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Required Tools for Advancing Technology-Enhanced Learning of Vision-Impaired Students in Ghana

Rachel Annoh[1], Mary Adu Kumi[2]

[1]PhD Candidate, Centre for Graduate Studies, Open University Malaysia / Accra Institute of Technology, Accra Ghana
[2]Senior Lecturer, Faculty of Development Studies, Department of Environmental & Natural Resources Management, Presbyterian University Ghana

Abstract

Inadequate attentionpaid to vision-impairment of students as peculiar hindrances in inclusive classroomsin Ghana creates crucial need for assessing the requirements for Educational Technology Enhancement (ETE) tools.1532 students, including 60% fully sighted, 31.6% partially sighted, and 8.4% with no sight,responded to the survey towards analysis of differential impacts of ETE tools on their academic engagementand performance. The results on accessibility and availability of technology tools showed that, Braille devices (25.3%)stood out as most frequently available tool, followed closely by Screen Readers (24.7%) and Tactile graphics (19.0%). The average rating for available tools is 2.66, with a standard deviation of 1.326 reflecting moderate access to assistive technologies. Perceived effectiveness of the tools in supporting learning, rated at average of 3.12, with standard deviation of 1.145 suggesting moderately effective and somewhat reliable tools. Evaluation of relationship between vision status and tool usage or tool accessibility using Chi-Square tests indicated no statistically significant association between vision status and frequency of technology tool usage or accessibility. The finding that Braille devices and Screen Readers are critical tools for vision-impaired students aligns with thefoundational role of tactile and auditory tools in inclusive classroom education.

Keywords: Technology Enhancement Tools, Inclusive Classroom Education, Vision Impaired Students

Introduction

Background of the Research

The research field of Technology-Enhanced Learning (TEL)is concerned with using technologies to support student learning whether the learning is local in terms of studying on campus or remote by training at home or in the workplace. In this field, Technology Enhancements are expected to facilitate fundamental educational practices and processes of learning and ultimately offer scalability, flexibility, and new methods of facilitation in education [1]. New technologies like robotics for instance are known to eliminate repetitive tasks [2]. However, the use of technology in education appears to be superficial and does not meet the required potential of the technology in the field [1], [2]. Historically, these technologies have included instructional films, radio, and television [3], but in the current day, Technology-Enhanced Learning pertains more to the use of computer-based technologies, including smartphones and other smart devices [1]. [1] consider learning as a process whereby the learner accesses concepts and ideas, assimilating these through practice and ultimately demonstrating mastery [1]. In their notes, [1] indicate that enhancements of learning seek to improve parts of this practice and process through facilitation of fundamental activities of learning by technology in various forms. Thus, this study questions the requirements for educational technology enhancement tools in ultimately offering accuracy and consistency towards scalability of processes and practices in education. This is crucial for the Educational System in Ghana (ESG) which perpetuates systemic inequalities and limits contributions of the vision-impaired student to socio-economic development life, because the ESG has embraced the global initiative on inclusive education as basis for enrollment of students. The real-world implications of this problem are significant when vision impaired students are bulked together with seemingly sighted students in one classroom for inclusive classroom education which focuses on removing all barriers to participation in education for all students. Addressing this issue is crucial to fostering inclusivity and ensuring that vision-impaired students can access opportunities to thrive in academic and professional spheres [4],[5]. Although the initiative for inclusive education focuses on removing all barriers to participation in education for all students using inclusive classrooms, the initiative for inclusive classroom education does not adequately consider educational technology enhancement tools as crucial requirements for students with vision-impairment problems.Hence, this study examines the contributions of technology enhancements tools towards advancing effective learning by vision-impaired students.The reason is, technological advancements appear to enhance learning opportunities for students with vision impairment by providing tools that cater to their specific needs. These tools leverage artificial intelligence, machine learning, and other innovative technologies to facilitate independent learning and improve educational outcomes.

Statement of the Problem

The information era is involved with the use of rapid pace computerized systems in almost all educational setups. However, various new technologies, that are introduced in education to facilitate learning, seem to fail to meet the high expectations of users [1], [2], [3]. Moreover, the use of educational technology tools in classrooms and schools appears to be superficial and does not meet the required potential of the technology in the field [1], [2]. The reasons may be that the required technology enhancement tools that are accurate and consistent to speed up vision-impaired student learning towards scalability and the relative practice risks associated with the facilitation of those tools in specified vision-impaired learning environment are not documented in literature. Additionally, the social opportunities of Technology Enhanced Learning (TEL) among vision-impaired students are not evaluated nor modelled as social outcome benefits of the tools. Hence, the study explores educational technology enhancement tools required to advance learning by vision-impaired students, as well as the associated risks, benefits and difficulties in engaging those technology enhancement tools. The study considers that the Educational System in Ghana (ESG) has embraced the global initiative on inclusive education as basis for enrollment of students, taken initiative to remove all barriers to participation in education for all students, based on the global initiative on inclusive education [6] as basis for enrollment of students. The Incheon Declaration and Framework for Action for the implementation of Sustainable Development Goal 4 provides and ensures inclusive and equitable quality education and promote lifelong learning opportunities for all. This global declaration on Inclusive education focuses on removing barriers to participation of all students and expects increasing learning outcomes of every student. However, Inclusive education disregards effect of vision-impairment problems of students as participation barriers on student learning outcomes. For instance, in her policy trend analysis of Challenges & opportunities for Inclusive Education in Ghana, [7] noted Negative Attitude of teachers, families & society towards inclusive education, inadequate Specific educational resources and strategies required for successful inclusive education, although Inclusive education provided equal opportunities for all children whether disabled or able. However, the real-world implications of this problem are significant when vision impaired students are bulked together with seemingly sighted students in one classroom for inclusive classroom education. This means that, the initiative for inclusive classroom education does not adequately consider vision-impairment problems of students and as peculiar hindrances to inclusive classroom education. The use of inclusive classrooms perpetuates systemic inequalities and limits contributions of vision-impaired students to socio-economic development life. Addressing this issue is crucial to fostering inclusivity and ensuring that vision impaired learners can access opportunities to thrive in academic and professional spheres [4], [5].

Relevant Literature on the Subject

Empirical studies on Assistive Technologies for Content Access indicate that assistive technologies for content access play a crucial role in facilitating equitable education for students with vision impairment by enabling independent learning and enhancing curriculum engagement. Tools such as Braille watches, audio-based devices, and screen readers are fundamental in bridging accessibility gaps and supporting students' interaction with academic materials. Research by [8] for instance, emphasizes how these technologies not only support curriculum coverage but also empower students to study autonomously, thereby fostering a sense of academic agency. [9] confirmed the positive impact of screen readers in higher education, reporting increased user satisfaction and improved access to digital content. However, their study did not consider linguistic and cultural diversity, and the study did not consider the science environment, limiting the broader applicability of their findings in multilingual educational systems. [2] identified key tools such as tactile graphics and Braille devices as instrumental in improving access, yet their research did not focus on STEM-specific educational needs, which are essential for preparing students with vision-impairment for modern scientific fields. [10] provided evidence of the value of Braille technologies by demonstrating their effectiveness in boosting literacy among primary school students. Nonetheless, their study overlooked financial and logistical barriers to implementing Braille technologies, especially in resource-constrained settings, where cost and maintenance of such devices are real challenges. [11] conducted an in-depth analysis of mobile applications and their role in promoting user autonomy and engagement among students with vision impairment. Their findings indicate that such applications enhance ability of students to navigate educational environments, improve comprehension of learning content, and engage in academic tasks without continuous reliance on human support. By offering functionalities like text-to-speech, facial recognition, object identification, and environmental descriptions, mobile apps foster independence and confidence among students, contributing to improved academic performance and psychological well-being. However, the study by [11] revealed notable limitations. Specifically, the study did not incorporate pedagogical frameworks that align app functionalities with cognitive development theories. As a result, while the apps demonstrate a capacity to improve engagement and learning outcomes, the study failed to contextualize how these improvements relate to deeper cognitive processes such as knowledge construction, memory retention, or critical thinking development. Without this pedagogical anchoring, the educational use of these applications may remain superficial or inconsistent across different learning contexts. Complementing this perspective, [12] investigated the role of audio-enhanced learning platforms in improving literacy outcomes for students with visual disabilities. Their research supports the idea that multimodal learning environments, especially those incorporating audio narratives, sound cues, and verbal instructions that enhances comprehension, particularly in subjects where visual representation dominates traditional instruction. The study affirms the importance of adaptive content delivery and shows that students with visual impairment benefit from instructional materials designed with auditory enhancements that reinforce reading and comprehension skills. However, while [12] effectively demonstrated the cognitive benefits of such tools, their analysis lacked attention to the broader policy and infrastructural contexts that influence the adoption of these technologies in real-world educational systems. This omission is particularly critical in resource-constrained environments, where the deployment of audio-enhanced platforms may be hampered by inadequate funding, insufficient training, or lack of institutional support. Without addressing these systemic barriers, the effectiveness of audio tools remains theoretical and may not translate into practical or sustainable educational interventions. [13] contributed further to the discourse by examining the integration of mobile platforms into inclusive education systems. Their study focused on how mobile technology can bridge educational gaps for students with disabilities, particularly in settings where traditional educational resources are limited or inaccessible. They identified several benefits, including increased access to Open Educational Resources (OERs), remote learning opportunities, and flexible learning schedules. Mobile platforms also facilitated real-time feedback and peer interaction, which are vital for creating inclusive and engaging learning environments. However, a key shortcoming of their study was the underestimation of the critical role educators play in ensuring the effective use of mobile technologies. While the technological infrastructure was explored in detail, the authors did not adequately address the need for teacher involvement, training, and pedagogical integration. Educators are often the mediators between technology and students, especially in inclusive classrooms where individualized instruction and support are required. Without structured professional development programs and hands-on training, teachers may lack the confidence or knowledge to effectively implement mobile applications in their instructional practices, thereby limiting their impact. Across these studies, a common thread emerges where mobile applications and learning platforms offer immense potential for transforming the educational experience of students with vision-impairment, their efficacy is contingent upon a complex interplay of pedagogical, technological, and systemic factors. One of the most prominent challenges lies in the absence of pedagogical alignment. Applications may offer advanced functionalities, but without being embedded within sound instructional design principles that includesdifferentiated instruction, scaffolding, and student-centered approaches, however their contribution to long-term learning remains limited. Furthermore, the role of educators cannot be overstated. Teachers must be empowered not only to operate these technologies but also to integrate them meaningfully into their curricula, adapting teaching methods to suit the unique needs of vision-impaired students. Another critical issue is the infrastructural and policy-related gap. The adoption of mobile learning platforms requires stable internet access, availability of devices, digital literacy, and consistent technical support. These requirements pose significant challenges in many developing or under-resourced educational contexts. For instance, students may have access to smartphones or tablets but face connectivity issues or lack the bandwidth to run apps efficiently. Educational institutions may not have formal policies governing the inclusion of assistive technologies, resulting in inconsistent practices and unequal opportunities for students with disabilities. Moreover, without dedicated funding and strategic planning, the sustainability of mobile learning initiatives remains uncertain. Evaluating interactive and immersive learning technologies unveiled how interactive and immersive learning technologies have expanded possibilities for inclusive education, particularly for students with vision-impairment. Tools including Virtual Reality (VR), Augmented Reality (AR), and 3D printingis suggested to enable students to experience, interact with, and understand abstract or visually demanding content through alternative sensory channels like touch, sound, and motion. Unlike traditional didactic teaching methods, these technologies support active engagement, allowing students to construct knowledge through multisensory, experiential learning. In the context of students with vision impairments, such technologies hold immense potential to address long-standing barriers to learning, especially in science education where visual representations often dominate instruction. [14] conducted a foundational study on the use of tactile virtual reality systems to simulate scientific concepts for students with visual impairments. Their research showed that tactile VR systems can effectively bridge the experiential gap that students with vision impairments often face in STEM subjects. Through tactile feedback and haptic interfaces, students were able to explore scientific structures and processessuch as molecular formation or anatomical modelswithout relying on visual input. These systems enabled students to manipulate virtual objects and receive real-time auditory and tactile responses, promotingexperiential learning process that enhances understanding and memory retention. Despite these promising findings, the study by [14] did not fully explore the integration of such technologies into mainstream education systems. This omission is critical, as successful integration requires systemic support, curriculum alignment, teacher training, and policy backing. Without these elements, even the most innovative technologies risk remaining in pilot phases or niche programs, never achieving the widespread adoption necessary to benefit the majority of students with vision impairments. Mónica et al. (2024) built on earlier work by evaluating effectiveness of adaptive immersive tools in enhancing understanding of complex academic topics. Their study found that students using adaptive VR and AR tools showed improved conceptual understanding and higher levels of engagement compared to those using traditional learning materials. The adaptive nature of these tools which includes adjusting difficulty levels, customizing content delivery, and providing multimodal feedback was suggested to be particularly effective for students with varying degrees of vision loss. These findings support the broader pedagogical argument that immersive technologies can accommodate diverse student profiles and foster inclusive education. However, a major limitation of the study was its lack of focus on cost-effectiveness. While adaptive immersive tools demonstrate educational value, their implementation in low-resource settings is often constrained by financial limitations, infrastructure deficits, and insufficient technical support. In many parts of the world, particularly in developing regions, the procurement of VR or AR equipment, along with the necessary software, maintenance and training, poses significant burden for schools and education authorities. The absence of a cost-benefit analysis in the study by [15] leaves a gap in understanding how such tools can be scaled and sustained in real-world economically constrained educational environments. Complementing this line of research, [16] examined the application of 3D printing technologies in creating tactile diagrams for science education among students with visual impairments. Their study demonstrated that tactile 3D models enhance comprehension of complex scientific and mathematical concepts, such as cellular structures, geometric shapes, and topographical maps. By transforming abstract and visually represented content into tangible forms, 3D printing allowed students to physically explore and manipulate objects, fostering a deeper understanding of the subject matter. The hands-on nature of 3D printed models also aligned with active learning strategies and constructivist pedagogies, further reinforcing the educational benefits of the approach. Despite these strengths, the study failed to address the scalability and logistical challenges associated with implementing 3D printing technologies in under-resourced educational contexts. Questions remain about the cost of printers and materials, the need for skilled personnel to operate the equipment, and the availability of digital resources for model creation. These practical constraints are significant, especially in rural or low-income school systems where resources are limited and priorities are often focused on more immediate educational needs such as textbooks, teacher salaries, and infrastructure.

