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Emerging Digital and Assistive Technologies in Special and Inclusive Education for Learners with Hearing Impairment: A Global Systematic Literature Review

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Abstract: *Inclusive education for learners with hearing impairment needs environments that ensure linguistic access and meaningful participation. This systematic literature review synthesises global research on emerging digital and assistive technologies in special and inclusive education for students with hearing impairment. Guided by PRISMA principles, 15 peer-reviewed empirical studies published from 2016 to 2025 were systematically found and analysed using thematic synthesis. The key findings show that sign language-embedded e-learning platforms, assistive communication tools, AI-based systems, and immersive visual technologies are mainly used to enhance instruction, communication, and engagement. Positive outcomes, such as improved comprehension and participation, are seen when technologies are pedagogically integrated and linguistically accessible. However, persistent challenges include limited teacher readiness, design gaps, and inconsistent institutional support. The review highlights that effectiveness relies most on language access and inclusive pedagogy, not technological sophistication. This study contributes an evidence based synthesis of practices, challenges, and implications for educators, institutions, and policymakers advancing equitable, inclusive education through technology.*

Keywords: Inclusive education, Hearing impairment, Assistive technology, Digital learning technologies, Sign language accessibility, Special education, Technology-enhanced learning

1. Introduction

Inclusive education is recognised as a cornerstone of global educational advancement. It emphasises equity, accessibility, and participation for learners with disabilities. DHH learners, or those with hearing impairment, still face barriers mainly in communication and language access. Even with inclusive policies, many environments prioritise spoken language instruction and limit DHH learners' participation. Research shows communication not cognition is the main barrier. Access to sign language shapes engagement, achievement, and social participation. Early and sustained language exposure leads to better outcomes. Educational environments should prioritise linguistic accessibility over post hoc accommodations. Digital technology has transformed education. Technology Enhanced Learning (TEL), online education, and blended models increase flexibility and access. Yet, digitalisation alone does not ensure inclusion for DHH learners. Platforms without sign language, captions, or visual communication reinforce inequities. During COVID-19, remote teaching often failed to

provide linguistic access, revealing gaps in digital design (Alshawabkeh et al., 2021). In response, research explores the use of digital and assistive technologies for DHH learners. These include sign language embedded environments, assistive tools, AI-based systems, and visual supports like augmented reality. Some results are positive showing better access, engagement, and participation but findings remain scattered across disciplines and technologies. Tool success depends more on pedagogy, language access, and support than on technology alone. Because results are fragmented, a systematic synthesis is needed to consolidate evidence, identify trends and gaps, and inform inclusive practice. This study systematically reviews global research on emerging digital and assistive technologies in special and inclusive education for DHH learners.

2. Problem Statement

Despite advances in inclusive education policy and technology, learners with hearing impairment still lack equitable educational access. Instruction, technologies, and environments often fail to meet their linguistic needs. Without intentional accessibility in educational design and pedagogy, digital and physical learning environments continue to exclude DHH learners. Though digital and assistive technologies are promoted as solutions, implementation is inconsistent and fragmented. Many lack sign language support, reliable captioning, and strong visual features, limiting effectiveness. Research across education, technology, and disability is dispersed and often narrowly targets specific tools or pilots, giving little guidance on broader outcomes or long-term effects. This fragmentation prevents educators, institutions, and policymakers from making informed decisions about effective technologies and optimal circumstances. Critically, treating emerging technologies especially AI as compensatory solutions ignores evidence. Studies show they cannot replace early, sustained language access, which remains a necessity that technology alone cannot adequately meet.

These challenges highlight a core argument. There is no comprehensive, systematic synthesis of emerging digital and assistive technologies for learners with hearing impairment from educational and social science perspectives. Without this synthesis, inclusive education may rely on fragmented evidence or technological trends rather than learner-centred, language inclusive principles. It is imperative to address this gap through collaborative research and policy action. Evidence based practice must support equitable and sustainable inclusive education for all learners.

This systematic literature review aims to synthesise existing global research on the use of emerging digital and assistive technologies in special and inclusive education for learners with hearing impairment. Specifically, the objectives of this study are to:

1. To identify and classify the types of emerging digital and assistive technologies used to support learners with hearing impairment in special and inclusive education settings.
2. Examine the educational purposes and reported outcomes of these technologies in enhancing access to instruction, language development, learning engagement, and participation among learners with hearing impairment.
3. To analyse implementation challenges, enabling factors, and research gaps associated with the use of digital and assistive technologies for learners with hearing impairment in educational contexts.

