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THE USE OF TECHNOLOGY IN TEACHING PHYSICS TO STUDENTS WITH DISABILITIES: A SYSTEMATIC REVIEW

Abstract. In recent years, incorporating technology into education for students with disabilities has significantly improved learning experiences and academic achievement. However, there remains a need for a deeper understanding of the most effective methods for using these technologies, particularly in physics education. This systematic review aims to consolidate research on the use of technology to support learning for students with disabilities, assess its effectiveness in improving educational outcomes, and identify areas for further study. The review focuses on the constructs, technological interventions, research gaps, limitations, and key findings from selected articles. The PRISMA framework was used to analyze research from databases, including EBSCO Host, Elsevier Science Direct, Emerald Insight, ProQuest, Google Scholar, ERIC, and Clarivate Analytics Web of Science. Out of 892 articles initially identified, 13 met the inclusion and exclusion criteria and validation from the experts. The most commonly studied disability was visual impairment, followed by intellectual disabilities. Most studies focused on learner achievement, with engagement and participation as secondary themes. The technologies used included assistive tools like web-based platforms, virtual and augmented reality (AR), and interactive learning systems. These adaptive technologies improved student involvement, social integration, and interest in science. Augmented reality, in particular, enhanced academic performance and knowledge retention, making it an effective tool for inclusive physics education. The findings indicate a growing trend towards integrating technology in inclusive education, emphasizing the role of personalized tools in improving accessibility and engagement for students with disabilities in physics.

Keywords: systematic review; PRISMA; student with disability; physics teaching; educational technology.

1. INTRODUCTION

The use of technology in education has significantly changed how we teach and learn, especially in the field of physics education. This is particularly important for students with disabilities, as traditional teaching methods may not fully meet their learning needs. The United Nations Children’s Fund (UNICEF) has emphasized the importance of governments promoting inclusive teaching practices and providing necessary assistive technologies to ensure that students with disabilities have equal access to quality science education [1]. It is essential to incorporate students with disabilities into regular education to create a diverse and inclusive future workforce that benefits from all individuals' distinct viewpoints and abilities. Hardly and Woodcock [2] explained that this incorporation promotes equal opportunities, diminishes societal obstacles, and equips students with disabilities to make meaningful and inventive contributions across different professional domains. León-Jiménez et al. [3] argued that this integration encourages social empathy and social cohesion, leading to mutual respect and understanding. This fosters an inclusive society that values diverse abilities, contributing to a more collaborative and supportive future workplace.

The problem statement. Despite the remarkable progress in educational technology, students with disabilities still encounter particular obstacles in learning physics. The conceptual nature of physics and conventional teaching techniques frequently do not cater to their individual requirements. Technologies like interactive simulations, assistive gadgets, and adaptive learning systems could help close this gap by providing inclusive and compelling learning opportunities customized to various abilities [4]. Nevertheless, there is still a need for a thorough grasp of how to effectively utilize these technologies for students with disabilities in physics education.

This systematic review focuses on four key research inquiries to explore this subject comprehensively. Initially, it investigates the current utilization of classroom technologies in supporting physics learning for students with disabilities. Secondly, it highlights gaps in the existing research regarding using these technologies in physics education for students with disabilities. Thirdly, it assesses the effectiveness of classroom technologies in enhancing the learning outcomes for these students, taking into account factors such as academic performance, conceptual comprehension, and levels of engagement. Lastly, it delves into the aspects assessed in research papers, including accessibility, usability, satisfaction, and cognitive load.

This systematic review seeks to offer valuable insights and identify areas requiring additional research by synthesizing current knowledge regarding the use and impact of classroom technologies in teaching physics to students with disabilities. The findings are intended to serve as a resource for educators, policymakers, and technology developers, outlining effective approaches and areas for enhancement. Ultimately, the objective is to improve the educational achievements of students with disabilities by ensuring that technological progress leads to meaningful learning experiences in physics.

Analysis of recent studies and publications. Several technologies have been developed to aid students with disabilities. New educational technologies, such as interactive simulations, assistive devices, and adaptive learning platforms, aim to make learning more accessible and engaging. For instance, interactive simulations can visually illustrate abstract concepts. At the same time, assistive technologies like speech-to-text and screen readers help students with visual or auditory impairments access course materials more efficiently [4]. Adaptive learning platforms personalize learning by adjusting content to match individual learning paces and styles [5]. Exploring how these technologies can be used in physics education and their effects on students with disabilities is essential for evaluating their impact.

Despite the progress made in educational technology, there are still substantial knowledge gaps concerning its efficacy and use for students with disabilities in physics education. Gaps include the absence of comprehensive studies on the lasting effects of technology usage [6], inadequate data on the experiences of students with varying disabilities [7], and limited examination of the effectiveness of different technological tools in diverse educational environments [8]. By identifying these gaps, this study emphasizes the areas requiring additional exploration to create more inclusive and successful educational technologies.