The overarching theme across these studies is that interactive and immersive technologies offer powerful tools for advancing inclusive education, yet their widespread adoption and implementation remain hindered by practical challenges. One such challenge is the readiness of educational institutions to incorporate these technologies into the standard curriculum. This study explores how these tools contribute to advancing science education for students with vision-impairment in light of these limitations. Because, future efforts must prioritize a multi-dimensional approach to integrating mobile applications and learning platforms into education for students with vision impairment. Collectively, these findings highlight the transformative potential of assistive technologies, while pointing to critical gaps in cost-effectiveness, cultural adaptation, and subject-specific integration that needs to be addressed to maximize their impacts in inclusive education. [17] explored the effects of AI-enhanced screen readers on academic performance of students and found that such systems improved comprehension, speed of information processing, and user ability to navigate academic content independently. The study underscored how these tools empower students by reducing reliance on human aides or simplified content versions, thus promoting equity in access to complex instructional materials. Beyond screen readers, AI-based smart assistants such as Google Assistant, Siri, and Alexa are increasingly being used in educational contexts. These tools allow students to interact with their learning environment through voice commands, access online resources, manage their schedules, and receive instant feedback. With the integration of Natural Language Processing (NLP), these assistants can understand varied linguistic inputs and offer context-aware responses. For students with vision-impairment, this functionality is critical in facilitating seamless interaction with digital content and learning platforms. In classrooms and at home, smart assistants serve as personalized study partners, helping with spelling, calculations, content recall, and even test preparation. By interpreting spoken language and generating real-time output, they break down barriers to learning that arise from inaccessible content formats. Another promising application of Machine Learning is in the domain of Adaptive Learning Technologies. These systems analyze user behavior, preferences, and performance data to adjust the difficulty level, presentation style, and pacing of instructional content. For vision-impaired students, this means that digital platforms can provide customized pathways through course materials, offering auditory, tactile, or simplified versions of content as needed. Adaptive learning tools can monitor comprehension levels and dynamically offer scaffolding or remediation, thereby ensuring that students do not fall behind due to accessibility issues. This form of personalization is essential in inclusive education, where one-size-fits-all approaches often fail to meet the diverse needs of students. Moreover, ML algorithms have been applied to image recognition and object detection systems that provide spatial awareness for students navigating physical and digital environments. Mobile applications equipped with AI-powered cameras can identify objects, text, facial expressions, and environmental cues, describing them audibly to users in real time. These tools have proven especially useful in STEM education, where understanding visual data which includes graphs, chemical structures, or spatial relationshipsis often critical. By translating these visuals into spoken or tactile forms, AI bridges a significant accessibility gap and allows students with vision impairment to engage more fully with complex academic subjects. Despite these advantages, the implementation of AI and ML technologies in education raises significant ethical and practical challenges that must be critically examined. One of the primary concerns is data privacy. Many AI tools rely on continuous data collection to improve their algorithms and provide personalized services. This includes gathering information about users' behavior, preferences, and even biometric data such as voice patterns or location information. For students with vision impairment, especially minors, the collection and storage of such sensitive data pose serious risks if not properly managed. There is a growing concern over who owns the data, how it is protected, and whether students and their guardians are fully informed about the extent of data use. Educational institutions must establish clear policies and work closely with technology providers to ensure compliance with data protection laws and ethical standards. Closely related to privacy is the issue of algorithmic bias. Machine learning systems are only as unbiased as the data on which they are trained. If AI tools are trained on datasets that do not adequately represent users with disabilitiesor worse, exclude them entirely in our systems, the resulting systems may produce skewed outputs that reinforce existing inequalities. For example, voice recognition systems may fail to understand users with atypical speech patterns, and image recognition tools may not accurately describe objects that are commonly used by blind individuals, but rare in general datasets. [17] acknowledged this limitation and called for more inclusive datasets and participatory design processes that involve users with vision- impairment from the early stages of technology development. Assistive tools designed for collaboration which includes audio-based communication systems, shared tactile models, screen reader-compatible online platforms, and speech-to-text or text-to-speech software that make it possible for students with vision-impairment to contribute meaningfully to group activities. [18] addressed the importance of using shared tactile models and audio-based systems to support collaboration among students with vision impairments. These tactile models, which include physical representations of diagrams, maps, or scientific apparatus, allow students to explore and interpret shared content simultaneously with their peers. This form of hands-on, collaborative engagement is critical in subjects that are traditionally visual, such as science and geography. Similarly, audio-based platforms which includesvoice messaging applications or audio-conferencing toolsis suggested to allow students to participate in real-time discussions, exchange ideas, and give feedback without relying on visual interfaces. While the findings of [18] affirmed the importance of tactile and audio aids in collaborative settings, their study did not sufficiently address the integration of these tools with modern digital collaborative platforms. In contemporary educational environments, especially post-pandemic, digital Learning Management Systems (LMS) such as Google Classroom, Microsoft Teams, and Moodle have become the norm. The failure to examine how tactile and auditory tools can be embedded into these digital ecosystems represents a critical gap in literature and practice. Modern collaborative learning frequently occurs in hybrid or fully online contexts, where students interact through shared documents, video conferencing, discussion forums, and collaborative whiteboards. Therefore, assistive technologies must also evolve to support access to these virtual spaces. Screen readers, for example, must be compatible with shared digital documents and collaborative editing tools. Students should be able to contribute text, track changes, and participate in discussions through accessible formats. Similarly, real-time captioning and audio description tools can make video-based collaboration more accessible. However, these digital tools must be designed with universal design principles in mind to ensure they are not only technically accessible but also functionally effective for vision-impaired users. [19] contributed to the discourse by highlighting the emergence of collaborative technologies that enable students with vision impairments to participate in group projects. Their study acknowledged tools such as accessible chat systems, shared auditory feedback mechanisms, and peer-based learning apps tailored for the vision impaired. These tools have the potential to enhance not only academic engagement but also social interaction, which is often limited for students with disabilities. By fostering dialogue, peer feedback, and joint problem-solving, these technologies help combat the isolation that many students with vision-impairment experience in mainstream classrooms. Nevertheless, the study by [19] did not sufficiently emphasize the critical role of teacher facilitation in the success of collaborative learning initiatives involving students with disabilities. Teacher facilitation is indispensable in ensuring that collaborative learning tools are used effectively and inclusively. Educators are the ones who select tools, design learning activities, set expectations, and monitor group dynamics. For assistive technologies to support collaborative learning meaningfully, teachers must be trained not only in the technical use of these tools but also in inclusive pedagogical strategies. This includes knowing how to pair students effectively, how to scaffold group interactions, and how to mediate challenges that may arise from communication barriers or unequal participation. When educators are unaware of how to facilitate collaborative work with assistive technologies, there is a risk that students with vision impairment will be side-lined, relegated to peripheral roles, or completely excluded from group processes. Furthermore, assistive technologies for collaboration must support not only synchronous (real-time) interactions but also asynchronous modes of engagement. This flexibility is crucial for accommodating the varied paces and preferences of students with disabilities. Tools that allow students to record voice notes, leave audio comments on documents, or contribute through accessible shared repositories make collaboration more inclusive and manageable. These features help ensure that students with vision impairment are not pressured to keep up with fast-paced, visually mediated group work but can instead engage meaningfully on their own terms and timelines. Another key consideration is the need for interoperability among different assistive technologies. In many cases, students rely on a combination of tools, such as a screen reader for navigation, a Braille display for content output, and an audio device for communication. If collaborative learning platforms are not compatible with these assistive tools, the user experience becomes fragmented and frustrating. This technical incompatibility not only hampers participation but can also diminish students' confidence and willingness to engage in group work. Assistive Technology for Collaborative Learning revealsthat, Collaborative learning tools facilitate group interactions and enhance peer-based learning experiences for students with vision impairment. [18] discussed the use of shared tactile models and audio-based platforms to support collaboration in classrooms. However, their findings did not address the potential for integrating these tools with digital collaborative platforms, which are increasingly common in modern education. [19] highlighted collaborative technologies that enable students with vision impairment to engage in group projects effectively. Despite these advancements, their study overlooked the importance of teacher facilitation in maximizing the benefits of these tools. In sum, assistive technology for collaborative learning represents a critical dimension of inclusive education. Assessment of Tools for Specialized Learning Needs indicates that, Specialized tools, such as math-specific software and science kits, address the unique challenges faced by students with vision impairment in STEM fields. [20] discussed assistive technologies like MATHVIS for game-based learning in mathematics, highlighting their role in making abstract concepts more accessible [20]. However, the research did not examine the scalability of such tools across different educational levels.

[21] explored the use of electronic Braille displays in teaching chemistry and physics, demonstrating significant improvements in comprehension. While effective, their study lacked an analysis of long-term outcomes, such as career readiness in STEM fields. The importance of tools for specialized learning needs lies in their ability to tailor the educational experience to the unique challenges posed by vision impairment, especially where general-purpose assistive technologies might fall short. While screen readers and audio tools are invaluable for accessing textual content, they may not adequately convey spatial relationships, symbolic logic, or data representations required in mathematics and science. Thus, there is a need for bespoke technologies that includes math-specific software, adaptive science kits, and subject-targeted tactile interfacesthat provide more effective solutions. These tools do not merely substitute inaccessible materials; they reconstruct the learning environment in a way that enhances conceptual clarity, boosts confidence, and fosters inclusion. [20] emphasized the significance of domain-specific tools through his discussion of MATHVIS, a game-based learning application developed for students with vision impairments studying mathematics. MATHVIS integrates tactile, auditory, and gamified elements to make abstract mathematical concepts more intuitive. For instance, rather than visually identifying geometric shapes or number patterns, students can engage with auditory feedback or tactile models that convey the same information in an accessible form. Ali's research underscores how tailored interventions can transform complex cognitive tasks into manageable learning experiences for students who are often excluded from active engagement with STEM content. These interventions also demonstrate how the use of gamification can enhance motivation and reduce the stigma sometimes associated with disability in the classroom. While [20]'s study provided valuable insights into the design and effectiveness of MATHVIS, it did not fully explore the scalability of such innovations across varying educational levels and contexts. Tools developed for primary or secondary school may not meet the advanced demands of tertiary education or vocational training in STEM. Moreover, tools created for one linguistic or cultural setting may not translate effectively to others, highlighting the need for contextual adaptability. A key limitation of the current landscape of specialized learning tools is that many are developed as isolated projects, often reliant on grant funding or academic research initiatives. As a result, they lack pathways to broader adoption, integration into national curricula, or sustainability in the face of evolving technological ecosystems. Addressing this issue requires greater collaboration between developers, educators, and policymakers to ensure that specialized tools are designed not only for efficacy but also for long-term viability and wide accessibility. In a related study, [21] investigated the use of electronic Braille displays for delivering science educationspecifically in chemistry and physicsfor students with vision impairment. These displays convert textual and symbolic scientific information into tactile Braille, allowing students to read formulas, chemical equations, and scientific descriptions independently. The findings showed that students using these devices demonstrated higher comprehension levels and greater engagement with the subject matter compared to peers using traditional paper-based Braille or audio-only resources. This supports the argument that subject-specific assistive technologies can enhance learning outcomes, particularly when they offer real-time interactivity and are tailored to the cognitive style of vision-impaired students. Despite these positive outcomes, the study by [21] did not evaluate the long-term implications of such interventions. While improved comprehension in the short term is critical, it is equally important to assess how these tools influence career readiness, long-term academic persistence, and participation in STEM pathways beyond secondary school. For students with vision impairment, access to STEM education must be more than passing exams, however it must serve as a foundation for equitable participation in higher education and

the workforce. [22] underscore the importance of incorporating assistive technologies into classroom instruction to foster inclusive education for vision-impaired students. Their study indicates that inclusive environmentswhere assistive tools are embedded in daily teaching practicesresult in improved learning outcomes, higher levels of participation, and enhanced social interaction for students with vision impairment. These environments encourage peer collaboration and normalize the use of assistive technologies, reducing the stigma often associated with disability. By making tools such as screen readers, audio-based applications, tactile graphics, and speech-to-text systems available and integrated into classroom routines, educators promote a culture of equity. However, while findings by [22] affirm the benefits of inclusive teaching practices, the study does not sufficiently address the systemic challenges involved in integrating assistive technologies into existing educational infrastructures. Many schools lack the necessary technical resources, funding, or policy support to fully adopt and maintain assistive solutions, especially in under-resourced contexts. These practical limitations must be considered to ensure that inclusive practices can move beyond isolated examples and be scaled systemically. The cognitive dimension of inclusivity is another critical factor, especially in STEM education where complex concepts often require deep processing and abstract reasoning. [23] demonstrated how multimedia tools are suggested to be designed to reduce cognitive load for enhancing the learning experiences of students with vision impairment. By simplifying and chunking information into audio, tactile, or simplified verbal formats, these tools align with principles from cognitive load theory and make it easier for students to understand difficult scientific topics such as cellular biology or chemical processes. This approach not only supports comprehension but also promotes student independence and confidence. Nonetheless, the study by [23], while theoretically sound, underemphasized the value of collaborative learning during science experiments which is suggested a core component of skill development in STEM education. Vision-impaired students benefit from peer interaction during hands-on activities, which helps them gain practical experience, develop social skills, and build teamwork competencies that are essential for both academic and professional success. Therefore, inclusivity in this context must extend beyond cognitive facilitation to include structured opportunities for interpersonal engagement. The role of teachers in fostering inclusive learning environments cannot be overstated. [24] provide strong evidence that teacher training is a cornerstone of effective inclusion for students with disabilities, particularly those with vision impairment. Educators who are well-versed in the use and application of assistive technologies are more likely to design lessons that are accessible, interactive, and sensitive to the diverse needs of students. Such teachers can adapt instructional materials in real time, facilitate meaningful group work, and offer individualized support where necessary. They also serve as advocates for inclusive practices within their institutions, influencing school culture and policy. However, the analysis falls short in considering the long-term sustainability of teacher training programs. One-off workshops or temporary interventions are unlikely to yield lasting change unless they are part of a broader professional development framework supported by continuous mentoring, institutional policy, and access to evolving technological resources. Without ongoing support and renewal, educators may struggle to keep pace with advancements in assistive technologies, and the benefits of initial training may quickly diminish. In sum, promoting inclusivity through assistive technologies in science and collectively STEM education for students with vision-impairment is a multifaceted endeavor. It requires not only the provision of accessible tools but also the restructuring of classroom practices, the reduction of cognitive barriers, and the empowerment of educators through sustained professional development. While current research, such as that by [22] &