In line with the objectives, this systematic literature review is guided by the following research questions (RQ):

RQ1: What types of emerging digital and assistive technologies have been used to support learners with hearing impairment in special and inclusive education settings?
RQ2: What educational purposes and learning outcomes are associated with the use of these digital and assistive technologies for learners with hearing impairment?
RQ3: What challenges, facilitating factors, and research gaps are reported in the implementation of digital and assistive technologies for learners with hearing impairment in educational settings?

3. Methodology

3.1 Research Design

This review focuses on empirical primary studies. However, methodological and synthesis papers were consulted to support reporting transparency and interpretive framing. This approach ensured methodological transparency, replicability, and broad coverage (Page et al., 2021). The selection process followed PRISMA 2020 guidelines. An initial search across the Scopus database yielded a pool of records. After duplicates were removed, titles and abstracts were screened using predefined criteria. The remaining articles underwent full text review for eligibility. This process resulted in 15 empirical studies included in the final synthesis. Figure 1 (PRISMA Flow Diagram) details the study selection process.

3.1.1 Identification

The identification phase involved a comprehensive search of peer-reviewed literature in Scopus. This database was selected for its broad coverage of high quality journals across education, the social sciences, and interdisciplinary research. Scopus supports systematic reviews in educational research (Elsevier, 2023) and offers broad disciplinary coverage (Gusenbauer & Haddaway, 2020).

A structured Boolean search strategy was developed to identify studies on digital and assistive technologies for learners with hearing impairment in special and inclusive education contexts. The search string combined terms related to hearing impairment, educational context, and technology use, and was applied to article titles, abstracts, and keywords. The final Boolean string was as follows:

TITLE-ABS-KEY (("hearing impairment" OR deaf OR "hard of hearing") AND ("special education" OR "inclusive education") AND ("assistive technology" OR "digital learning" OR "mobile learning" OR "e-learning" OR caption* OR "speech-to-text" OR "artificial intelligence"))*

Table 1: Scopus search string

Database	Search string
Scopus	*TITLE-ABS-KEY (("hearing impairment" OR deaf OR "hard of hearing") AND ("special education" OR "inclusive education") AND ("assistive technology*" OR "digital learning" OR "mobile learning" OR "e-learning" OR caption* OR "speech-to-text" OR "artificial intelligence"))*

This initial search yielded a pool of records representing recent empirical research on emerging digital and assistive technologies relevant to the study aims.

3.1.2 Screening

During the screening phase, retrieved records were organised and duplicates removed to ensure each study was reviewed only once. Titles and abstracts were screened using predefined inclusion and exclusion criteria. Studies were retained if they (1) focused on learners with hearing impairment, including deaf or hard-of-hearing populations; (2) examined digital or assistive technologies in educational settings; and (3) fit within special or inclusive education contexts. Studies were excluded if they (1) focused exclusively on medical, clinical, or audiological interventions that lacked educational relevance; (2) addressed other disabilities without presenting disaggregated findings for hearing impairment; (3) were non-empirical publications, such as conceptual papers, editorials, conference proceedings, or review articles; or (4) lacked a clear connection to teaching, learning, or educational outcomes. This systematic process ensured that only studies aligned with the review's educational and technological scope progressed. The search was further refined using the following parameters:

Table 2: The selection criterion in searching

Component	Description
Database	Scopus
Search fields	Title, Abstract, Keywords
Time span	2016 – 2025
Language	English
Document type	Journal articles
Subject area	Social sciences
Inclusion criteria	Empirical studies: focus on learners with hearing impairment, digital or assistive technologies, educational settings
Exclusion Criteria	Non-empirical studies: reviews, editorials, conference papers and studies without educational outcomes

3.1.3 Eligibility

During the eligibility phase, full text versions of the studies that passed the screening stage were retrieved and examined in detail against predefined inclusion and exclusion criteria. To be considered eligible for inclusion, studies were required to report empirical findings based on qualitative, quantitative, or mixed methods research designs explicitly examine the use of digital or assistive technologies for learners with hearing impairment describe the educational purposes, learning outcomes, or pedagogical implications associated with technology use and be conducted within formal educational settings, including special schools, inclusive classrooms, or higher education institutions. Articles were excluded if they lacked sufficient methodological detail, focused exclusively on technological development without a clear educational application, or failed to provide evidence relevant to at least one of the study aims. The final set of eligible studies constituted the corpus for synthesis and analysis. The overall selection process adhered to PRISMA recommendations and is summarised in a PRISMA flow diagram illustrating the number of records identified, screened, excluded, and included at each stage.

