marble-Flint et al. [7] approached the virtualization of storybooks for handheld devices to support learners in ASD-inclusive classrooms. After two individualized testing sessions of the study, a comparative evaluation of the differences in story comprehension scores using paper-based and iPad storybooks among 15 children with ASD and 15 TD peers indicated that all the participants performed better with the virtual storybook than the paper book. The study findings also suggest that virtualized storybooks function similarly for children with and without ASD. Equally, Nally et al. [28] compared the efficacy of the Edmark Reading Program (ERP) across an inclusive school and self-contained classroom setting in teaching basic reading outcomes using both computer-assisted instruction (CAI) and tabletop instruction (TTI). Descriptive analyses of pre-post data of the 31 students from nine schools, randomized into two groups and exposed to ERP in one of two conditions, slightly favored TTI on reading accuracy, rate, and phonemic awareness, despite preferential response on the CAI administration among teachers. Furthermore, Siyam and Abdallah [30] designed and implemented a mobile app called IEP-Connect for Individualized Educational Plans (IEP) and information sharing. Results of the evaluation of the app indicated favorable usability and user preferences for the app for recording and sharing IEP information. Nonetheless, Ozdowska et al. [29] evaluated the impact of using a mobile app for self-regulated strategy development on the quality and length of persuasive writing of students with ASD. Findings from the ABAC study design revealed positive perceptions of the participants about the intervention, with improved quality and/or length of written compositions in the persuasive writings of students with ASD.

4.6 Web Applications for ASD Inclusive Education

Studies have demonstrated how applications accessed through web browsers can be used on various devices, including computers, laptops, and mobile devices, to provide a convenient and accessible way to access educational resources for ASD-inclusive education [32, 33]. Particularly, Trujillo et al. [32] developed a user-centered web application to aid in learning the basic concepts of music in ASD-inclusive classrooms. The app allows teachers or caregivers to set up a customized learning environment according to each student's needs so that these students can play songs in collaboration with classmates. Tunc-Naftali [33] examined the impact of e-coaching through a web-based professional development portal with a simultaneous prompting procedure for teaching discrete skills to learners with ASD. After nested multiple probe designs across four preschool teacher and student dyads, the study findings revealed the positive opinions of the teachers about the intervention and its effectiveness in teachers' professional development and teaching discrete skills to students with ASD.

4.7 Educational Multimedia Contents for ASD Inclusive Classrooms

Studies have shown how educational multimedia content, such as videos and animations, can be used to support ASD-inclusive education with a visually rich and engaging way to learn and practice new skills, including language and communication skills [34-36]. For example, Smith et al. [34]

investigated the effectiveness of slideshow presentations on iPad in teaching science terms and the application of those terms based on explicit instructions in ASD-inclusive classrooms. The study results revealed that the number of correct responses made during the multiple probe sessions is significantly related to the introduction of the intervention. Knight et al. [35] conducted a similar study involving paraprofessionals in identifying socially critical academic skills and contents for inclusive classes. Results from the multiple probes across participants and skills design indicated a functional relation between the paraprofessional-delivered video prompting and correct responses to academic tasks among students with autism and intellectual disability. Recently, Ntalindwa et al. [36] conducted qualitative data analysis using educational multimedia to improve numeracy learning among children with ASD in inclusive settings. The study findings identified ten themes to help ASD inclusion, tailored around content translation, gamification, and re-creation based on two clustered sets of questions administered to the few dozen participants and analysis of video contents on early math.

4.8 Application of Video Modelling for ASD Inclusive Education

Video modeling (VM) is a technique that provides a visual and auditory representation of a model performing a specific skill, such as communicating with others or navigating a new environment, allowing learners with ASD to see and hear how the skill is performed. Studies have shown the efficacy of this technique in helping learners with ASD understand the steps involved in performing assorted skills and providing them with a reference for their performance [37-40]. Notably, Özerk [37] used VM to teach assorted behavioral and social communication skills to an eleven-year-old bilingual boy with ASD. The study findings revealed that VM is a valuable technology for social inclusion in school settings, and the language skills earned are memorable and can be transferred to another language. Yakubova et al. [38] examined the effects of providing instruction via VM on the accuracy of fraction problem-solving of three middle school students with ASD. The result of the experimental study with multiple probes across the students revealed a functional relation between the intervention and students' improved accuracy in solving simple proper fraction problems. Thus, offering an option for teachers to accommodate the diverse learning needs of students with ASD in various settings. Similar results were found in the study by Helbig et al. [39], which evaluated packaged interventions, including VM, on the acquisition of social skills in young adults with neurodevelopment disabilities, including ASD. Similar packaged interventions consisting of VM were examined by Dueñas et al. [40] to promote unstructured indoor and outdoor extra-curricular activities among children with ASD and TD peers. Findings from the multiple probe design across participants demonstrated that all the TD peers learned to invite children with ASD to play after observing video models and children with ASD increased independent responses to initiations with least-to-most prompting from an adult.