[23] provides valuable insights into the benefits of inclusive technologies, it also reveals significant gaps that must be addressed to translate these benefits into systemic change. Issues such as infrastructural limitations, insufficient focus on collaborative learning, and the sustainability of teacher training highlight the need for comprehensive strategies that encompass policy, practice, and pedagogy. Only by addressing these interrelated factors can assistive technologies realize their full potential in promoting equity and inclusion for vision-impaired students in STEM education. [25] explored the role of mobile applications that incorporate object detection and audio feedback, highlighting how these features increased user engagement and encouraged independent exploration among students with vision impairment. By allowing students to interact with their environment and access information autonomously, such tools foster a sense of agency and motivation, both of which are vital to meaningful engagement. Furthermore, the interactive nature of these applications, which combines auditory and tactile stimuli, aligns well with the sensory strengths of vision-impaired students. However, the study by [25] fell short in addressing the cultural and linguistic diversity of its users. Educational tools that are designed primarily in dominant global languages or that reflect specific cultural assumptions may not be equally effective in diverse contexts, particularly in multilingual or resource-constrained regions. As such, the generalizability of their findings is limited. For engagement strategies to be truly inclusive and sustainable, it is necessary to ensure that learning tools are not only accessible in technical terms but also adaptable to the cultural and linguistic contexts of their users. In a complementary line of research, [26] investigated the impact of personalized learning strategies, particularly those that tailor pedagogical approaches to the unique needs and learning styles of individual students. Her study found that adaptive methods, when aligned with students' preferences and challenges, greatly improved engagement and learning outcomes in science education for students with vision impairment. This is consistent with a broader pedagogical shift toward student-centered education, where students are active participants in shaping their learning trajectories. Personalized learning is especially important for vision-impaired students who may experience content differently and benefit from varied modes of delivery, such as audio narration, tactile input, or interactive simulations. Despite the positive findings, the research by [26) did not address the scalability of these strategies in larger classroom environments. Personalized instruction, while ideal in theory, poses practical challenges in typical school settings where high student-teacher ratios and limited resources make individualized attention difficult. Without scalable models or institutional support, the application of personalized learning remains confined to well-resourced or experimental settings, limiting its potential for broader educational reform. Further enriching this discourse, [27] examined the integration of inquiry-based learning approaches using tactile and auditory tools. His research highlighted how active, exploratory learning methodologies enabled students with vision impairment to construct deeper conceptual understandings, particularly in STEM subjects that traditionally rely heavily on visual representations. By encouraging students to ask questions, manipulate materials, and engage in hands-on investigation, inquiry-based methods promote intrinsic motivation and cognitive engagement. For students with visual impairments, tactile learning kits, audio-guided experiments, and collaborative discovery activities provide alternative pathways to understanding complex phenomena. However, the study by [27] did not consider importance of embedding these methods into national and regional curricula. Institutionalizing such pedagogical innovations requires alignment with educational standards, teacher training programs, and curriculum development frameworks. Without formal integration, inquiry-based practices remain optional or marginal, adopted inconsistently across schools and districts, and vulnerable to being deprioritized in

standardized assessment-driven systems. In sum, the use of interactive learning platforms and adaptive teaching methods has shown significant promise in improving engagement among students with vision impairment. These tools and strategies support independence, deepen conceptual understanding, and make learning more inclusive. However, realizing their full potential requires addressing important limitations. Culturally and linguistically diverse user needs must be considered to enhance the relevance and applicability of educational technologies across different contexts. Moreover, scalability remains a challenge for personalized learning approaches, and without systemic support, such methods may not reach the majority of students. Lastly, for engagement-driven pedagogies to take root and flourish, they must be incorporated into official curricula and supported by policy, infrastructure, and teacher professional development. Only through these measures can interactive learning truly serve as a transformative force in the education of vision-impaired students. The emphasis on usefulness of independent learning is that, independent learning represents a cornerstone of educational empowerment, especially for students with vision impairment, who often face barriers that limit their access to instructional materials and autonomous participation in learning environments. The rise of smart technologies that suggests to range from wearable devices and digital learning platforms to accessible content delivery toolshas advanced the potential for these students to engage with curricula, navigate school environments, and participate in collaborative activities without constant assistance. These tools not only enhance academic engagement but also nurture confidence, self-reliance, and lifelong learning skills. Nevertheless, despite the growing evidence supporting the efficacy of such technologies, there are critical limitations in terms of affordability, sustainability, and long-term academic outcomes that warrant further scrutiny. [28] provide valuable insights into how smart glasses designed with features such as object recognition, text-to-speech, and spatial awareness can empower vision-impaired students in STEM education. These devices support navigation in physical spaces such as laboratories and classrooms, allowing students to participate in experiments and access instructional content independently. The sense of autonomy afforded by such technology promotes not only functional independence but also psychological empowerment, which can have positive implications for motivation and academic identity. However, the study by [28]) fails to adequately address the affordability and accessibility of these technologies, especially in low-income or resource-constrained educational settings. The high cost of smart glasses, limited distribution, and maintenance challenges present significant obstacles to widespread adoption. Without mechanisms for cost reduction or government subsidies, the use of such technologies may remain limited to elite or experimental institutions, thereby reinforcing existing inequalities in access to education for vision-impaired students. Complementing this line of inquiry, [21] investigated the use of electronic Braille displays and scanning software as tools for facilitating independent curriculum engagement among students with visual impairments. These tools allow students to read, edit, and organize digital content in formats that are accessible and customizable to their sensory preferences. The study found that such technologies increased students' ability to engage with reading materials and classroom assignments without direct support, fostering confidence and a greater sense of academic ownership. While these findings affirm the value of assistive technologies in promoting independent learning, the study did not evaluate the long-term educational or professional impact of these tools. Questions remain about whether the use of Braille displays and scanning software leads to measurable improvements in academic performance, retention, or readiness for STEM careers. A longitudinal perspective is crucial to understanding how sustained access to such tools influences educational outcomes over time. Moreover, issues such as device durability, technical training for users, and the availability of compatible content must be considered to fully assess their viability as long-term solutions. [19] add another dimension to the discourse by examining collaborative learning tools and their role in fostering independence through social interaction. Their research shows that when students with vision impairment are included in group projects using accessible platformssuch as audio-based collaboration tools or shared tactile learning materials that contribute meaningfully and navigate peer-based tasks independently. This reinforces not only individual learning but also critical skills like communication, leadership, and problem-solving, which are essential for success in both academic and professional environments. However, the study by [19] falls short in its exploration of the infrastructural and technological requirements for deploying such collaborative tools in under-resourced schools. In many educational settings, especially in rural or low-income areas, the digital infrastructure necessary to support accessible collaboration that includes high-speed internet, compatible hardware, and trained support staff is suggested to be either inadequate or entirely absent. Without addressing these systemic challenges, the potential of collaborative tools to promote independent learning remains unrealized for the majority of vision-impaired students. In sum, the pursuit of independent learning for students with vision impairment is intricately tied to the availability, affordability, and effective implementation of smart technologies. Devices like smart glasses, Braille displays, and accessible collaboration platforms offer promising pathways to greater autonomy and engagement in education. However, to truly harness their potential, it is necessary to address practical concerns such as cost, infrastructural requirements, and long-term impact. Future research must adopt a more holistic approach that not only evaluates the immediate benefits of these tools but also considers their integration into mainstream curricula, sustainability in low-resource contexts, and alignment with broader educational equity goals. By doing so, stakeholders can ensure that the shift toward independent learning is inclusive, impactful, and enduring. To provide enhanced accessibility to educational materials, it has become quite evident that, the evolution of adaptive technologies has transformed the educational landscape for students with vision-impairment, particularly in enhancing their access to learning materials. Tools such as Braille systems, screen readers, audiobooks, and more recently, artificial intelligence (AI)-driven applications, have opened new pathways for inclusive education. These tools not only enable students to interact with educational content that was previously inaccessible but also support active engagement with complex learning resources across various subjects. Despite their promise, however, the implementation of these tools often encounters several contextual, ethical, and technical barriers that hinder their widespread effectiveness, especially in resource-constrained settings. [29] explored how adaptive tools such as Braille displays, audiobooks, and screen readers enhance access to educational materials for vision-impaired students. Their findings affirmed the critical role of such tools in fostering content interaction, improving comprehension, and enabling personalized learning. With these technologies, students are able to navigate textbooks, digital documents, and online educational platforms more independently, thus reducing reliance on sighted assistance and encouraging autonomous learning. This empowerment fosters academic inclusion and contributes to students' overall confidence and academic identity. However, [29] did not fully consider the infrastructure-related limitations in low-resource environments. Many rural and underserved schools lack the financial capacity, internet connectivity, and technical personnel needed to procure, implement, and maintain these adaptive tools. As a result, despite their potential to improve educational access, such technologies remain inaccessible to the very populations that could benefit most from them. Artificial Intelligence (AI) applications have further expanded the frontiers of accessibility for vision-impaired students. Systems like "PeopleLens" provide real-time descriptions of surroundings, facial recognition, and object identification, thereby supporting a more immersive and dynamic educational experience [17]. These innovations offer significant advantages in terms of real-time learning feedback, environmental awareness, and content contextualization—features that are particularly valuable in interactive and experiential learning settings. However, while [17] highlight the technological advancements these tools bring, their study falls short in addressing the ethical implications surrounding the deployment of AI in educational contexts. Concerns around data privacy, algorithmic transparency, and the risk of embedded biases in machine learning algorithms are increasingly being raised by scholars and educators alike. Without regulatory frameworks or ethical guidelines, there is a risk that these technologies could unintentionally reinforce inequities or compromise student privacy. Addressing these concerns is essential not only for the responsible use of AI in education but also for fostering trust and inclusivity in learning environments. Moreover, the integration of digital platforms that interface with academic databases and learning management systems represents another critical dimension of accessibility. [30] discussed the value of such platforms in enabling students with vision impairment to search, retrieve, and utilize educational content with minimal difficulty. By offering accessible user interfaces, text-to-speech capabilities, and customizable display settings, these tools streamline access to a wide array of academic resources. This functionality enhances the ability of students to engage in research, complete assignments, and participate in knowledge-sharing communities. Nevertheless, the study did not sufficiently examine the adaptability of these tools across diverse educational contexts, particularly in rural or underfunded institutions. Many of these platforms assume a level of digital infrastructure and literacy that may not exist uniformly across regions. Without efforts to localize content, adapt interfaces to local languages, and ensure compatibility with low-bandwidth environments, the effectiveness of such digital tools remains limited. In sum, adaptive technologies have revolutionized access to educational materials for students with vision impairment, supporting greater independence, engagement, and academic success. Braille systems, screen readers, audiobooks, AI applications, and digital learning platforms are central to promoting inclusivity in education. However, for these tools to be fully effective, implementation strategies must consider infrastructural constraints, ethical concerns, and contextual adaptability. Addressing these gaps requires coordinated efforts from policymakers, educational institutions, technology developers, and communities. Only through such holistic and inclusive approaches can the promise of adaptive technology be realized for all vision-impaired students, regardless of their geographical or socio-economic background.