The use of classroom technologies to enhance the learning experiences of students with disabilities in physics education needs to be thoroughly investigated. Research should focus on measuring the impact of these technologies on students' academic performance, understanding of concepts, engagement levels, and ability to retain information. Schreffler et al. [9] argued that it is important to analyze quantitative and qualitative data from various sources, such as educational assessments, student input, and comparative studies, to determine how effective these technologies are. This knowledge can guide educators and policymakers in adopting best practices and making the necessary enhancements.

The last inquiry centers around scrutinizing the constructs assessed in present research literature concerning the application of classroom technologies in physics education for students with disabilities. These concepts may encompass accessibility, usability, engagement, satisfaction, academic performance, and cognitive burden. By examining these concepts, insights into the key areas of emphasis in current research and the standards utilized to evaluate the efficacy of educational technologies can be gained. This analysis can also unveil patterns and prevalent approaches, laying the groundwork for developing standardized assessment frameworks in future research.

The research goal. The following are the objectives of this systematic review: determine the classroom technologies used for students with disabilities and their effectiveness, identify which constructs these classroom technologies are effective to, and identify the research gaps, findings, and limitations of the reviewed articles. The review aims to summarize current knowledge about using these technologies to support learning, assess their effectiveness in enhancing educational outcomes, and pinpoint areas where further research is needed. By analyzing a wide range of studies, the review aims to understand how classroom technologies can be optimized to meet the diverse needs of students with disabilities. This study helps educators, policymakers, and technology developers identify best practices and areas that require more exploration.

To accomplish this, the review will explore the following research questions: What constructs are being evaluated in the research papers? How are classroom technologies utilized to assist students with disabilities in learning physics? What are the current research gaps in using classroom technologies for physics education for students with disabilities? How do classroom technologies improve the learning outcomes of students with disabilities in physics education? What are the identified limitations of the reviewed articles? By addressing these questions, the review aims to establish a comprehensive framework for enhancing the effectiveness and inclusivity of physics education through technology.

2. RESEARCH METHODS

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. This framework was employed to lead this structured investigation on improving physics education for students with disabilities using classroom technologies. The PRISMA method offers a consistent and thorough approach to conducting structured reviews, guaranteeing clearness, reproducibility, and thorough reporting of results [10]. The study involved several important stages, including developing precise research inquiries to shape the review's scope. These inquiries concentrated on using classroom technologies, recognizing research gaps, assessing learning results, and investigating the concepts evaluated in current studies.

2.1. Data Collection Procedure

The articles came from different repository websites like EBSCO Host, Elsevier Science Direct, Emerald Insight, Proquest, Google Scholar, ERIC, and Clarivate Analytics Web of Science. These journal repository websites are well-trusted hosting organizations for journal articles and books. They also follow a rigorous peer review process and host the most highly cited articles. To look for the articles in these journal repository websites, keyword combinations were used like “physics teaching of students with disabilities,” “learning disabilities,” “STEM Education for disabled students,” and “speech and vision difficulties” were encoded in the search bar. For faster search, Boolean operators like AND and + were used.

The PRISMA selection process's flow diagram, shown in Figure 1, showcases a thorough and systematic method for identifying and incorporating pertinent studies into this review. The process starts with the identification phase, during which 892 records are gathered from different journals. Following a de-duplication process, 440 unique records proceed to the screening phase. Here, the titles and abstracts are assessed against specific criteria, excluding 452 records that need to align with the criteria.