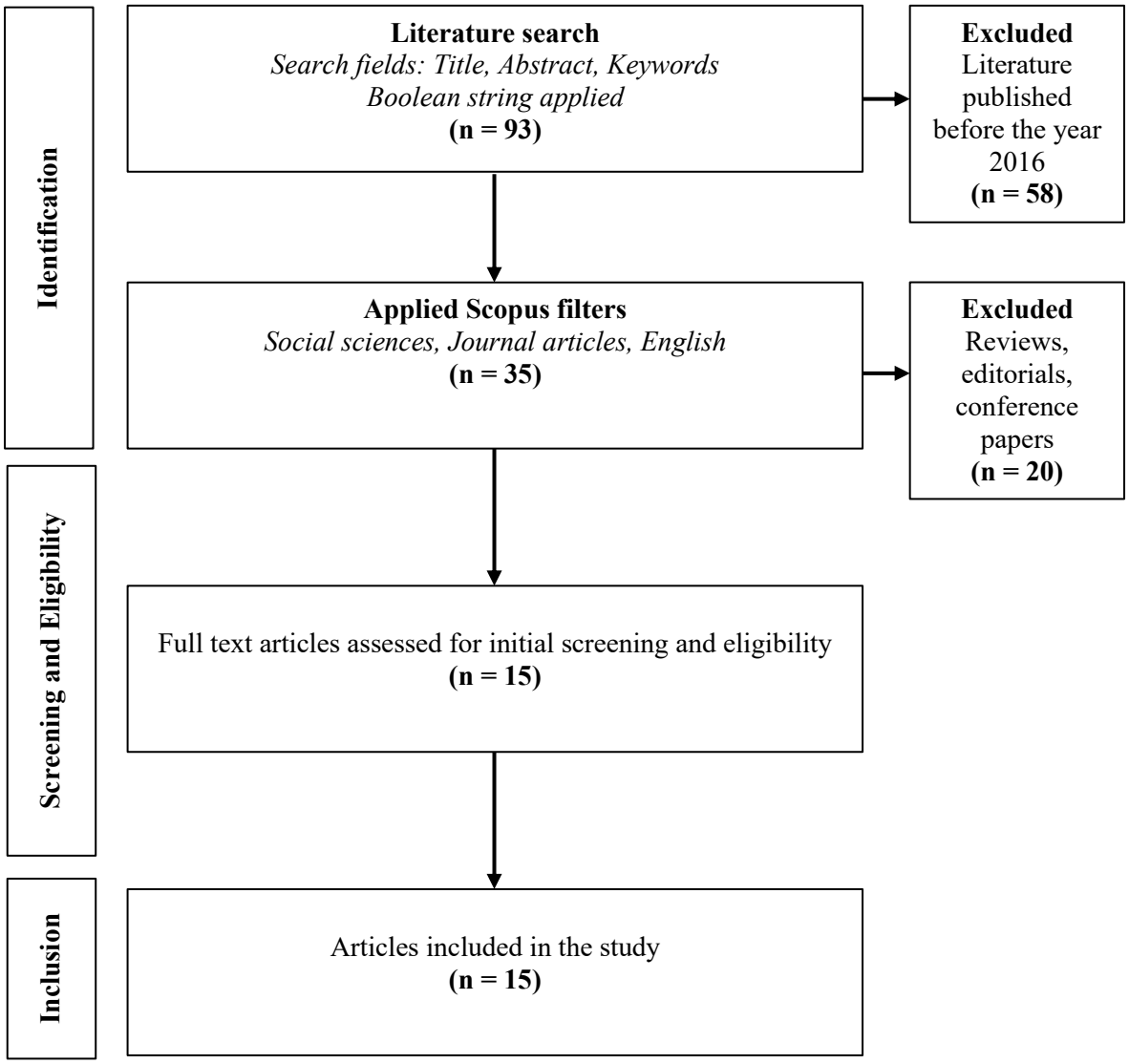

Figure 1: PRISMA 2020 Systematic Literature Flow Diagram

3.1.4 Data Collection and Data Analysis

A structured data extraction matrix was developed to systematically capture key information from each included study. Extracted data included authors and year of publication, study title, research objectives, methodology, key findings, identified gaps, limitations, and recommendations for future research.