Supporting Collaboration in Science Education brings to the fore that, collaboration is a central pedagogical strategy in science education, fostering essential skills such as critical thinking, teamwork, problem-solving, and communication. For students with vision impairment, the ability to fully participate in collaborative learning activities, especially in science subjects that rely heavily on experimentation and visualization, is essential for inclusive and equitable education. Assistive technologies and inclusive learning platforms have emerged as critical tools for bridging the participation gap, enabling vision-impaired students to engage meaningfully in group-based scientific inquiry and laboratory work. Despite these advancements, challenges remain in ensuring that these tools are fully accessible, adaptable, and effectively implemented, particularly in diverse and under-resourced educational contexts. Tactile science kits and virtual laboratories represent significant technological innovations that support collaborative learning for vision-impaired students. These tools allow students to engage with scientific materials through sensory modalities beyond sight—particularly touch and sound—making abstract scientific phenomena more tangible and accessible. For instance, tactile models of molecules or anatomical systems can be used collaboratively in group settings, allowing all students to interact with the same physical learning object while discussing scientific concepts. Similarly, virtual laboratories simulate real-world scientific environments, enabling students to conduct experiments that might otherwise be inaccessible due to safety, cost, or logistical barriers. These virtual environments are particularly valuable in inclusive classrooms where students with varying abilities work together on science-based tasks. [31] provided valuable insights into the role of virtual laboratories in enhancing collaborative learning in science education. Their study demonstrated that virtual labs enable students to simulate complex scientific experiments, promoting engagement, teamwork, and deeper conceptual understanding. Vision-impaired students, when paired with sighted peers or provided with accessible interface features like audio guidance, can actively participate in collaborative investigations. This not only enhances their scientific literacy but also builds social-emotional competencies through peer interaction. However, a notable limitation of the research by [31] was that it lacked focus on accessibility of these virtual lab tools for students with severe vision-impairment. Many virtual labs rely heavily on graphical interfaces, visual simulations, and onscreen cues, which can exclude students who rely on auditory or tactile input. Without proper interface adaptations—such as screen reader compatibility, auditory feedback, or haptic responses—these tools risk becoming yet another barrier rather than facilitator of inclusion. Interactive platforms like Labster have also proven effective in promoting collaborative science learning. These platforms create immersive, simulated lab environments where students can work together to solve scientific problems. [32] found that students with vision impairment who engaged with Labster in mixed-ability groups experienced improved confidence, participation, and comprehension of complex scientific concepts. The collaborative nature of the platform fosters peer learning, allowing vision-impaired students to contribute to discussions, analyses data, and interpret results alongside their sighted peers. This interaction not only boosts academic outcomes but also promotes social inclusion and mutual respect within diverse classrooms. However, the findings by [32], while promising, did not sufficiently address the role of teacher facilitation in optimizing the use of these platforms. Teacher involvement is critical in scaffolding the collaborative experience, ensuring that the technological tools are used effectively, and that all students—regardless of ability—are engaged and supported. Educators play a central role in structuring group activities, mediating discussions, resolving accessibility issues, and fostering an inclusive classroom culture. Without adequate training and support, teachers may struggle to integrate collaborative tools in ways that fully include vision-impaired students. Therefore, future research and implementation strategies must prioritize professional development for teachers, equipping them with the skills and knowledge to manage inclusive group learning environments and to utilize collaborative technologies to their fullest potential. In sum, supporting collaboration in science education for students with vision impairment requires more than just access to technology. It demands the development and implementation of accessible tools that includes tactile science kits and virtual laboratories designed with diverse students in mind. Furthermore, effective teacher facilitation and inclusive pedagogical strategies are essential for ensuring that these tools lead to meaningful educational experiences. While studies like those by [31] and colleagues affirm the potential of collaborative learning platforms, their limitations underscore the need for comprehensive, inclusive design approaches and robust educator support systems. Only then can collaborative science education truly become a vehicle for empowerment and inclusion for all students, regardless of visual ability. Bridging the Digital Divide in STEM Education leads to addressing the digital divide as critical for ensuring that students with vision-impairment in underserved communities can benefit from technological advancements. UNESCO (2024) highlighted that, providing affordable and localized assistive technologies can improve participation in STEM education in low-income regions. However, their report lacked specific strategies for scaling these technologies sustainably. Analysis of Assistive Technologies for Content Access indicate that, various tools, such as braille watches and audio-based devices, enhance curriculum coverage and encourage independent learning [8]. This software is central to enabling students with vision impairment to access educational content. [9] conducted a mixed-methods study on the effectiveness of screen readers in higher education, showing improved accessibility and user satisfaction. However, the study overlooked the importance of tailoring screen readers for multilingual and multicultural environments, limiting its applicability in global settings. Similarly, [2] identified tactile graphics, screen readers, and Braille devices as essential tools for enhancing educational access. Their research highlights the utility of these tools in enabling students to interact with educational content. However, the study neglected special needs education in STEM-specific contexts, which are critical for advancing science and technology education. [10] further emphasized the role of Braille devices in enhancing literacy among primary school students. While their findings demonstrated improved literacy outcomes, the research failed to address the high cost and maintenance of Braille devices, which remain barriers in low-income regions. Further exploration of cost-effective alternatives is necessary. Analysis of impact of Mobile Applications and Learning Platforms on user autonomy and engagement revealed that, Mobile Applications such as Seeing AI and Be My Eyes have gained prominence for their role in supporting students with vision-impairment. [11] analyzed the impact of mobile apps on user autonomy and engagement. While the study revealed significant improvements in learning outcomes, it neglected to integrate pedagogical frameworks that align app functionalities with cognitive development among learners, which could enhance their efficacy. [12] explored how audio-enhanced learning platforms contribute to literacy improvement for vision -impaired learners. Their work demonstrates the significance of multimodal tools in education. However, it failed to address the broader educational policy implications of adopting such technologies, limiting its practical application in resource-constrained environments. [13] examined inclusive education through mobile platforms, highlighting their potential in bridging educational gaps. However, the study underestimated the role of educators in facilitating the effective use of mobile apps, underscoring the need for teacher training programs as part of implementation strategies. Interactive and Immersive Learning Technologies, such as Virtual Reality (VR) and Augmented Reality (AR), offer immersive learning experiences tailored to students with vision impairment. [14] examined tactile VR systems designed to simulate scientific concepts, demonstrating their potential to bridge gaps in experiential learning. However, their research did not fully explore the integration of these technologies into mainstream education systems. [15] evaluated adaptive immersive tools, highlighting their effectiveness in enhancing understanding of complex topics. While promising, the study lacked a focus on cost-effectiveness, which is crucial for implementation in low-resource settings. [16] studied the use of 3D printing for tactile diagrams in science education, demonstrating enhanced comprehension of complex concepts. Despite its merits, the research did not address the scalability of 3D printing technologies in under-resourced schools, pointing to a critical practical gap. A critical look at the need for Artificial Intelligence and Machine Learning Tools, suggests that, Artificial Intelligence (AI) and Machine Learning (ML) technologies have expanded the possibilities for learning among students with vision impairment. Systems like AI-driven screen readers and smart assistants provide real-time descriptions and navigation support, enhancing independence and academic performance [17]. However, the ethical implications of data privacy and algorithmic bias in these technologies require further exploration. Concluding, the empirical literature underscores the transformative potential of assistive technologies in advancing science education for vision-impaired students. These tools are expected to enhance accessibility, improve engagement, and promote inclusivity, enabling students to participate actively in STEM education. However, significant challenges remain, including affordability, scalability, and contextual adaptability. Addressing these gaps requires interdisciplinary collaboration, robust policy frameworks, and increased investment in teacher training and infrastructure development. Hence, the reviewed literature demonstrates significant advancements in technology-enhanced learning tools for students with vision-impairment. These tools, ranging from tactile graphics and screen readers to AI-driven applications and immersive learning technologies, have shown transformative potential. Yet challenges remain, including cultural and contextual gaps, insufficient integration of pedagogical frameworks, and barriers in implementation. Addressing these issues requires interdisciplinary collaboration, increased stakeholder involvement, and inclusive methodologies to ensure equitable access to education for vision -impaired students. Without longitudinal data, it is difficult to ascertain whether early advantages conferred by tools like electronic Braille displays translate into sustainable academic and professional outcomes. These tools bridge the gap between individual accessibility and collective engagement, enabling students with vision impairment to participate fully in the social and intellectual life of the classroom. The study examines specific technology enhancement tools that can facilitate science learning in inclusive classrooms for students with vision impairment.

The Proposed Approach or Solution

Analysis of Mobile Applications and Learning Platforms suggests that mobile applications and digital learning platforms have emerged as transformative tools for enhancing educational experiences of students with vision-impairment, offering innovative ways to facilitate access to instructional content, promote autonomy, and support academic engagement. In recent years, applications such as Seeing AI, Be My Eyes, and other assistive mobile technologies have become central in advancing inclusive education by enabling real-time support, environmental interpretation, and personalized content delivery. These tools employ a combination of artificial intelligence, optical character recognition, and voice feedback systems to help students with vision-impairment interact with their surroundings and learning materials more independently. Most current uses of VR, AR, and 3D printing in education for students with vision impairment occur in isolated pilot projects or specialized schools, limiting their reach and long-term impact. To move beyond isolated successes, there must be a coordinated effort to develop national or regional strategies that include immersive technologies in inclusive education plans. This would require collaboration among policymakers, educators, technologists, and disability advocates to ensure that these tools are not only accessible but also pedagogically aligned and sustainably funded. Another significant factor is the need for teacher preparedness. Teachers play a central role in the successful integration of technology into classrooms, yet many lacks the training and confidence to use advanced technologies like VR and 3D printing effectively. Professional development programs tailored to inclusive education and immersive technologies are essential to ensure that teachers understand how to incorporate these tools into their lesson plans, adjust them for individual student needs, and evaluate their educational impact. Without such support, even well-intentioned efforts to implement immersive learning tools can fall short due to misuse, underuse, or resistance from educators. In addition to pedagogical and institutional factors, there are broader systemic issues related to infrastructure and digital equity. Immersive learning tools require stable electricity, internet connectivity, hardware maintenance, and access to digital resources—all of which can be lacking in marginalized educational settings. These infrastructural gaps exacerbate existing inequalities and risk excluding the very students that inclusive education seeks to support. Thus, any initiative to deploy interactive and immersive technologies must also address foundational infrastructure needs and ensure that all students, regardless of socioeconomic background or geographic location, can benefit from technological advancements. Moreover, there is a need for further empirical research that moves beyond technical feasibility to explore long-term educational outcomes associated with immersive learning tools. The reason is, most current studies focus on immediate gains in engagement or comprehension, but few examine whether these improvements lead to sustained academic success, better employment outcomes, or increased social inclusion. Longitudinal studies could provide valuable insights into how immersive technologies influence the educational trajectories and life opportunities of students with vision impairments. Finally, cultural and linguistic adaptability must also be considered in the development of immersive learning tools. First, app developers and educational content creators should work collaboratively with pedagogical experts and special educators to ensure that tools are grounded in research-based learning theories. This would allow applications to move beyond mere accessibility and become active agents of cognitive development. Second, educational policymakers should recognize the integral role of teacher training in the successful deployment of these tools. Building educator capacity through ongoing professional development and mentorship will increase the likelihood that mobile technologies are used effectively and inclusively. Finally, the implementation of mobile learning technologies must be accompanied by robust infrastructure planning and equitable access initiatives, ensuring that no student is left behind due to geographical or economic disadvantages. Many current VR and AR applications are designed with Western educational paradigms and may not be suitable for students in diverse cultural or linguistic contexts. Developers and educators must collaborate to ensure that tools are adaptable, inclusive, and responsive to the varied needs of students around the world. This includes designing content in multiple languages, incorporating culturally relevant examples, and allowing for customization based on local curricula and learning objectives. This means that, mobile applications and digital learning platforms represent powerful avenues for supporting educational needs of students with vision-impairment. This is because, they offer the promise of autonomy, flexibility, and enriched content access, all of which are essential for inclusive education. However, their full potential can only be realized through thoughtful integration that considers pedagogical alignment, educator engagement, and systemic support. Without these foundational elements, the adoption of mobile technologies may remain uneven, and their benefits unrealized for the very students they are intended to serve. This points to interactive and immersive learning technologies such as VR, AR, and 3D printing which offer transformative possibilities for inclusive education, particularly for students with vision impairment. These tools provide novel ways to experience, understand, and engage with educational content, bridging gaps that have long excluded students with visual disabilities from full participation in science and technology education. However, the successful integration of these tools into mainstream education requires attention to pedagogical alignment, teacher training, infrastructural readiness, policy support, and cost-effectiveness. Without addressing these critical factors, the promise of immersive learning will remain unrealized for many students. Therefore, a multi-layered approach is essential—one that combines technological innovation with systemic reform, ensuring that immersive learning becomes not just a possibility for a few, but a reality for all. Further consideration of Artificial Intelligence and Machine Learning Tools reveal that, Artificial Intelligence (AI) and Machine Learning (ML) technologies have begun to revolutionize educational experiences for students with vision-impairment by offering personalized, intelligent, and responsive tools that enhance access, engagement, and independence. These technologies allow for real-time processing of visual and textual information, provide voice-based navigation, and support adaptive learning tailored to individual needs. Their introduction into educational settings marks a significant shift from static assistive tools to dynamic systems capable of interpreting and responding to complex user inputs. As such, AI and ML have the potential not only to overcome the traditional limitations associated with vision impairment but also to create more inclusive and flexible learning environments. AI-driven screen readers represent one of the most impactful innovations for vision-impaired students. Unlike conventional screen readers that rely on pre-programmed voice output to read text aloud, AI-powered systems can interpret and describe images, recognize patterns in documents, and adapt their output based on user preferences and learning styles. For instance, these screen readers can scan complex PDF documents, detect headings and tables, and offer summarized interpretations of academic materials. Without such efforts, there is a risk that AI tools may inadvertently marginalize the very users they aim to support. Another challenge lies in the cost and accessibility of AI-based technologies. While AI tools offer considerable advantages, many require advanced hardware, stable internet connectivity, and technical literacy to operate effectively. In low-resource educational settings, these prerequisites may not be met, thereby excluding a significant portion of the population. The digital divide between high-and low-income schools, urban and rural communities, or developed and developing countries, may be further widened if AI tools are introduced without accompanying strategies for equitable access. This includes government subsidies, localized content development, and investments in teacher training to ensure that educators are equipped to support students using AI tools. Teacher training, in particular, is a critical but often overlooked aspect of successful AI integration. Teachers must not only understand how to use these tools but also be able to guide students in using them safely, ethically, and effectively. Moreover, they must be prepared to troubleshoot common issues, customize tools for individual students, and integrate AI functionalities into the curriculum in a pedagogically meaningful way. Without adequate training, even the most sophisticated AI systems may be underused or misused in educational settings. Additionally, the integration of AI in learning for students with vision impairment must be guided by inclusive pedagogical principles. Technological tools should not replace human support or reduce learning to a mechanical process. Instead, AI should augment traditional teaching methods by offering new ways to engage, assess, and support students. This requires thoughtful instructional design that considers how AI can enhance learning outcomes without compromising critical human elements such as empathy, social interaction, and ethical reasoning. Educational technologists and curriculum developers must work collaboratively to ensure that AI-enhanced learning environments are inclusive, interactive, and aligned with broader educational goals. Furthermore, long-term research is needed to evaluate the impact of AI and ML tools on the academic trajectories and life outcomes of students with vision impairment. While short-term gains in engagement and performance are important, it is equally crucial to understand how these tools affect motivation, self-esteem, social integration, and employment prospects of students. Longitudinal studies can provide insights into whether AI truly levels the playing field or merely offers superficial improvements that do not translate into lasting empowerment. Such research should also examine whether these technologies foster genuine inclusion or create new forms of dependency and isolation. In sum, Artificial Intelligence (AI) and Machine Learning (ML) technologies offer ground-breaking opportunities to enhance learning for students with vision impairment. From AI-powered screen readers and smart assistants to adaptive learning platforms and spatial navigation tools, these innovations have redefined what is possible in inclusive education. They promote autonomy, increase engagement, and allow for personalized instruction that meets the unique needs of each student. However, their adoption must be approached with caution and responsibility. Issues related to data privacy, algorithmic bias, cost, accessibility, teacher preparedness, and long-term impact require careful consideration and strategic action. By addressing these challenges through inclusive design, ethical governance, and equitable policy implementation, stakeholders can ensure that AI and ML technologies fulfil their potential to transform education for students with vision impairment—making learning not just accessible, but truly inclusive and empowering. A focus on Assistive Technology for Collaborative Learning shows that assistive technology for collaborative learning plays an essential role in promoting inclusion and enhancing educational outcomes for students with vision-impairment. As education increasingly emphasizes group work, communication, and peer engagement as critical competencies, the necessity for tools that allow students with disabilities to fully participate in collaborative learning environments becomes more pronounced. Traditional collaborative activities—such as group projects, discussions, and peer reviews—often rely heavily on visual cues, shared visual content, and non-verbal communication. This visual-centric approach inherently excludes or limits the participation of students with visual disabilities unless supported by thoughtfully designed assistive technologies. Thus, integrating assistive technologies tailored for collaborative learning is a necessary step toward achieving educational equity and fostering a more inclusive pedagogical environment. Collaborative learning encourages knowledge sharing, critical thinking, and social development, which are foundational components of holistic education. For students with vision-impairment, engaging in such learning formats provides not only academic benefits but also crucial social and emotional gains. However, the effectiveness of collaborative learning for these students largely depends on the availability and accessibility of technologies that support their participation in group settings.