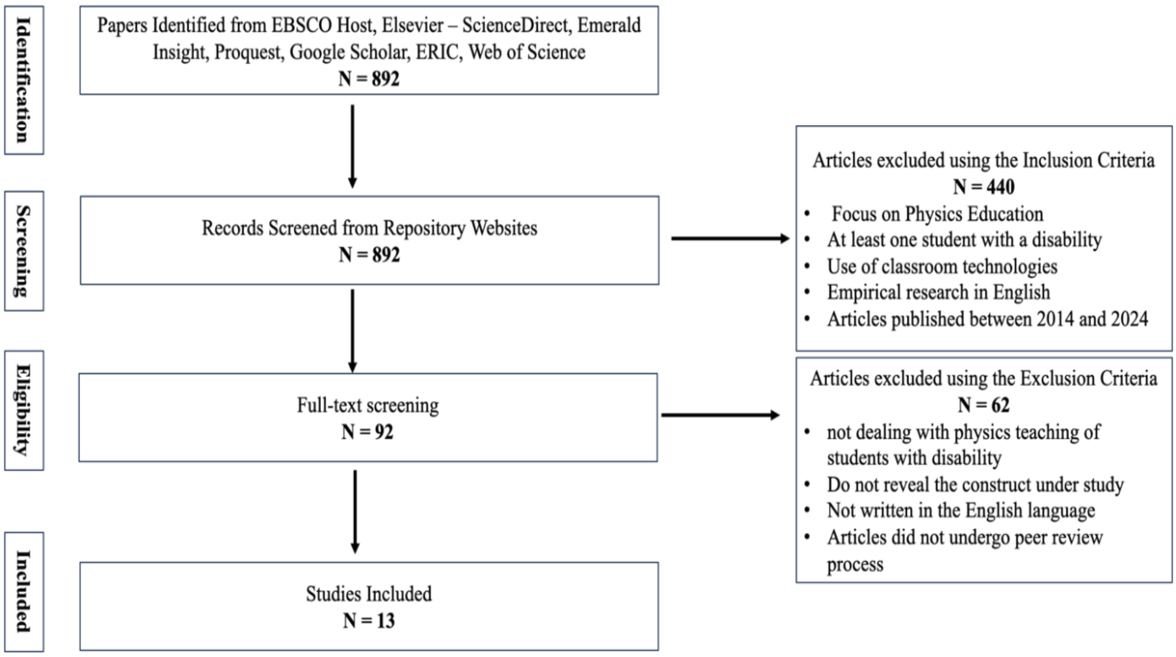

Figure 1. The systemic review process using PRISMA was used in this research.

Afterward, the remaining 92 records move on to the eligibility phase, where the full-text articles undergo in-depth evaluation for eligibility. During this phase, 62 articles are excluded due to lack of relevance to the research questions, insufficient empirical data, or failure to meet specific inclusion criteria, leaving 13 articles eligible. Subsequently, these 13 studies are integrated into the qualitative synthesis, constituting the primary dataset for the systematic review. This thorough selection process ensures the inclusion of only the most pertinent and high-quality studies, thereby bolstering the reliability and validity of the review findings.

2.2. Inclusion and Exclusion Criteria

The studies should focus specifically on applying technology within the physics education environment. In general, research related to different subjects or science education was only considered if it directly addressed its relevance to physics education. Research should specifically concentrate on students with disabilities like students with hearing and vision problems, intellectual disabilities (ID), and handwriting difficulties. Studies that involve students without disabilities will only be considered if they provide separate data specifically related to students with disabilities. These studies should examine classroom technologies intended to facilitate teaching and learning. This includes various educational technologies such as interactive simulations, assistive devices, and adaptive learning platforms.

The research should assess educational outcomes of physics learning, encompassing academic performance, conceptual understanding, engagement levels, retention rates, and other relevant educational indicators. Only empirical studies, including quantitative, qualitative, or mixed-methods research providing data-driven evidence on the use and effectiveness of classroom technologies for students with disabilities in physics education, will be considered. The articles should also offer the research gap, their findings on utilizing the technological intervention for students of physics with disabilities, and their limitations. Additionally, the studies must be published in reputable academic sources such as peer-reviewed journals and conference proceedings. Grey literature like dissertations, theses, and reports will be considered if they adhere to rigorous academic standards and offer valuable insights related to the research questions.

To include the most recent and relevant research on classroom technologies for students with disabilities in physics education, this review only focused on articles published between 2014 and 2024. Articles not within this timeframe were not included. This time frame reflects the latest advancements in educational technology and current trends and practices, ensuring that our findings are up-to-date and applicable to modern educational settings.

Articles that do not deal with the physics teaching of students with disabilities and do not reveal the effect on any construct (e.g., learning outcomes, critical thinking) of the students with disabilities were omitted. Papers that were not written in the English language were omitted. Research papers that did not undergo the rigorous peer review process were excluded.

2.3 Validity of the Articles and the Review

Once the PRISMA protocol had been followed and 13 articles were found and selected, the entire process flow in Figure 1 was validated by five experts in literature and systematic review. They were doctoral professors from a state university in the Philippines. These reviewers critically evaluated the methodology, inclusion criteria, and interpretations, ensuring that the selection of studies is objective and comprehensive. Their insights help prevent the omission of crucial research and provide a balanced assessment of the current innovations in the field. Additionally, expert consultation allowed validating educational tools and technologies discussed in the review.