4.9 Application of Wearable Devices in ASD Inclusive Education

Wearable devices are worn on the body and can be equipped with a variety of sensors and technologies that can be used to monitor the physiological and emotional state of learners with ASD, providing them and teachers with real-time feedback on their arousal levels and helping them to regulate their emotions [14, 41, 42]. For instance, Zheng et al. [41] developed and evaluated WELI (Wearable Life) across 58 classes in a postsecondary inclusive setting to understand the

effectiveness of the intervention for learners with ASD. The study findings indicated high student satisfaction and perceived usefulness concerning Focus and Rewards features. Douglas et al. [42] compared video-coded data with sensor data using a point-by-point agreement to measure the accuracy of the sensor system in measuring social proximity between three children with ASD and their peers in an inclusive preschool setting. The study results suggest that the sensor system can adequately measure social proximity between children with ASD and their peers and support teachers and practitioners in making instructional decisions.

4.10 Autism Inclusion Using Maker Program

A maker program is a hands-on approach to learning that focuses on providing learners with the tools and resources they need to design, create, and build their projects. Studies have indicated that this intervention is particularly beneficial for learners with ASD, as it allows them to work on projects tailored to their interests and abilities, such as robot building and art and music creation. Thus, allowing them to learn and practice various skills, including problem-solving, critical thinking, and creativity [50, 51]. For example, Martin et al. [50] described the impact of a collaborative program entitled the IDEAS Maker Club among 30 middle school students with ASD and their 79 TD peers. After running the program for more than two years, the study findings based on a mixed study design revealed improved outcomes in STEM-related competencies among both learners with and without ASD that were administered the technological intervention. Chen et al. [51] further explored the IDEAS Maker Club program with the interview responses of 26 students, 13 parents, and nine teachers and identified five common themes that could poster students' postsecondary pathways based on the positive student experience and engagement, skills acquisition, development of interest in STEM and related careers, social relationships and community, as well as safe spaces that supported self-determination.

5. Conclusion and Recommendations

The present study systematically analyzed recent studies on applying emerging computer technologies for inclusive education involving learners with ASD. The systematic literature review provides vital information on the study area, including the various technological interventions utilized during ASD-inclusive education and the various educational activities supported by the technologies. In essence, this study has made unique contributions to inclusive education for learners with ASD by systematically exploring and analyzing recent studies on the application of emerging computer technologies. However, there are still demands for studies on cost-effective, sustainable, and more practical strategies for ASD-inclusive education using computer technologies. Thus, future studies need to revisit the efficacy of the existing technological interventions and possible enhancements to cover new life-long skills that learners with ASD must acquire in evolving societies. Furthermore, many relevant studies utilized small sample sizes. They lacked long-term data and evidence of consensus with best ASD-inclusive practices, which could imply limited generalizability, lack of sustainability, and practical evidence, respectively. In addition, future studies could focus on ethical issues, such as privacy and data security, and financial considerations, as some of the emerging technologies, such as VR and AR systems, could be expensive to implement in large educational settings. The current work has some limitations, including not considering non-English documents and being limited to a specific time frame and databases. The results are also

limited by the search terms used. Relaxing these filters and considering additional databases could yield more relevant studies. Consequently, the future research agenda would consider expanding the scope of the present study, in terms of literature source and time coverage, to identify, assess, and disseminate various technological interventions for cost-effective and sustainable ASD-inclusive education.

Acknowledgments

None.

Author Contribution

Conceptualization, A.A.L., S.I.A., K.I.Y., H.I.U.; methodology, A.A.L., S.I.A., K.I.Y., H.I.U., H.U.Y., A.G.M.; software, A.A.L., S.I.A., K.I.Y., H.I.U., H.U.Y., A.G.M.; validation, A.A.L., S.I.A., K.I.Y., H.I.U.; formal analysis, A.A.L., K.I.Y.; investigation, A.A.L., S.I.A., K.I.Y., H.I.U., H.U.Y., A.G.M.; resources, A.A.L., S.I.A. H.I.U., H.U.Y.; data curation, A.A.L., K.I.Y., H.I.U., H.U.Y., A.G.M.; writing—original draft preparation, A.A.L.; writing—review and editing, A.A.L., S.I.A., K.I.Y., H.I.U., H.U.Y., A.G.M.; visualization, A.A.L., S.I.A., K.I.Y., H.I.U., H.U.Y., A.G.M.; supervision, A.A.L., S.I.A.; project administration, A.A.L., K.I.Y.

Funding

This research received no external funding.

Competing Interests

The authors have declared that no competing interests exist.

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