Developers and educational institutions must prioritize the creation and adoption of systems that integrate smoothly with a wide range of assistive devices, thereby reducing friction and enhancing usability for students with vision impairments. Peer sensitivity and training also play a significant role in the success of collaborative learning involving assistive technology. Even when the right tools are in place, group collaboration can break down if peers are not aware of how to communicate effectively with a vision-impaired classmate. Educational programs must therefore include components of disability awareness and inclusive communication strategies for all students. When peers are equipped to understand and accommodate diverse needs, the collaborative process becomes more authentic, respectful, and productive. Moreover, collaboration through assistive technology can foster a sense of agency and leadership among students with vision impairment. When provided with equitable access and appropriate support, these students can take on leadership roles within their groups, share unique perspectives, and develop critical interpersonal and problem-solving skills. This empowerment is essential not only for academic achievement but also for building the confidence and social capital necessary for success beyond the classroom. Despite the progress in developing collaborative assistive technologies, challenges persist. Many schools lack the funding and technical infrastructure required to procure and maintain these tools. Additionally, there is a limited body of empirical research assessing the long-term impact of collaborative assistive technologies on educational and psychosocial outcomes.

Without such data, it is difficult to advocate for widespread policy changes or sustained investment. Future research should aim to address this gap by exploring how these tools influence academic performance, peer relationships, and self-esteem among students with vision impairment over time. While the use of tactile models and audio-based systems has proven effective in supporting collaboration, there is a pressing need to integrate these tools with digital learning platforms to reflect contemporary educational realities. Furthermore, teacher facilitation, peer awareness, technical compatibility, and flexible design must all be considered to ensure that collaborative learning truly benefits all students. Through thoughtful implementation and continuous evaluation, assistive technologies can transform collaborative learning from a challenge into a powerful vehicle for inclusion, equity, and shared academic success. As the education sector continues to embrace digital transformation, a more holistic and inclusive approach to mobile technology deployment will be essential in fulfilling the goals of equitable and accessible learning for all. Hence this study evaluates the criteria for selecting effective technology enhancement tools to advance science education for students with vision-impairment.

The New Value of Research which is Innovation

To promote inclusivity, integration of assistive technologies into STEM education for students with vision-impairment represents a pivotal step toward achieving educational equity and fostering inclusive learning environments. These technologies are not merely supplementary tools but are essential components that empower students to participate fully in academic activities that would otherwise be inaccessible due to their visual limitations. Inclusivity in education demands more than physical access to classrooms; it involves restructuring curricula, pedagogy, and classroom interactions in a way that ensures all students, regardless of their abilities, have the opportunity to succeed. In this context, assistive technologies play a transformative role by bridging gaps in content accessibility, supporting comprehension, and encouraging active engagement in learning processes, particularly within the complex and often visually dense fields of Science, Technology, Engineering, and Mathematics (STEM). To improve engagement, the study recognizes that, student engagement is a critical determinant of academic success, particularly for students with vision impairment who often face additional barriers in traditional educational environments. In recent years, interactive learning platforms that includes comprising mobile applications, adaptive learning systems, and multimodal educational tools is suggested to have proven to be instrumental in enhancing engagement and supporting independent learning. These tools, when thoughtfully designed and implemented, create accessible, stimulating, and personalized learning experiences that foster curiosity, autonomy, and sustained attention. While multiple studies affirm the positive impact of interactive technologies on student engagement, deeper examination reveals certain gaps related to cultural responsiveness, scalability, and systemic integration that must be addressed to ensure their long-term effectiveness and inclusive reach. Evaluation of Tools for Specialized Learning Needs reveal that students with vision-impairment face multifaceted barriers in education, particularly in STEM disciplines. These fields often depend heavily on visual materials such as graphs, diagrams, charts, symbols, and experimental observations. Without appropriate accommodations, students with vision impairments risk being excluded from full participation in these subjects, leading to diminished academic performance and limited career opportunities in STEM. To address this inequality, a range of specialized assistive tools has emergedparticularly those designed to translate abstract or visual information into accessible formats. These tools are expected to support the cognitive and sensory needs of students with vision impairment and help bridge the gap in STEM education by offering alternative pathways to understanding. Another key consideration in implementing specialized tools is teacher readiness and institutional support. Even the most advanced tools will fall short if educators are not trained in their use or if schools lack the infrastructure to deploy them effectively. This includes everything from ensuring reliable electricity and internet access to creating maintenance and technical support systems. In many low-resource educational environments, these infrastructural barriers are significant, meaning that the introduction of sophisticated tools often requires holistic planning that includes teacher training, budget allocation, policy endorsement, and community engagement. It is not sufficient to introduce a tool; it must be embedded within a supportive pedagogical framework and institutional ecosystem to realize its full potential. Moreover, student attitudes and user preferences must be considered in the design and deployment of specialized tools. Some students may prefer tactile methods, while others might benefit more from audio or haptic feedback. Tools must therefore be flexible and customizable to accommodate these variations. Inclusive education is not about imposing uniform solutions but offering multiple access points that reflect the diversity of student needs. This user-centred approach can enhance both the effectiveness and acceptability of assistive technologies in STEM education. Involving students in the design and evaluation process can ensure that the tools developed are aligned with their real-world challenges and expectations. Equity in STEM also demands a focus on gender, language, and socio-economic variables that intersect with disability. Specialized tools must be sensitive to these intersectional dynamics. For instance, girls with vision impairments in some cultures may have more limited access to technology or face societal expectations that discourage them from pursuing science. Similarly, students who speak minority languages may struggle with tools that assume proficiency in a dominant language. These issues must be addressed through inclusive design and adaptive localization of content, ensuring that tools are not only accessible but also culturally and linguistically relevant. Policy frameworks at institutional and national levels also play a critical role in determining whether specialized learning tools can move from research trials to widespread adoption. National education policies must explicitly support the integration of assistive technologies in STEM education and allocate funding accordingly. Accreditation bodies and examination boards must also be involved to ensure that assessments are adapted for students using specialized tools, thereby legitimizing their use and preventing systemic discrimination. Without such institutional backing, specialized tools may remain marginal, their benefits confined to isolated classrooms rather than extended across the education system. Finally, interdisciplinary collaboration is essential to advance the field of specialized assistive technology. Educators, technologists, disability advocates, and policy experts must work together to create a comprehensive strategy that addresses both the technical and social aspects of tool development and implementation. Research in this area must be continuous, iterative, and responsive to user feedback, ensuring that innovations remain relevant as educational demands evolve. More inclusive R&D ecosystems that involve universities, non-profits, and private tech companies can accelerate the development of scalable, cost-effective tools for diverse educational settings. In sum, tools for specialized learning needs play a transformative role in facilitating access to STEM education for students with vision impairment. Technologies like MATHVIS and electronic Braille displays have demonstrated their ability to make abstract and complex concepts more accessible. However, the broader impact of these tools hinges on their scalability, integration into educational systems, and the support structures surrounding their use. Long-term research, cross-sector collaboration, inclusive design, and policy alignment are all necessary to ensure that such tools contribute meaningfully to educational equity. As STEM fields continue to define the future of work and innovation, ensuring that students with vision impairment are equipped with the tools they need to participate fully is both a moral imperative and a strategic necessity for inclusive societal development. A critical look at how Tools Contribute to Advancing Science Education for Vision -impaired Students reveal that assistive technologies play pivotal role in advancing science education for vision-impaired students by enhancing accessibility, engagement, and learning outcomes. These technologies, including Artificial Intelligence (AI), mobile applications, and adaptive tools, create inclusive educational environments that empower students with vision impairment to participate effectively in STEM subjects.

THEORETICAL BASIS

This study focuses on the research subject area of Technology-facilitated Learning with Constructionism as a constructivist learning theory and theory of instruction as basis. The central concept of this theoretical framework is Technology Enhancement for Vision -impaired Learners, which serves as the foundation for exploring how specific technological interventions can improve educational outcomes. This concept is examined through the lens of three key theories: Constructivist Learning Theory, Cognitive Theory of Multimedia Learning, and Dual Coding Theory. Each theory highlights unique aspects of how technology supports the learning process for students with vision impairment and connects directly to specific outcomes that address the research objectives. Constructivism is seen by [34] as an approach to learning that holds that people actively construct or make their knowledge and that reality is determined by the experiences of the learner. The theory states that building knowledge occurs best through building things that are tangible and sharable [35]. Constructionism in the context of learning is the idea that people learn effectively through making things [27]. These assertions imply that learners would require the use of technology enhancement tools to advance knowledge and skills. It also means that to benefit from learning the learner could face risks associated with using the tools in educational technological practices or processes. The insights help the study to examine educational technology enhancement tools that are required to advance learning of vision-impaired students, as well as the associated risks, benefits and difficulties in engaging technology enhancement tools. Constructivist Learning Theory emphasizes the active role of learners in constructing knowledge through meaningful experiences and social interactions. In the context of vision -impaired learners, this theory underscores how tactile and auditory tools can facilitate active engagement with educational content. For example, tools like tactile graphics and audio descriptions allow learners to interact with scientific concepts in a hands-on and experiential manner, fostering deeper understanding and retention [35],[36].This theory links directly to the outcome of Enhanced Learning Outcomes and Knowledge Construction, as it provides a framework for understanding how adaptive tools enable learners to create meaningful connections between prior knowledge and new information. Cognitive Theory of Multimedia Learning, developed by Richard Mayer, provides insights into how information is processed and retained through dual channels. For vision -impaired learners, this means designing materials that integrate auditory and tactile modalities to replace traditional visual components. By reducing extraneous cognitive load and emphasizing essential content, this theory ensures that learners can efficiently process and retain information [37]. Well-designed educational materials, such as tactile maps paired with synchronized audio narratives, align with this theory's principles. The associated outcome, Improved Information Processing and Retention, reflects the effectiveness of technology-enhanced materials in promoting active engagement and cognitive efficiency for vision -impaired learners [2],

[38]. Dual Coding Theory complements this framework by focusing on the integration of verbal (auditory) and non-verbal (tactile) inputs to enhance memory and learning. This theory highlights the importance of creating multiple retrieval pathways, allowing learners to access stored knowledge through both tactile and auditory modalities. For instance, a tactile model of a molecule, accompanied by a detailed auditory description, ensures that learners can connect abstract scientific concepts to concrete representations. This approach leads to the outcome of Strengthened Comprehension and Recall, illustrating how dual-modality inputs enhance understanding and memory retention for students with vision impairment [23], 38]. In sum, the theoretical framework positions Technology Enhancement for vision-impaired learners at its core, connecting it to three foundational theories that illuminate distinct aspects of the learning process. Constructivist Learning Theory explains how technology facilitates active knowledge construction and improved learning outcomes. Cognitive Theory of Multimedia Learning demonstrates how multimodal tools optimize information processing and retention. Dual Coding Theory highlights the role of dual-modality inputs in strengthening comprehension and recall. Together, these theories provide a comprehensive basis for understanding how technology can transform the educational experiences of vision -impaired learners, ultimately advancing equitable and inclusive education. Technological advancements have significantly enhanced learning opportunities for students with vision impairment by providing tools that cater to their specific needs. These tools leverage artificial intelligence, machine learning, and other innovative technologies to facilitate independent learning and improve educational outcomes. This empirical review synthesizes research on technology enhancement tools that facilitate learning for students with vision impairment, integrating findings from various studies to identify gaps and propose directions for future research.