Table 1

Instrument to measure the validity of the articles for systematic review

Criteria	1	2	3	4	5
Relevance	Not relevant	Barely related	Somewhat relevant	Closely related	Directly addresses the review's topic
Research Quality	Poor design, unclear methods	Weak design, significant issues	Acceptable design, some limitations	Solid design, minor limitations	Strong, well-executed research design
Innovation	Outdated technology	Basic, limited innovation	Somewhat innovative	Modern and relevant technology	Cutting-edge or highly innovative technology
Educational Outcomes	No clear outcomes	Weak or indirect outcomes	Some outcomes, lacking detail	Clear outcomes with good support	Strong, well-defined educational outcomes
Generalizability	Not generalizable	Very limited applicability	Somewhat generalizable	Broad applicability, with some limits	Highly generalizable to different contexts
Contribution	Minimal contribution to the field	Modest contribution	Useful but not groundbreaking	Substantial contribution	Significant advancement in the field

The experts used a researcher-made instrument to review the article, as shown in Table 1. The instrument for validating the articles in this systematic review is divided into six sections: relevance, quality of research design, innovation of technology, inclusion of educational outcomes, generalizability, and overall contribution to the field. Each section was rated on a 1-5 scale, with 5 indicating the highest quality or alignment with the review's objectives and 1 indicating the lowest. This scale comprehensively evaluated each article's relevance to the topic, research rigor, technological innovation, and educational impact. The instrument ensured a consistent and objective literature assessment by assigning scores across these dimensions.

3. THE RESULTS AND DISCUSSION

The total number of articles that resulted from using the PRISMA protocol is 13. These articles are highly cited and reliable because they came from double-blind reviews of the different journal repositories mentioned above. Despite covering articles from 2014 to 2024, there is an apparent scarcity of research focused on technological innovations in physics education for students with disabilities. This highlights the need for further exploration and development in this area, with emerging technologies like augmented reality and AI offering promising future directions.

3.1. Participants' disabilities and technological intervention

The articles reviewed have focused on students under the 13-17 age category. The use of technology in schools has dramatically improved the learning experiences for students with different disabilities. After looking at 13 studies, it's clear that various technology tools have been used to help students with specific disabilities, resulting in better overall educational outcomes. The focus has been on helping students with VI (31%), followed by ID (23%), with many studies exploring different ways technology can support these students. Most papers measured the constructs of learning achievement (38%), followed by engagements and participation (23%).

Most of the technology utilized is assistive technology (31%), such as web-based assistive learning platforms, JAWS screen-reader software, SEED, tablets, and smartphones. Comes second with 23% virtual and AR, such as a SLOODLE integrated into a 3D virtual physics laboratory, Magic Leap on an AR device, and Minecraft. Also, 23% are interactive learning tools like tactile-visual analog models of a circuit, LEGO Education EV3 Mindstorms, and tronic Boards.

VI is the most commonly studied disability (f = 4), and researchers examined various technologies designed to improve conceptual understanding and learning outcomes for these students. De Azevedo et al. [11] utilized laser devices and building models, effectively improving students' conceptual understanding. Supalo et al. [12] incorporated Vernier Software & Technology probeware and JAWS screen-reader software to promote hands-on participation and social acceptance, highlighting the significance of accessibility tools in enhancing engagement and inclusivity for students with LV. Alatas and Solehat [8] introduced interactive conversation dialogues in audiobooks, positively impacting students' perception and learning outcomes. Velloso et al. [13] used a tactile-visual analogue model of a circuit, demonstrating the effectiveness of multimodal learning aids for students with VI.

Various digital learning tools and interactive platforms have been used to enhance educational outcomes for students with ID. In this review, students with ID account for three or 23% of all studies reviewed. Disseler et al. [14] utilized LEGO Education EV3 Mindstorms, which positively influenced content knowledge and learning disposition, indicating that hands-on, interactive activities can significantly improve learning for students with ID. Iatraki and Mikropoulos [15] employed Magic Leap on AR devices. They found that the intervention positively impacted student achievement, showcasing the potential of augmented reality (AR) in creating a more immersive and engaging learning experience for these students. Senaratne et al. [16] utilized Tronic Boards to increase student engagement, emphasizing the importance of interactive tools in maintaining student interest and participation. Similarly,

Table 2

Overview of studies on technology use in the classroom for students with disabilities