Table 3: Analysis Matrix of Included Studies

No.	Authors and (Years)	Study Title	Research Objectives	Methodology	Key Findings	Identified Gaps, Limitations, and Recommendations for Future Research
1.	M V, N., Ricky Gill, J.C. (2024)	*English Reading and Writing Enhancement for Deaf and Hard of Hearing (DHH) Students with Skybox AI: Utilization of AI Image Generators*	To evaluate the effectiveness of using Artificial Intelligence (AI), specifically Skybox AI, to improve English reading and writing skills among DHH students.	Quasi-experiment with pre-test and post-test using a sample of 36 secondary school DHH students; paired sample t-test analysis.	Significant improvement in reading and writing skills after Skybox AI intervention; enhanced comprehension, engagement, and motivation of DHH students.	Limited to one AI tool and specific school context. Future research should involve multiple AI technologies, other subjects, and longer durations to assess long-term effectiveness.
2.	O'Boyle, S., Mathews, E., Brosens, C., Omardeen, R., Van Landuyt, D., Jones, A., & Quigley, L. (2024)	*A deaf-centred art-science approach to community engagement with sign language technologies*	To explore a deaf-centred community approach to public engagement with sign language translation technologies (SLMT).	Qualitative; co-creation methods, theatre performances, audience discussions, thematic analysis.	Art-science approaches centred on sign language enhance understanding, trust, and community engagement. Audience highlighted machine translation limitations and importance of deaf leadership.	Need for more ethical, accurate, and inclusive SLMT development. Future research should expand into formal education contexts and assess educational impacts.
3.	Hashim, M. H. M., & Tasir, Z. (2020)	*An e-learning environment embedded with sign language videos: research into its usability and the academic performance and learning patterns of deaf students*	To evaluate usability of e-learning environments with sign language videos and their effects on academic performance and learning patterns of deaf students.	Mixed methods: usability surveys, performance tests (pre–post), e-learning log analysis, interviews, decision tree analysis.	Significant improvement in academic performance of deaf students. High performers accessed sign language videos more frequently. Usability rated moderate but effective for learning outcomes.	Focused on one Science subject and limited context. Future studies should cover multiple subjects, adaptive design, and long term learning pattern analysis.
4.	Koddebusch, M., Hinrichs, J. A., He, J. & Becker, J. (2024)	*Design Requirements for Inclusive Assistive Technologies: Facilitating Communication Between the Deaf and the Hearing*	To develop design requirements for inclusive assistive technologies enabling equal communication between deaf and hearing communities.	Design Science Research (DSR): literature review, web content analysis, interviews.	Produced 18 functional requirements, 8 UI/UX requirements, and 9 process requirements emphasizing socio-technical perspectives and deaf-centred design.	Requirements not yet tested via prototypes. Future research should involve system development and evaluation in educational and social contexts.