METHOD

The study employed the mixed methods approach[39].Quantitative methods employed interview guides with questionnaires and checklists. Qualitative methods employed observation checklists, focus groups discussions guide questions, application of theoretical and conceptual frameworks to obtain data [40]. Thetarget population for this study comprised 13,950 students including those with vision impairment alongside other students in inclusive classrooms within science educational institutions implementing Technology-Enhanced Learning (TEL). This population was chosen to provide a comprehensive understanding of how TEL interventions impact diverse learners, particularly those with vision-impairments. The institutions included in the study were specifically identified for their active adoption of TEL interventions, which are designed to foster inclusivity, enhance accessibility, and improve academic outcomes for students with varying levels of visual ability. By focusing on this population, the study aimed to capture the experiences, challenges, and benefits associated with TEL in environments that prioritize equity and inclusivity in education. The diverse composition of the population ensures a holistic representation of students' perspectives across different levels of vision and educational settings.The sample unit for this study comprised individual students within inclusive classrooms that actively employed Technology-Enhanced Learning (TEL) tools. These included those who were fully sighted, partially sighted, and no sight students, ensuring a diverse and comprehensive representation of vision statuses within the sample. By focusing on this broad range of vision abilities, the study aimed to capture the nuanced experiences and perspectives of all students engaging with TEL interventions. This approach not only highlights the inclusivity of the research design but also provides valuable insights into how TEL tools affect learners with varying levels of vision impairment. The inclusion of students across this spectrum ensures that the findings reflect the diverse realities of educational settings employing TEL, emphasizing the importance of equitable access and tailored support in inclusive classrooms.The sampling frame for this study encompassed inclusive classrooms within various educational institutions equipped with Technology-Enhanced Learning (TEL) infrastructure. This frame was systematically developed by utilizing institutional records and databases, which provided detailed lists of classrooms actively supporting vision-impaired students through TEL tools. By focusing on classrooms with established TEL tools interventions, the sampling frame ensured that the study targeted settings where the integration of technology into learning environments was already in practice. This approach facilitated identification of suitable classrooms that could offer rich insights into the effectiveness and challenges of TEL tools in inclusive educational settings.A total of 1,532 students were surveyed. The justification is that, this substantial sample size was selected to ensure the collection of a comprehensive and diverse dataset, capturing a wide range of student demographics, vision statuses including fully sighted, partially sighted, and no sight students, and varying levels of technology access. Such diversity enhances the study's representativeness and allows for robust statistical analyses [40] to examine the impacts of Technology-Enhanced Learning (TEL) tools on learning outcomes in inclusive classrooms. The sample size also ensures sufficient statistical power to identify meaningful patterns and relationships within the data, thereby reinforcing the study's reliability and validity.Adopted Method of Sampling is Stratified Random Sampling[40], [41], [42]. This sampling method was utilized to guarantee equitable representation across various vision statuses such as fully sighted, partially sighted, and no sight students and educational levels such as first-year, second-year, and third-year students. Stratification ensured that each subgroup was proportionately included in the sample, capturing a diverse range of experiences with Technology-Enhanced Learning (TEL) tools. This approach enabled the study to comprehensively examine the differential impacts of TEL tools on academic engagement, accessibility, and performance, thereby enhancing the depth and generalizability of the findings.The method of analysis for specific technology enhancement tools that can facilitate learning for students with vision impairmentis ANOVA[39], [40]. The reason for Method Adoption was that, it was suitable for summarizing and presenting the frequency and types of TEL tools identified in the study, providing a clear overview of their prevalence and importance.Adopted method of analysis of how these tools contribute to advancing science education for students with vision impairment is ANOVA, the reason for method adoptionwas that, it was ideal for comparing perceived contributions of TEL tools across groups of students with varying vision statuses. Chi-Square Testwas adopted method of analysis of the criteria for selecting effective technology enhancement tools for students with vision-impairment. The reason for method adoption is that, it is effective for determining associations between vision status and criteria preferences for tool selection.

RESULTS AND DISCUSSION

For the study to obtain a comprehensive analysis of technology-enhanced learning tools in inclusive classrooms, Table 1 provides demographic information of respondents.In terms of age distribution, the majority of participants fall within the above 18 years category, accounting for 61.0% of the respondents. This is followed by those aged 15–18 years (29.3%) and a smaller proportion under 15 years (9.7%). This distribution indicates that the sample is predominantly composed of older adolescents and young adults, which may influence their exposure to and interaction with technology-enhanced learning tools.Regarding the year of study, Table 1 shows that, a significant portion of respondents are in their second year of academic pursuits (41.6%), followed by those in their first year (28.8%) and third year (29.6%). This even distribution across academic levels suggests that the data captures varied experiences from students at different stages of their educational journey.In terms of vision status, Table 1 indicates that most respondents are fully sighted (60.0%), with a substantial proportion being partially sighted (31.6%) and a smaller group with no sight (8.4%). This distribution highlights the inclusion of diverse vision abilities in the study, allowing for a comprehensive exploration of technology-enhanced learning tools in inclusive classrooms.This diverse sample ensures that the findings are relevant and applicable to a wide spectrum of learners in inclusive educational settings.

Table 1. Demographic Information

Variables		**Frequency**	**Percent**
Gender	Male	754	49.2
	Female	778	50.8
Age	Under 15	148	9.7
	15–18	449	29.3
	Above 18	935	61.0
Year of study	One	441	28.8
	Two	638	41.6
	Three	453	29.6
Vision status	Fully sighted	919	60.0
	Partially sighted)	484	31.6
	No Sight	129	8.4

Source: Survey Data 2024

To examine the required technology enhancement tools for advancing learning by students with vision impairmentAccessibility and Availability of Technology Tools were examined. In Table 2 the analysis of available technology enhancement tools sheds light on the resources accessible to students with vision impairment and their role in advancing learning within classrooms. Among the tools examined, Braille devices stand out as the most frequently available, with 25.3% of respondents acknowledging their presence. This finding underscores the critical importance of Braille devices in supporting literacy and learning, particularly for students who depend on tactile inputs for effective education. Their prominence may also reflect longstanding efforts to integrate foundational assistive technologies in classrooms, as Braille literacy remains a cornerstone of inclusive education.Following closely, Table 2 shows that, screen readers were identified by 24.7% of respondents as available tools. These tools play an indispensable role in enabling students with vision impairment to access digital content, including electronic textbooks, online resources, and classroom presentations. Their relatively high availability suggests progress in adopting digital tools to foster inclusive learning, especially in environments that rely increasingly on electronic materials. However, this availability could be limited by factors such as inadequate teacher training, insufficient funding, or a lack of infrastructure to support widespread implementation.In Table 2, Tactile graphics, essential for subjects requiring spatial understanding, such as mathematics and science, were reported as available by 19.0% of respondents. Similarly, accessible e-books, which provide students with vision impairment with equitable access to textual materials, were indicated as available by 20.9% of participants. While these tools are critical for inclusive education, their moderate availability points to gaps in resource provision. Limited funding, inconsistent policy implementation, or a lack of prioritization for specialized resources in educational budgets could explain their relatively lower prevalence compared to Braille devices and screen readers.Of significant concern in Table 2 is that, 10.2% of respondents reported the absence of any of the listed tools in their classrooms. This troubling statistic suggests that a subset of students may lack access to even the most basic assistive technologies, effectively hindering their ability to engage in meaningful learning. The reasons for this disparity could stem from systemic barriers, such as unequal resource distribution, limited government investment in inclusive education, or challenges faced by schools in acquiring or maintaining assistive tools. Additionally, regional disparities in infrastructure and training could exacerbate this issue, leaving some schools unable to provide adequate support for their students with vision impairment. These results underscore the urgent need for targeted interventions to address the gaps in resource availability.

Table 2.Which of the following tools are available for your use in the classroom? (Select all that apply)

		Frequency	Percent
Valid	**Braille devices**	387	25.3
	Screen readers	378	24.7
	Tactile graphics	291	19.0
	Accessible e-books	320	20.9
	None of the above	156	10.2
	Total	1532	100.0

Source: Survey Data 2024

In Table 3 the descriptive statistics provide valuable insights into the presence and utilization of technology enhancement tools in classrooms, shedding light on their role in facilitating learning for students with vision impairment. The average rating for the availability of tools is 2.66, with a standard deviation of 1.326. This reflects moderate access to assistive technologies, with significant variability across classrooms. The high standard deviation suggests disparities in resource distribution, where some classrooms are well-equipped while others lack basic tools. Such differences may stem from factors like unequal funding allocation, infrastructural challenges, or regional disparities in educational support.Table 3 shows that, frequency of use of these tools during the learning process has an average score of 3.28, accompanied by a standard deviation of 1.192. This indicates that, on average, students use assistive technologies moderately often. However, the variability in responses highlights differences in how regularly these tools are utilized. This could be influenced by their availability, the level of teacher familiarity with the tools, or the specific learning needs of students. In classrooms with adequate access and trained educators, tools might be integrated more seamlessly into daily learning activities, whereas resource constraints could hinder their consistent use in other settings.Table 3 provides the perceived effectiveness of the tools in supporting learning, rated at an average of 3.12, with a standard deviation of 1.145. This suggests that students view the tools as moderately effective in aiding their learning. However, the findings also point to opportunities for improvement in the functionality, usability, or integration of these technologies. Factors such as outdated equipment, a lack of tailored resources for specific subjects, or inadequate user training could impact perceptions of effectiveness.The reliability of the tools receives an average rating of 3.07, with a standard deviation of 1.137. While this indicates that students generally find the tools somewhat reliable, the variability in responses underscores challenges such as inconsistent functionality, maintenance issues, or limited technical support. These factors may contribute to occasional disruptions in learning and reduce confidence in the tools' dependability.The skewness and kurtosis values for all variables fall within acceptable ranges for large samples (skewness ±1 and kurtosis ±2). This indicates that the data approximates normality sufficiently for inferential statistical analyses.

Table 3.Presence and Utilization of Technology Enhancement Tools in Classrooms

	N	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Tools are available for your use in the classroom	1532	2.66	1.326	.251	.063	-1.158	.125
How frequently these tools during learning process	1532	3.28	1.192	-.358	.063	-.693	.125
Effectiveness of these tools in supporting learning	1532	3.12	1.145	-.190	.063	-.775	.125
Reliability of tools	1532	3.07	1.137	-.179	.063	-.754	.125
Valid N (listwise)	1532						

Source: Survey Data, 2024

Evaluation of Relationship Between Vision Status and Tool Usage and Tool Accessibility

Chi-Square Test

Chi-Square tests were conducted to evaluate the relationship between vision status and two critical variables: tool usage and tool accessibility. These analyses aimed to determine whether students with vision impairment' interactions with technology tools differ based on their vision status.For tool usage, the Chi-Square test yielded a statistic of 6.22 and a p-value of 0.62. Since the p-value is greater than the commonly used significance threshold (e.g., alpha = 0.05), the null hypothesis (H_0) cannot be rejected. This result indicates no statistically significant association between vision status and the frequency of technology tool usage. In other words, students with different vision statuses appear to use assistive technologies at similar rates, suggesting that vision status alone does not influence the frequency of tool utilization.For tool accessibility, the Chi-Square statistic was 6.50, with a p-value of 0.59, again exceeding the standard significance threshold. As with tool usage, the null hypothesis (H_0) cannot be rejected, indicating no statistically significant relationship between vision status and the reported accessibility of technology tools. This finding implies that students across varying vision statuses experience similar levels of access to assistive technologies in the classroom.These results collectively suggest that vision status does not significantly influence either the usage or accessibility of technology tools in classrooms. This is a promising outcome, as it indicates that efforts to ensure equitable access to technology for students with vision impairment may be yielding positive results. However, the absence of significant associations also highlights the need to investigate other potential influences on tool usage and accessibility. Factors such as resource availability, teacher training, or school infrastructure may play a more critical role in shaping students' experiences with technology-enhanced learning tools. Addressing these areas could further strengthen the inclusivity and effectiveness of assistive technologies in educational settings.

- Assessing the relationship between vision status and tool usage or accessibility.

 Null Hypothesis (H0): There is no association between vision status and tool usage/accessibility.

 Alternative Hypothesis (HA): There is an association between vision status and tool usage/accessibility.

Table 4.Chi-square test

Test	Statistic	p-Value
Chi-Square (Vision Status vs. Tool Usage)	6.22	0.62
Chi-Square (Vision Status vs. Tool Accessibility)	6.50	0.59

Source: Survey Data, 2024

- Evaluating Differences in Perceptions of Tool Effectiveness among Students with varying Vision Statuses

One-Way ANOVA:

- Compare perceptions of tool effectiveness across different vision statuses.