Authors/Year	Participants	Disability	Technology	Construct measured

Elfakki et al. (2023)	N = 40	attention deficits; poor concentration	SLOODLE integrated in 3D virtual physics laboratory developed	cognitive skills
de Azevedo et al. (2014)	N = 3	visual impairment (VI)	use of laser devices and building models	Conceptual understanding
Nugraha et al. (2023)	N = 40	hearing disorders	Web-based assistive learning platform	Satisfaction level
Fichten et al. (2019)	N = 15	Various disorders	Tablets and smartphones	Extent of use
Velloso et al. (2021)	N = 1	VI	Tactile-visual analogue model of a circuit	Learning outcomes
Alatas & Solehat (2020)	N = 8	VI	interactive conversation dialogue in an audiobook	perception and learning outcomes
Iatraki & Mikropoulos (2022).	N = 60	ID	Magic Leap On AR device Digital Learning Object	Students achievement
Supalo et al. (2016)	N = 6 (2 females, 4 males)	Low Vision (LV)	Vernier Software & Technology line of classroom laboratory probeware; Job Access with Speech (JAWS) screen-reader software	Hands-on participation; social acceptance; attitude; interest
Jaber et al. (2022)	N = 1	handwriting difficulty	Smart Equation Exam System (SEED)	Perception; extent of help
Hobbs et al. (2019)	N = 50	Autism spectrum disorder (ASD)	Minecraft	Lived experiences; scientific understanding
Gehret et al. (2017)	N = 180	deaf or hard of hearing (D/HH)	Google Hangouts	Extent of active learning activity
Disseler et al. (2017)	N = 11	ID	LEGO Education EV3 Mindstorms.	content knowledge and learning disposition
Senaratne et al. (2022)	N = 148	ID	Tronic Boards	engagements

Hearing difficulties account for 15% of all research. The students were supported with technologies that aid communication and learning. Gehret et al. [17] utilized Google Hangouts to enrich active learning for deaf or hard-of-hearing students, showcasing the impact of communication technologies in promoting inclusivity and active engagement. Nugraha et al. [18] introduced a web-based assistive learning platform, that assessed students' satisfaction levels and highlighted the significance of user-friendly interfaces in fostering positive educational experiences.

Elfakki et al. [5] investigated the integration of SLOODLE into a 3D virtual physics laboratory to support students with attention deficits and poor concentration. This technology aimed to improve cognitive skills, demonstrating considerable potential in sustaining engagement and enhancing focus, which is particularly important for students facing attention-related challenges.

Hobbs et al. [19] addressed ASD by investigating the use of Minecraft to enhance lived experiences and scientific understanding. This research emphasizes the importance of utilizing familiar and engaging platforms to support learning in students with ASD, illustrating how such tools can make learning more relatable and enjoyable. Additionally, Jaber et al. [7] focused on addressing specific learning difficulties, such as handwriting issues, by developing the SEED, which assessed perception and the level of assistance provided. This targeted approach highlights the importance of specialized tools in tackling specific educational challenges, ensuring that all students have the opportunity to succeed.

3.2. Research Gaps of the reviewed articles

The research gaps indicate the importance of creating more comprehensive and proven educational interventions for students with disabilities. Many of these gaps emphasize the need to develop and evaluate technology-based educational resources, such as 3D virtual labs [5], mobile technologies [6], AR [7], and auditory adaptive technologies [17],[7]. These tools are designed to improve learning experiences and results, but further research is needed to confirm their effectiveness and long-term benefits.

Table 3

Summary of research gaps, outcomes, and limitations of the 13 articles reviewed

Authors	Research Gap	Findings	Limitations
Elfakki et al. (2023)	Exploring the potential benefits of using 3D virtual physics labs to improve the cognitive and practical skills of students with learning disabilities.	Enhanced physics skills; high mastery levels and effective skill development.	Restricted internet in special education centers; Insufficient tools to assess digital materials' impact
de Azevedo et al. (2014)	There is a shortage of hands-on teaching approaches that transform light-based experiments into tactile and auditory experiences to help visually impaired students comprehend light concepts.	greatly assists visually impaired students in comprehending the topic; students able to construct conceptual models of the light phenomena.	Potential for eye and skin damage
Nugraha et al. (2023)	The difficulties and limitations in providing fair education for students with special needs.	The system is highly accessible; students with disabilities can easily interact with the provided learning materials.	Did not discuss any limitations
Fichten et al. (2019)	Extensive research is lacking on how mobile technologies can aid academic activities and promote classroom inclusion for students with various disabilities.	Mobile devices are utilized for educational purposes such as recording lectures, accessing PowerPoint slides, and researching related topics, but they are also misused for activities like texting, social media, and online shopping during class; AR and interactive whiteboards are more prominently used.	Small sample size; Potential broader applications and uses of mobile devices and apps outside the study sample
Velloso et al. (2021)	scarcity of resources and strategies for effectively integrating blind students into physics education	substantial engagement and educational progress	The study represents an initial step, suggesting more research is needed.
Alatas & Solehat (2020)	There is a shortage of comparative studies evaluating the educational achievements and levels of involvement of visually impaired students using traditional versus integrated audiobook methods in STEM education settings.	The learning outcomes for blind students were significantly improved, as demonstrated by increased post-test scores; high student satisfaction rates.	Blind students need time to adapt to interactive audiobooks; Totally blind students require more hands-on experiences than those with LV
Iatraki & Mikropoulos (2022)	Creating and validating evidence-supported AR interventions designed to improve academic skills for students with ID.	Substantial enhancements in learning outcomes; high social validity reports.	Baseline sessions were completed for all students before the intervention
Supalo et al. (2016)	understanding the long-term effects of these audible adaptive technologies LV students'	adaptive technologies significantly enhanced hands-on participation of students; greater	Occasional malfunction of the adapted technologies;