No.	Authors and (Years)	Study Title	Research Objectives	Methodology	Key Findings	Identified Gaps, Limitations, and Recommendations for Future Research
5.	Ploylim, T., & Michel, C. P., (2023).	*Development of Augmented Reality Learning Materials for the Hearing Impaired Students in Primary I*	To develop and evaluate effectiveness of AR-based learning materials for primary school deaf students.	Developmental research & quasi-experiment (pre–post); sample of 10 students.	AR-Book highly effective; post-intervention achievement improved; high student satisfaction.	Small sample size and single school. Replication in broader contexts and long-term impact studies recommended.
6.	Coppola, M., & Walker, K. (2025)	*Early Language Access and STEAM Education: Keys to Optimal Outcomes for Deaf and Hard of Hearing Students*	To assess effects of timing of language access and language modality on cognitive development and STEAM outcomes of DHH students.	Large-scale quantitative study (n = 404); behavioural and cognitive assessments.	Early language access more significant than modality. Early access supports better cognitive, math, and STEAM skills.	Did not focus on specific technological interventions. Future research should integrate STEAM pedagogy with visual and sign language technologies.
7.	Kydyrbekova, A., Karymsakova, A., Abildinova, G., Serik, M. & Dokuz, A. S. (2025)	*Exploring Digital Storytelling for Enhancing Computer Science Education: A Case Study with Deaf Students*	To evaluate effectiveness of digital storytelling in improving computational thinking and digital literacy of DHH students.	Quasi-experiment/case study – pre–post with control group (n = 64).	Experimental group showed clear improvement in computational thinking and digital literacy; motivation and engagement also increased.	Limited to one country and CS subject. Future studies should expand across curricula, cultures, and larger scales.
8.	Ferreiro-Lago, E., & Osuna-Acedo, S. (2017)	*Factors Affecting the Participation of the Deaf and Hard of Hearing in e-Learning and Their Satisfaction: A Quantitative Study*	To identify participation levels of DHH individuals in e-learning and relationships between sociodemographic factors, accessibility, and learning satisfaction.	Quantitative – online survey; non-probability sample (n = 484); chi-square and correspondence analysis.	Participation influenced by education level, sign language proficiency, household size. Accessibility directly linked to learning satisfaction.	Limited to Spain and survey method. No specific interventions tested. Future studies should design sign language-friendly e-learning and conduct longitudinal/cross-country comparisons.
9.	Hazaymeh, O. M. (2025)	*Interactive Sign Singing and Embodied Song for the Deaf and Hard of Hearing Using Hologram Technology*	To evaluate effectiveness of hologram-based sign language technology in enhancing DHH individuals' understanding	Experiment – treatment and control groups; quantitative and qualitative data from live performance experiences.	Hologram sign language improved song comprehension, artistic interaction, and emotional	Small sample size; focused on music context. Not yet tested in formal education. Future studies should involve classrooms and

No.	Authors and (Years)	Study Title	Research Objectives	Methodology	Key Findings	Identified Gaps, Limitations, and Recommendations for Future Research
			and engagement with music content.		engagement compared to conventional methods.	improve accuracy of audio-to-sign conversion.
10.	Sivunen, U. (2025)	*Lived Experiences of Language Use and (In) Accessibility among Multilingual Deaf and Hard-of-Hearing Adolescents and Young People in Technology-Enhanced Learning in Finland*	To explore experiences of language use and accessibility in Technology-Enhanced Learning (TEL) among multilingual DHH adolescents and youth.	Qualitative – semi-structured video interviews; data-based content analysis (n = 23).	TEL often not sign-language friendly due to lack of skilled teachers, real-time captions, and interpreting services. Translanguaging and social media identified as sources of learning support and linguistic identity.	Small-scale study limited to Finland; findings not generalizable. Future research should include large-scale quantitative studies and TEL interventions based on Universal Design for Learning (UDL) and sign language.
11.	Ibrahim, Z., Alias, N., & Nordin, A. B. (2016).	*Needs Analysis for Graphic Design Learning Module Based on Technology & Learning Styles of Deaf Students*	To identify learning needs of deaf students for a graphic design module based on technology and their learning styles.	Quantitative – descriptive survey using questionnaires; purposive sampling (n = 58 deaf students in vocational schools & polytechnics in Malaysia).	High need for technology-based visual learning modules, use of sign language, videos, animations, and ICT tools. Deaf students prefer visual, active, and sequential learning styles.	Limited to needs analysis without actual module development/testing. Future studies should involve module development, pedagogical effectiveness testing, and larger-scale experiments.
12.	Karthigadevi, G., & Thangarasu, N. (2021)	*Projecting the Learning Attainment of Speech and Hearing Impairment Students from Domestic, Discrete, Communication and Educational Aspects*	To evaluate domestic, communication, cognitive, and educational factors influencing learning attainment of students with speech and hearing impairments.	Mixed methods – quantitative, qualitative, and experimental; cognitive tests and group comparisons.	Students with hearing impairments performed better in visual tasks and short-term memory using digital materials compared to printed ones. Technology support and visual teaching strategies improved learning attainment.	Focused more on cognitive comparisons, less on designing specific educational interventions. Future studies should develop technology- and sign-language-based pedagogical models and conduct longitudinal research.
13.	Sreemathy, R., Turuk, M., Kulkarni, I., &	*Sign Language Recognition Using Artificial Intelligence*	To develop and evaluate a sign language recognition system using AI as a tool	Experimental – system development using computer vision & machine learning (ANN,	Sign language recognition system achieved up to 99% accuracy with deep learning models.	Focused mainly on technical system performance. No evaluation of pedagogical