Null Hypothesis (H0): The mean perception of tool effectiveness is the same across all vision statuses.
Alternative Hypothesis (HA): There is a significant difference in the mean perception of tool effectiveness across vision statuses.
A One-Way ANOVA was conducted to evaluate differences in perceptions of tool effectiveness among students with varying vision statuses: fully sighted, partially sighted, and no sight. The analysis aimed to determine whether these groups hold significantly different views on how effective technology tools are in supporting their learning.In Table 5, the analysis yielded an F-statistic of 1.29 and a p-value of 0.28. Since the p-value exceeds the commonly used significance threshold ($\alpha = 0.05$), the null hypothesis (H_0) cannot be rejected. This indicates that there are no statistically significant differences in the mean perceptions of tool effectiveness among the three vision status groups.These results suggest that students, regardless of their vision status, perceive the effectiveness of technology tools similarly. This uniformity implies that, as currently implemented, assistive tools may be meeting the needs of students across different vision statuses in a relatively consistent manner. However, it is important to note that the absence of significant differences does not necessarily indicate that all students experience equal levels of effectiveness. Instead, it reflects that the average perceptions of tool effectiveness across groups do not show statistically meaningful variation.The lack of significant differences in perceptions of tool

effectiveness underscores the potential inclusivity of the technology tools in use. This encouraging resultsuggests that the tools are not disproportionately benefiting or disadvantaging specific groups of students based on their vision status. However, it also calls attention to the importance of ongoing evaluation and refinement of these tools to ensure that they cater effectively to the unique needs of all students, particularly those with specific learning challenges or preferences.

Table 5.One-Way ANOVA

Metric	F-Statistic	p-Value
ANOVA (Tool Effectiveness across Vision Statuses)	1.29	0.28

Source: Survey Data, 2024

Conclusions

Technology Enhancement Tools and Learning Facilitation: The finding that Braille devices and screen readers are critical tools for vision -impaired learners aligns with [2], who emphasized the foundational role of tactile and auditory tools in inclusive education. The studies underscore the importance of these tools in creating equitable learning environments, particularly in STEM education. However, while this study identified limited use of advanced tangible interfaces like 3D printed models,significant benefits of such tools had been reported in enhancing spatial awareness and tactile learning by [42]& [43].This difference may stem from variations in technological access and funding across study contexts, as this study highlighted resource constraints as a key barrier. The reliance on more conventional tools such as Braille devices and screen readers could reflect infrastructural and training limitations in the study setting. Addressing these barriers may enable broader adoption of innovative tools to enhance learning outcomes.

APPENDIX

1. Questionnaire on Educational Technology tools required to advance inclusive classroom education of vision-impaired students in Ghana.

Introduction

Dear Participant,

You are invited to join a study called "Using Technology to Help Students with Vision Impairment Learn Science". The study focuses on discovering the role played by technology tools among students with vision impairment, specifically related to science education.We want your real opinions and experiences about how accessible, effective, difficult, and beneficial technology-enhanced learning (TEL) tools are, for you in your education. We will use your answers to discover important approaches and obstacles for young people with vision problems that are learning science. It can contribute to the creation of stronger standards and practices in supporting students with different needs.There are two sections in the questionnaire and respondents use the Likert scale (from 1 to 5) to rate each answer. Every answer is acceptable as long as it comes from your viewpoint.All information collected will be private and only be used within the study. It is your decision whether to continue and you are allowed to withdraw whenever you wish.

Section A: Demographic Information (For Control Variables)

- Age: ____
- Gender: [ ] Male [ ] Female [ ] Other
- Vision impairment status[ ] Partial [ ] Severe [ ] Total
- Educational level: [ ] JHS [ ] SHS [ ] Tertiary
- Location: ____________________\

Section B: Technology Tools for Science Learning
1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree

Construct	Item No.	Question Item	1	2	3	4	5
Availability and Use of Tools	1	I have access to specialized technological tools designed for science education.					
	2	The tools I use are tailored to support my vision impairment needs in science learning.					
	3	These tools help me understand complex science topics more easily.					
Contribution to Learning	4	Technology tools have improved my ability to conduct science experiments.					
	5	I can now engage more effectively in science learning through the use of assistive technology.					
	6	I feel more confident participating in science classes due to these tools.					
Selection	7	The tools I use were chosen					

Criteria		based on my specific vision needs.					
	8	Functionality and ease of use are key reasons I prefer certain science tools.					
	9	I believe schools use clear criteria to choose the best technology for visually impaired students.					

Conflict of Interest
Authors declare that this study is solely academic and was not influenced by anybody or any organization. The results of the research were not affected by anybody.

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Authors' Biography
1. Rachel Annoh graduated in Mechanical Engineering from the Kwame Nkrumah University, Kumasi. She served with skills training at assembling engineer at Neoplan Ghana, handset engineer at Kasapa Telecommunications limited and marketing support Mantrac Ghana; She holds and Master'sin Educational Studies, and MPhil. Education from the Presbyterian University Ghana. Asa seasoned Physics Teacher in Senior High School, she moderates Regional & National Science and Mathematics Quiz teams. She is also leader of the STEM and member of Robotics teams. Currently a final year PhD scholar at OUM/AIT, her interest is in solving socio-technical issues affecting student education, with particular focus on vision-impaired student education. She mentors young talents in improving their insights in STEM and shares her ideations to make positive impacts to make a difference.

2. Mary Adu Kumi is Senior Lecturer, Presbyterian University, Ghana. She has provided mentorship to Lecturers, trained over 33,000 Cocoa farmers in Farmer Field School (FFS), Video Viewing Clubs (VVCs) & Microfinance, developed Field Training Manuals for USAID, reviewed University Regulatory Instruments, prepared Total Quality Management Policy Manual, internship assessment, Syllabus for Department of B.A. Communication Studies, Education, and 6 Master programs for Graduate studies and reviewed Syllabus of Department of Environmental and Natural Resources Management. Her PhD in 2019 (IT - Advanced Technologies) was obtained from Open University Malaysia /Accra Institute of Technology Ghana. She is reviewer of several research reports, conducts research on socio-technical effects on learning and contributes to academic workshops, books, research articles on training, learning and development. She won Bronze Award of the 2014 IRIC

Conference Presentation, and Silver for 2015 Computing Sciences Category published in more than 80 refereed articles, books. Her email: mary.adu-kumi@presbyuniversity.edu.gh

REFERENCES

[1] Sen A., Leong C.K.C. (2020) Technology-Enhanced Education. In: Tatnall A. (eds) Encyclopedia of Education and Information Technologies. Springer, Cham. https://doi.org/10.1007/978-3-319-60013-0_72-1

[2] Niederhauser, D. S., Howard, S. K., Voogt, J., Agyei, D. D., Laferriere, T., Tondeur, J. & Cox, M.J. (2018) Sustainability and Scalability in Educational Technology Initiatives: Research-Informed Practice Technology, Knowledge and Education October 2018 DOI: 10.1007/s10758-018-9382-z Retrieved March 16 2022 from file:///C:/Users/User/AppData/Local/Temp/Niederhauser2018_Article_SustainabilityAndScalabilityIn-2.pdf

[3] Westera W (2010) Technology-enhanced education: review and prospects. Serdica J Comput 4(2):159–182. [online]. Retrieved from: http://sci-gems.math.bas.bg/jspui/handle/10525

[4] Iakovidis, D. K., Diamantis, D., Dimas, G., Ntakolia, C., & Spyrou, E. (2020). Digital enhancement of cultural experience and accessibility for the visually impaired. Technological trends in improved mobility of the visually impaired, 237-271.

[5] Miesenberger, K. (2015). Advanced and emerging solutions: ICT and AT in education of low vision and blind students. Enabling Access for Persons with Visual Impairment, 17-26.

[6] UNESCO (2017) Education 2030: Incheon Declaration and Framework for Action for the implementation of Sustainable Development Goal 4

[7] Akoto Ofori, E. (2018) Challenges and Opportunities for Inclusive Education in Ghana. Thesis Submitted for B.A. degree International Studies in Education to Faculty of Education and Diversity School of Education, University of Iceland

[8] Kauts, D., & Sharma, I. (2022). Role of assistive technology in teaching-learning process of the students with visual impairment: an insight study. Scholarly Research Journal for Humanity Science & English Language, 10(52). https://doi.org/10.21922/srjhsel.v10i52.11526

[9] Kırboyun Tipi, S. (2023). How Screen Readers Impact the Academic Work of College and Graduate Students with Visual Impairments. Sakarya University Journal of Education, 13(3), 416-434. doi: https://doi.org/10.19126/suje.1201482

[10] Jones, E. J., Pride, M., Edwards, C., & Tumilty, R. (2020). Challenges and Opportunitiesin co-creating a wellbeing toolkit in a distance learning environment: a case study. The Journal of Educational Innovation, Partnership and Change, 6

[11] Zhang L. & Smith J. (2022) Investigating and Comparing the Effects on LearningAchievement and Motivation for Gamification and Game Based Learning: A Quantitative Study Employing Kahoot Journal: Education Research International

[12] Takacs, Z. K., Swart, E. K., & Bus, A. G. (2015) Benefits and Pitfalls of

Multimedia and Interactive Features in Technology-Enhanced Storybooks: A Meta-Analysis Review of Educational Research 85, 4, pp. 698–739 DOI: 10.3102/0034654314566989 © 2015 The Author(s). http://rer.aera.net
[13] Patel, D. & Kumar, V. (2021) Time management practices and challenges in blendedlearning: A student perspective. Educational Technology Research and Development, 69(1), pp. 153–171
[14] Hashim, N. M., & Jones, M. 2014) Activity Theory: A framework for qualitative analysisResearch Online Pg. 1-21 School of Management and Marketing, Faculty of Commerce, University of Wollongong https://www.researchgate.net/publication/30389157_Activity_Theory_A_framework_forqualitative analysis Research Online
[15] Sultana, T., Ruiz Casares, M., Iwo, R., Janus, M., & Nazif Muñoz, J. I. (2024). Maternaleducation and children home alone in 63 low- and middle-income countries. Global Pediatric Health, 11. https://doi.org/10.1177/2333794X241258179
[16] Gonzalez-Gutierrez J., Godec D., Guran R., Spoerk M., Kukla C., Holzer C. (2018) 3Dprinting conditions determination for feedstock used in fused filament fabrication (FFF) of 17-4PH stainless steel parts. Metalurgija. 2018; 57:117–120.
[17] Tsouktakou, A., Hamouroudis, A. & Anastasia, Horti, A. (2024) The use of Artificialintelligence in the education of people with visual impairment World Journal of Advanced Engineering Technology and Sciences, 13(01), 734–744DOI: https://doi.org/10.30574/wjaets.2024.13.1.0481
[18] Frances M. D'A. & Yue-Ting Siu (2015) "Students with Visual Impairments: Considerations and Effective Practices for Technology Use" In Efficacy of Assistive Technology Interventions. Published online: 11 Jun 2015; 111-138 http://dx.doi.org/10.1108/S2056-769320150000001005
[19] Ahmed, I. & Chao, T. (2018) Investigations in Mathematics Learning, Assistive learningtechnologies for students with visual impairments: A critical rehumanizing review Volume 10, Edition 3, Pages 173-185 DOI:10.1080/19477503.2018.1463005
[20] Ali, C. A. (2021) Visually Impaired Student-Teachers' Knowledge and Use of BasicAssistive Technology Tools for Mathematics. African Educational Research Journal, v9 n4 p945-955 Dec 2021
[21] Orim, S. O., Ajayi, D. E., & Ndifon, F. O. (2013) Application of Assistive Technology in the Education of Children with Visual Impairment. Journal of Qualitative Education, 9(2), 162–166
[22] Maruf, N., Husain, D., Arifin, S., &Mujayanah, S. (2024). Cognitive processes in EFLlearners' reading comprehension: A comparative analysis of WhatsApp and traditional group-driven reading, 13(3), 623-635. https://doi.org/10.17509/ijal.v13i3.66945I
[23] Mayer, R. E. (2014). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), TheCambridge handbook of multimedia learning (2nd ed., pp. 43–71). Cambridge University Press. https://doi.org/10.1017/CBO9781139547369.005
[24] Chanana, K. (2022)"Women and Leadership: Strategies of Gender Inclusion in Institutionsof Higher Education in India" Chapter in Strategies for Supporting Inclusion and Diversity in the Academy, August 2022

[25] Silva, A. L. dos R., Lira, B.R.F., Ruela, G. de A. (2024) Importance of Active Teaching–Learning Methodologies in Higher Education: An Integrative Review Published in: Research, Society and Development, Vol. 13, No. 4, April 19, 2024

[26] Gaynutdinovna, A. D. (2024) “Technology of Formation of Science Competences inStudents with Disabilities: A Case Study in Natural Sciences” International Journal of Pedagogics, Vol. 4, No. 09 (Sept 2024), pp. 44–49 dpublication.com

[27] McLeod, S. (2019) Constructivism as a Theory for Teaching and Education simplypsychology.org/constructivism.html 1. Theories 2. Constructivism Retrieved online from file:///C:/Users/User/AppData/Local/Temp/simplypsychology.org-Constructivism as a Theory for Teaching and Education.pdf March 16, 2021

[28] Sudhakar, R., Elango, S., Surendran, A. & Venu, G. (2023) Reading Assistant for VisuallyChallenged Peoples with Advance Image Capturing Technique Using Machine Learning. Migration Letters Volume: 20, No: S13(2023), pp. 361-365 ISSN: 1741-8984 (Print) ISSN: 1741-8992 (Online) www.migrationletters.com

[29] Martínez-Arbelaiz, A., Gutierrez-Cabello, A., Aberasturi-Apraiz, E., & Correa-Gorospe, J. (2024). Juggling Academic Practice and Care: Collaborative Autoethnography within a Basque University Research Group. The Qualitative Report, 29(4), 968-985. https://doi.org/10.46743/2160-3715/2024.6627

[30] Prabhu P, J. Sujathamalini, G. Ravichandran. (2023) Assistive and digital technology for the education of students with visual disabilities. International Journal of Research and Review. 2023; 10(2): 714-719.DOI: https://doi.org/10.52403/ijrr.20230287

[31] Wiyono, K., Sury, K., Hidayah, R. N., Nazhifah, N., Ismet, I., & Sudirman, S. (2022).STEM-based E-learning: Implementation and Effect on Communication and Collaboration Skills on Wave JurnalPenelitian&Pengembangan Pendidikan Fisika, 8(2), 259–270. https://doi.org/10.21009/1.08208

[32] Shehu I, Badi I, Dangaya J, Abubakar I, Sahabi M (2021). Impact of guidance andcounselling services on Academic performance of students in some selected secondary schools in Sokoto Metropolis, Journal of Applied Guidance and Counselling 2(2):22-30

[33] UNESCO IITE. 2024. Digital technologies for inclusive education: Recommendations for promoting an ICT-based learning environment for resource centres and schools.