	sustained engagement in scientific inquiry	independence and engagement, were observed	Insufficient training for teachers and students
Jaber et al. (2022)	Investigating the enduring impact of auditory adaptive technologies on the sustained involvement of BLV students in scientific investigation and their subsequent pursuit of careers in STEM.	high level of satisfaction with the technology; user-friendly and accessible digital tool for learning and assessment in physics.	Limited generalizability due to small sample size
Hobbs et al. (2019)	need for more empirical studies that systematically assess the long-term educational outcomes and retention of scientific knowledge imparted through Minecraft	increased engagement, deeper understanding of scientific concepts, and improved social interactions	Did not discuss any limitations
Gehret et al. (2017)	There is a necessity for additional empirical research that methodically evaluates the enduring educational results and retention of scientific knowledge taught through Minecraft.	improved students active involvement and effectiveness.	The tutor had no prior experience with remote tutoring; The use of online whiteboards had technical issues
Disseler & Mirand (2017)	Examining the efficacy of using LEGO Education, for students with mild and moderate disabilities.	significant academic progress; high level of confidence among students	Small sample size; Access to and cost of the LEGO Education EV3 Mindstorms kits
Senaratne et al. (2022)	The availablity of specially crafted electronic toolkits designed specifically for individuals with ID.	There were high levels of engagement and positive academic results; participants varied in their ability to grasp module functionality and operate controls.	Inconsistent study durations; The study did not evaluate long-term impacts of TronicBoards

Numerous studies emphasize the need for interactive and multi-sensory teaching approaches, particularly for students with VI. For example, light-based experiments can be adapted into tactile and auditory experiences [11], and blind students can be integrated into physics education [13]. These approaches are essential for making abstract concepts more accessible to students with sensory disabilities. Additionally, there is a lack of comparative studies assessing different educational methods and their outcomes, such as comparing traditional and integrated audiobook methods for visually impaired students in STEM [8]. Furthermore, there is a need for more empirical research on the long-term educational impacts of tools like Minecraft [17],[19].

Furthermore, research gaps addressing the broader challenges in delivering fair education for students with special needs [18] and assessing the effectiveness of specially designed electronic toolkits for individuals with ID [16] are crucial for ensuring that all students receive quality education tailored to their requirements. Research gaps also highlight the significance of understanding the long-term impacts of educational interventions, including sustained involvement in scientific inquiry [12],[7] and retention of scientific knowledge [17],[19].

3.3. Main findings of the studies reviewed

All 13 papers in the review revealed a positive impact of the technological intervention. de Azevedo et al. [11] investigated the application of laser tools and model construction to assist visually impaired students in grasping light-related concepts. This hands-on and auditory method helped students effectively develop conceptual models, leading to improved participation and understanding of topics in Physics. Supalo et al. [12] examined the utilization of Vernier probeware and JAWS screen-reader software to enable the hands-on involvement of students with VI in physics laboratory activities. Adaptive technologies bolstered student engagement, promoted social inclusivity, and sparked enthusiasm for science within this student demographic.

Disseler et al. [14] dedicated their research to implementing LEGO Education EV3 Mindstorms for inquiry-based physics learning with students with mild to moderate disabilities. This method enhanced academic performance, behavior, and teamwork abilities, underscoring the advantages of interactive, experiential learning. Fichten et al. [6] investigated the widespread utilization of tablets and smartphones by students with disabilities, highlighting their significance as assistive devices for various academic and non-academic endeavors. The research emphasized the value of incorporating mainstream technologies to facilitate inclusive learning environments in physics education. Hobbs et al. [19] utilized Minecraft to launch the Science Hunters initiative, which involved children, particularly those encountering educational obstacles, in scientific education. The project effectively enhanced interpersonal skills and cultivated enthusiasm for scientific professions among the participants, highlighting the promise of integrating game elements into comprehensive physics education.

Alatas and Solehat [8] created an interactive physics audiobook with the Quran and demonstration tools to educate blind students about the solar system. This multimedia approach significantly improved the students' understanding of intricate physics concepts, underscoring the effectiveness of customized educational resources for visually impaired learners. In a separate study, Velloso and colleagues [13] developed a tactile-visual model of a circuit to involve blind students in physics education. The comprehensive lesson plan and organized script facilitated seamless lesson delivery and encouraged thoughtful learning, showcasing successful approaches for improving accessibility and involvement in physics learning settings.