[34] Elliott, S. N., Kratochwill, T.R., Littlefield Cook, J. & Travers, J. (2000). Educational psychology: Effective teaching, effective learning (3rd ed.). Boston: McGraw-Hill College.

[35] Ackermann E., Gauntlett D., &Weckstrom, C. (2009). Defining Systematic Creativity, LEGO Learning Institute

[36] Vygotsky, L. S. (1978). Mind in Society: The Development of Higher PsychologicalProcesses. Cambridge, MA: Harvard University Press.

[37] Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in Multimedialearning. Educational Psychologist, 38(1), 43–52. https://doi.org/10.1207/S15326985EP3801_6

[38] Paivio, A. (2007). Mind and its evolution: A dual coding theoretical approach. LawrenceErlbaum Associates Publishers.
[39] Bernard, H. R. (2011) Research Methods in Anthropology: Qualitative and Quantitative Approaches. Fifth ed. Altamira press NY
[40] Creswell, J. W., Creswell, J. D. (2023). Research Design: Qualitative, Quantitative, and Mixed Methods Approaches (5th ed.). SAGE Publications.
[41] Adam, A. M. (2020). Sample Size Determination in Survey Research. Journal of Scientific Research and Reports, 26, 90-97 https://doi.org/10.9734/jsrr/2020/v26i530263
[42] Jafri, R., Aljuhani, A. M & Ali, S. A. (2017) "A tangible user interface-based applicationutilizing 3D-printed manipulatives for teaching tactual shape perception and spatial awareness sub-concepts to visually impaired children," International Journal of Child-Computer Interaction, vol. 11, pp. 3-11, 2017https://doi.org/10.1016/j.ijcci.2016.12.001
[43] Najjar, A. B., Alhussayen, A., & Jafri, R. (2021) Usability Engineering of a Tangible User Interface Application for Visually Impaired Children. Human-centric Computing and Information Sciences (2021) 11:14 DOI: https://doi.org/10.22967/HCIS.2021.11.014

References in the Reference List at the End of the Research Paper

1. Ackermann E., Gauntlett D., &Weckstrom, C. (2009). Defining Systematic Creativity, LEGO Learning Institute
2. Adam, A. M. (2020). Sample Size Determination in Survey Research. Journal of Scientific Research and Reports, 26, 90-97 https://doi.org/10.9734/jsrr/2020/v26i530263
3. Ahmed, I. & Chao, T. (2018) Investigations in Mathematics Learning, Assistive learning technologies for students with visual impairments: A critical rehumanizing review Volume 10, Edition 3, Pages 173-185 DOI:10.1080/19477503.2018.1463005
4. Akoto Ofori, E. (2018) Challenges and Opportunities for Inclusive Education in Ghana. Thesis Submitted for B.A. degree International Studies in Education to Faculty of Education and Diversity School of Education, University of Iceland
5. Ali, C. A. (2021) Visually Impaired Student-Teachers' Knowledge and Use of Basic Assistive Technology Tools for Mathematics. African Educational Research Journal, v9 n4 p945-955 Dec 2021
6. Bernard, H. R. (2011) Research Methods in Anthropology: Qualitative and Quantitative Approaches. Fifth ed. Altamira press NY
7. Chanana, K. (2022)"Women and Leadership: Strategies of Gender Inclusion in Institutions of Higher Education in India" Chapter in Strategies for Supporting Inclusion and Diversity in the Academy, August 2022
8. Creswell, J. W., Creswell, J. D. (2023). Research Design: Qualitative, Quantitative, and Mixed Methods Approaches (5th ed.). SAGE Publications.
9. Elliott, S. N., Kratochwill, T.R., Littlefield Cook, J. & Travers, J. (2000). Educational psychology: Effective teaching, effective learning (3rd ed.). Boston: McGraw-Hill College.
10. Frances M. D'A. & Yue-Ting Siu (2015) "Students with Visual

Impairments: Considerations and Effective Practices for Technology Use" In Efficacy of Assistive Technology Interventions. Published online: 11 Jun 2015; 111-138 http://dx.doi.org/10.1108/S2056-769320150000001005

11. Gaynutdinovna, A. D. (2024) "Technology of Formation of Science Competences in Students with Disabilities: A Case Study in Natural Sciences" International Journal of Pedagogics, Vol. 4, No. 09 (Sept 2024), pp. 44–49 dpublication.com
12. Gonzalez-Gutierrez J., Godec D., Guran R., Spoerk M., Kukla C., Holzer C. (2018) 3D printing conditions determination for feedstock used in fused filament fabrication (FFF) of 17-4PH stainless steel parts. Metalurgija. 2018; 57:117–120.
13. Hashim, N. M., & Jones, M. 2014) Activity Theory: A framework for qualitative analysis Research Online Pg. 1-21 School of Management and Marketing, Faculty of Commerce, University of Wollongong https://www.researchgate.net/publication/30389157_Activity_Theory_A_framework_for qualitative analysis Research Online
14. Iakovidis, D. K., Diamantis, D., Dimas, G., Ntakolia, C., & Spyrou, E. (2020). Digital enhancement of cultural experience and accessibility for the visually impaired. Technological trends in improved mobility of the visually impaired, 237-271.
15. Jafri, R., Aljuhani, A. M & Ali, S. A. (2017) "A tangible user interface-based application utilizing 3D-printed manipulatives for teaching tactual shape perception and spatial awareness sub-concepts to visually impaired children," International Journal of Child-Computer Interaction, vol. 11, pp. 3-11, 2017 https://doi.org/10.1016/j.ijcci.2016.12.001
16. Jones, E. J., Pride, M., Edwards, C., & Tumilty, R. (2020). Challenges and Opportunities in co-creating a wellbeing toolkit in a distance learning environment: a case study. The Journal of Educational Innovation, Partnership and Change, 6
17. Kauts, D., & Sharma, I. (2022). Role of assistive technology in teaching-learning process of the students with visual impairment: an insight study. Scholarly Research Journal for Humanity Science & English Language, 10(52). https://doi.org/10.21922/srjhsel.v10i52.11526
18. Kırboyun Tipi, S. (2023). How Screen Readers Impact the Academic Work of College and Graduate Students with Visual Impairments. Sakarya University Journal of Education, 13(3), 416-434. doi: https://doi.org/10.19126/suje.1201482
19. Martínez-Arbelaiz, A., Gutierrez-Cabello, A., Aberasturi-Apraiz, E., & Correa-Gorospe, J. (2024). Juggling Academic Practice and Care: Collaborative Autoethnography within a Basque University Research Group. The Qualitative Report, 29(4), 968-985. https://doi.org/10.46743/2160-3715/2024.6627
20. Maruf, N., Husain, D., Arifin, S., &Mujayanah, S. (2024). Cognitive processes in EFL learners' reading comprehension: A comparative analysis of WhatsApp and traditional group-driven reading, 13(3), 623-635. https://doi.org/10.17509/ijal.v13i3.66945I
21. Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in Multimedia learning. Educational Psychologist, 38(1), 43–52. https://doi.org/10.1207/S15326985EP3801_6
22. Mayer, R. E. (2014). Cognitive theory of multimedia learning. In R. E.

Mayer (Ed.), The Cambridge handbook of multimedia learning (2nd ed., pp. 43–71). Cambridge University Press. https://doi.org/10.1017/CBO9781139547369.005

23. McLeod, S. (2019) Constructivism as a Theory for Teaching and Education simplypsychology.org/constructivism.html 1. Theories 2. Constructivism Retrieved online from file:///C:/Users/User/AppData/Local/Temp/simplypsychology.org-Constructivism as a Theory for Teaching and Education.pdf March 16, 2021
24. Miesenberger, K. (2015). Advanced and emerging solutions: ICT and AT in education of low vision and blind students. Enabling Access for Persons with Visual Impairment, 17-26.
25. Najjar, A. B., Alhussayen, A., & Jafri, R. (2021) Usability Engineering of a Tangible User Interface Application for Visually Impaired Children. Human-centric Computing and Information Sciences (2021) 11:14 DOI: https://doi.org/10.22967/HCIS.2021.11.014
26. Niederhauser, D. S., Howard, S. K., Voogt, J., Agyei, D. D., Laferriere, T., Tondeur, J. & Cox, M.J. (2018) Sustainability and Scalability in Educational Technology Initiatives: Research-Informed Practice Technology, Knowledge and Education October 2018 DOI: 10.1007/s10758-018-9382-z Retrieved March 16 2022 from file:///C:/Users/User/AppData/Local/Temp/Niederhauser2018_Article_SustainabilityAndScalabilityIn-2.pdf
27. Orim, S. O., Ajayi, D. E., & Ndifon, F. O. (2013) Application of Assistive Technology in the Education of Children with Visual Impairment. Journal of Qualitative Education, 9(2), 162–166
28. Paivio, A. (2007). Mind and its evolution: A dual coding theoretical approach. Lawrence Erlbaum Associates Publishers.
29. Patel, D. & Kumar, V. (2021) Time management practices and challenges in blended learning: A student perspective. Educational Technology Research and Development, 69(1), pp. 153–171
30. Prabhu P, J. Sujathamalini, G. Ravichandran. (2023) Assistive and digital technology forthe education of students with visual disabilities. International Journal of Research and Review. 2023; 10(2): 714-719. DOI: https://doi.org/10.52403/ijrr.20230287
31. Sen A., Leong C.K.C. (2020) Technology-Enhanced Education. In: Tatnall (eds) Encyclopedia of Education and Information Technologies. Springer, Cham. https://doi.org/10.1007/978-3-319-60013-0_72-1
32. Silva, A. L. dos R., Lira, B.R.F., Ruela, G. de A. (2024) Importance of Active Teaching–Learning Methodologies in Higher Education: An Integrative Review Published in: Research, Society and Development, Vol. 13, No. 4, April 19, 2024
33. Shehu I, Badi I, Dangaya J, Abubakar I, Sahabi M (2021). Impact of guidance and counselling services on Academic performance of students in some selected secondary schools in Sokoto Metropolis, Journal of Applied Guidance and Counselling 2(2):22-30
34. Sudhakar, R., Elango, S., Surendran, A. & Venu, G. (2023) Reading Assistant for Visually Challenged Peoples with Advance Image Capturing Technique Using Machine Learning. Migration Letters Volume: 20, No: S13(2023), pp. 361-365 ISSN: 1741-8984 (Print) ISSN: 1741-8992 (Online) www.migrationletters.com

35. Sultana, T., Ruiz Casares, M., Iwo, R., Janus, M., & Nazif Muñoz, J. I. (2024). Maternal education and children home alone in 63 low- and middle-income countries. Global Pediatric Health, 11. https://doi.org/10.1177/2333794X241258179
36. Takacs, Z. K., Swart, E. K., & Bus, A. G. (2015) Benefits and Pitfalls of Multimedia and Interactive Features in Technology-Enhanced Storybooks: A Meta-Analysis Review of Educational Research 85, 4, pp. 698–739 DOI: 10.3102/0034654314566989 © 2015 The Author(s). http://rer.aera.net
37. Tsouktakou, A., Hamouroudis, A. & Anastasia, Horti, A. (2024) The use OfArtificial intelligence in the education of people with visual impairment World Journal of Advanced Engineering Technology and Sciences, 13(01), 734–744 DOI: https://doi.org/10.30574/wjaets.2024.13.1.0481
38. UNESCO (2017) Education 2030: Incheon Declaration and Framework for Action for the implementation of Sustainable Development Goal 4
39. Westera W (2010) Technology-enhanced education: review and prospects.Serdica J Comput 4(2):159–182. [online]. Retrieved from: http://sci-gems.math.bas.bg/jspui/handle/10525
40. UNESCO IITE. 2024. Digital technologies for inclusive education: Recommendations for promoting an ICT-based learning environment for resource centres and schools.
41. Vygotsky, L. S. (1978). Mind in Society: The Development of Higher Psychological Processes. Cambridge, MA: Harvard University Press.
42. Wiyono, K., Sury, K., Hidayah, R. N., Nazhifah, N., Ismet, I., & Sudirman,S. (2022). STEM-based E-learning: Implementation and Effect on Communication and Collaboration Skills on Wave JurnalPenelitian&Pengembangan Pendidikan Fisika, 8(2), 259–270. https://doi.org/10.21009/1.08208
43. Zhang L. & Smith J. (2022) Investigating and Comparing the Effects on Learning Achievement and Motivation for Gamification and Game Based Learning: A Quantitative Study Employing Kahoot Journal: Education Research International