Jaber et al. [7] implemented the SEED, which allowed students, including those with disabilities, to solve physics problems step-by-step during exams. SEED was widely embraced as an alternative assessment approach, promoting learning and review processes in physics education. Additionally, Iatraki and Mikropoulos [15] utilized Magic Leap AR devices to enrich the understanding of microscopic water states for students with mild ID. The use of AR technology led to enhanced performance and improved retention of knowledge, demonstrating its effectiveness as an engaging and accessible tool in inclusive physics education.

Elfakki et al. [5] incorporated SLOODLE into a 3D virtual physics laboratory, improving cognitive abilities, performance, and practical skills among students with learning disabilities. The virtual environment also facilitated social interactions, promoting engagement and empowerment among students with similar challenges. Similarly, Nugraha et al. [18] created the CDIES web-based assistive learning platform to aid students with hearing impairments, integrating simulations and interactive tools to enhance the accessibility and understanding of physics concepts. The platform exhibited high usability and dependability, providing effective learning support for students with special needs.

3.4. Limitations of the reviewed articles

The most frequent limitations include small sample sizes and limited generalizability, technological and resource constraints, adaptation and training needs, and practical and technical issues. The recurring issue of small sample sizes and their impact on the generalizability of findings is a prominent concern [6], [7], [14]. When studying diverse groups of students with disabilities, small sample sizes limit the ability to apply findings to a broader population. To address this limitation, further research using larger and more representative samples is essential to substantiate conclusions and validate their applicability across various settings. In addition, challenges like limited internet access, intermittent malfunctions of adapted technologies, and the expensive nature of educational resources such as LEGO kits underscore the limitations of technology and resources [5], [12], [14]. These constraints hinder the reliable and successful integration of educational technologies, emphasizing the necessity for improved infrastructure, dependable technology, and accessible resources to aid students with disabilities.

Adaptation and training were the focus of the limitations discussed by Alatas and Solehat [8], Supalo et al. [12], and Gehret et al. [17]. The necessity for students, especially those who are visually impaired, to adjust to new technologies, coupled with inadequate training for both teachers and students, represents a significant limitation. This highlights the critical importance of comprehensive training initiatives and adequate adaptation periods to guarantee the effective utilization of educational tools and technologies.

Real-world obstacles, such as technical difficulties with online tools, limited past exposure to remote tutoring, and sporadic malfunctions of adapted technologies, are substantial [12], [17], [14]. These challenges impact the practicality and overall efficiency of educational interventions, underscoring the requirement for dependable technical assistance and practical remedies tailored to the unique requirements of students with disabilities.

The inadequate availability of assessment tools to evaluate the influence of digital materials and the potential hazards like eye and skin injuries are notable issues [5], [11]. These constraints emphasize creating comprehensive assessment instruments and implementing safety precautions when introducing new educational technologies. Concerns such as the requirement to complete baseline sessions before the intervention and variations in study durations among participants indicate areas for improvement in experimental design [15], [16]. These shortcomings can impact the credibility and consistency of the research results, emphasizing the necessity for stringent experimental controls and uniform methodologies to derive precise conclusions.

Moreover, one limitation of this review is that the researcher should have considered the participants' age characteristics and health status in the articles reviewed. Also, the reviewer needed to explore the various types of physics skills and competencies. It would be a good study area for future undertaking in this field.

4. CONCLUSIONS AND PROSPECTS FOR FURTHER RESEARCH

This systematic review included 13 studies from the initial 892 articles from different journal repository websites, such as EBSCO Host, Elsevier Science Direct, Emerald Insight, Proquest, Google Scholar, ERIC, and Clarivate Analytics Web of Science. The most common student disability under study is VI, followed by ID. Most of these articles studied the constructs of learner achievement, and the next is engagement and participation. The number one category of technology used to enhance the learning of students' disability is assistive technologies such as web-based assistive learning platforms, JAWS screen-reader software, SEED, tablets, and smartphones, followed by virtual and AR (e.g., magic leap, Minecraft) and interactive learning tools (e.g., LEGO Education EV3 Mindstorms, tronic boards).

All 13 papers in the review revealed a positive impact of the technological intervention. Adaptive technologies bolstered constructs like student engagement, social inclusivity, and enthusiasm for science within this student demographic. AR technology led to enhanced performance and improved knowledge retention, demonstrating its effectiveness as an engaging and accessible tool in inclusive physics education. These research studies show a movement towards incorporating technology into inclusive education, highlighting how personalized tools can improve access and participation for physics students with disabilities. Each method tackles the unique obstacles experienced by various disability groups, underscoring technology's ability to create equal opportunities and foster interactive learning tailored to diverse educational requirements. Future studies could delve into the wider implementation and lasting effects of these tech-based interventions in various educational environments and for different types of disabilities, aiming to broaden access and improve the effectiveness of inclusive physics education programs.

Many of these gaps emphasize the need to develop and evaluate technology-based educational resources, such as 3D virtual labs, mobile, augmented reality, and auditory adaptive technologies. Research gaps also highlight the significance of understanding the long-term impacts of educational interventions, including sustained involvement in scientific inquiry and retention of scientific knowledge. Future research should strive to involve more extensive and diverse groups of participants to strengthen the dependability of findings and enhance their applicability to various settings. Furthermore, the most common limitations include small sample sizes and limited generalizability, technological and resource constraints, adaptation and training needs, and practical and technical issues.

Therefore, future research should prioritize increasing the sample size by collaborating across multiple schools and regions to include a broader representation of students with various disabilities. This will help make the findings more applicable to diverse contexts. Additionally, more resources should be allocated to address technological and infrastructure gaps in educational institutions. It is crucial to invest in accessible technologies and provide necessary tools to students and educators, especially in under-resourced areas.

Additionally, a limitation of this review is that the researcher should have considered the participants' age characteristics and health status in the articles examined. Furthermore, the reviewer should have investigated the different physics skills and competencies the students with disabilities were learning. The idea can also be extended to students coming from diverse backgrounds. Knowing what physics tools are appropriate for students of a particular intellect or background is an incredible prospect for future research. This presents a valuable area for future research in the field.

Future undertakings could also be focused on thoroughly studying various areas in physics education and analyzing the connections and similarities between them and other subjects in the curriculum. This study intends to evaluate the current potential of teachers and students to identify and connect internal subject links, particularly concerning solving physics problems. Thus, the study will highlight the significance of interdisciplinary connections in physics teaching and identify the key requirements for building connections among disciplines. Besides, the saw-tooth, along with peer-reviewed materials assessment, will give insight into how such approaches can be incorporated into physics teaching to assist students in understanding concepts and overcoming the difficulties they face in problem-solving.

Furthermore, comprehensive teacher training programs tailored to the unique needs of students with disabilities are essential. These programs should focus on adapting physics content and teaching methods to ensure accessibility using assistive technologies and differentiated instruction techniques. It is also important to develop robust pilot programs to test the feasibility of physics interventions for students with disabilities. Longitudinal studies are needed to explore the long-term impacts of educational interventions, especially in fostering sustained engagement in scientific inquiry and improving retention of physics knowledge among students with disabilities. Lastly, it is crucial to investigate how physics education interventions for students with disabilities can be effectively scaled up to ensure equitable access and success for a broader population of learners. Addressing these recommendations can significantly improve the quality and inclusiveness of physics education for students with disabilities.

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ВИКОРИСТАННЯ ТЕХНОЛОГІЙ У НАВЧАННІ ФІЗИКИ УЧНІВ З ОБМЕЖЕНИМИ МОЖЛИВОСТЯМИ: СИСТЕМАТИЧНИЙ ОГЛЯД

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Анотація. В останні роки впровадження технологій в освіту для студентів з обмеженими можливостями значно покращило їх навчання та академічну успішність. Однак залишається потреба ширшому застосуванні найбільш ефективних методів використання технологій, зокрема в навчанні фізики. Цей систематичний огляд має на меті консолідувати дослідження щодо використання технологій для підтримки навчання учнів з обмеженими можливостями, оцінити їхню ефективність з покращення результатів навчання та визначити напрями подальшого дослідження. Огляд зосереджується на конструкціях, впровадженні технологій, прогалинах у дослідженнях, обмеженнях і основних висновках з вибраних статей. Для аналізу досліджень з баз даних, як-от EBSCO Host, Elsevier Science Direct, Emerald Insight, ProQuest, Google Scholar, ERIC та Clarivate Analytics Web of Science був використаний метод PRISMA. З 892 відібраних статей, 13 відповідали критеріям включення та виключення, а також були схвалені експертами. Найбільш часто досліджуваними обмеженнями можливостей учнів були порушення зору та інтелектуальні порушення. Більшість досліджень зосереджувались на результатах навчання учнів, а залучення учнів до навчального процесу та участь їх у ньому були другорядними темами. Використовувані технології мали допоміжні інструменти, такі як вебплатформи, віртуальна і доповнена реальність (AR) та інтерактивні навчальні системи. Ці адаптивні технології сприяли залученню учнів до навчання, їх соціальній інтеграції та підвищенню їх інтересу до науки. Доповнена реальність, зокрема, покращила академічну успішність та сприяла збереженню знань, що робить її ефективним інструментом для інклюзивної освіти з фізики. Отримані результати свідчать про зростаючу тенденцію інтеграції технологій в інклюзивну освіту, завдяки важливій ролі персоналізованих інструментів у підвищенні доступності та залученості учнів з обмеженими можливостями до вивчення фізики.

Ключові слова: систематичний огляд; PRISMA; учень з обмеженими можливостями; навчання фізики; освітні технології.