No.	Authors and (Years)	Study Title	Research Objectives	Methodology	Key Findings	Identified Gaps, Limitations, and Recommendations for Future Research
	Khurana, S. (2023)		for learning and communication support.	CNN, Deep Learning); model accuracy testing.	Technology has potential to enhance comprehension, cognition, and learning of hearing-impaired children.	effectiveness in real classrooms. Future studies should test integration in formal education and across multiple sign languages.
14.	Alzahrani, A. (2022)	*The Implementation of Assistive Technology with a Deaf Student with Autism*	To examine use of Assistive Technology (AT) in classrooms to support sign language acquisition and learning progress of a deaf student with autism.	Qualitative – semi-structured interviews with one teacher and one interpreter; classroom observations; thematic analysis.	AT such as iPads and laptops had very positive effects on learning, behaviour, and communication. AT increased engagement, motivation, and supported sign language acquisition. Main barrier was limited AT access in school systems.	Single case study with limited generalizability. Future studies should involve more students, diverse AT types, and long-term effectiveness evaluations in different formal education contexts.
15.	Abdallah A. Alshawabkeh a, M. Lynn Woolsey b, Faten F. Kharbat (2021)	*Using Online Information Technology for Deaf Students during COVID-19: A Closer Look from Experience*	To explore perceptions of deaf students and lecturers on use of technology in distance learning during COVID-19.	Qualitative – semi-structured interviews; thematic analysis; sample of deaf university students (n = 15) and lecturers (n = 3).	Five main themes identified: course content, technology, delivery methods, assessment, and social interaction. Online learning was challenging in terms of communication and social interaction but improved technological skills and adaptability of students.	Limited to one institution and pandemic period. Future studies should focus on sign-language-friendly online learning design, lecturer training, interpreter roles, and UDL integration in higher education.

3.1.5 Trustworthiness and Rigor

To enhance the rigor and trustworthiness of the review, several strategies were employed. A transparent search strategy and explicit inclusion criteria were used to minimise selection bias. The use of a structured data extraction matrix ensured consistency across studies, while the PRISMA guided process enhanced methodological transparency. Together, these procedures strengthen the credibility and replicability of the review.

4. Research Findings

This section presents findings from the systematic review. The analysis applied thematic synthesis of 15 studies, guided by the research questions. Three themes emerged: (i) types of digital and assistive technologies, (ii) educational purposes and outcomes, and (iii) implementation factors and research gaps.

4.1 Types of Digital and Assistive Technologies Used (RQ1)

The reviewed studies reported a wide range of digital and assistive technologies that support learners with hearing impairments in special and inclusive education settings. These technologies can be grouped into TEL platforms, assistive communication technologies, AI-based systems, and immersive visual technologies. TEL and e-learning platforms were the most frequently reported, especially when enhanced with visual resources, captions, and sign language videos. Assistive communication tools, such as speech-to-text systems and captioning, helped learners access instructional content and classroom discourse. Several studies examined AI-based technologies, such as sign language recognition and automated translation systems. Most of these remain at the experimental or pilot stage. Immersive technologies, including augmented reality and hologram based applications, were less common. However, they showed potential to enhance visual engagement and understanding.

4.2 Educational Purposes and Reported Outcomes (RQ2)

The studies identified key outcomes for learners with hearing impairments using digital and assistive technologies: (1) increased access to instruction; (2) greater engagement and motivation, especially with interactive or visually rich tools; (3) improved comprehension, literacy, and subject learning; and (4) better participation in online and blended learning via real time tools. These outcomes depended on the quality of instructional design and effective technology implementation.

4.3 Implementation Factors, Challenges, and Research Gaps (RQ3)

Implementation factors strongly shaped the effectiveness of digital and assistive technologies. Teacher readiness was a major issue. Limited skill in inclusive pedagogy, sign language, or using technology reduced effective use. Accessibility challenges included unreliable captions, few sign language options, and poor interface design. Institutional constraints, such as weak infrastructure, inconsistent policy, and resource gaps, also affected outcomes. This was especially true in low and middle income settings. The review identified research gaps: few longitudinal studies, rare large scale classroom trials of new technologies, and limited coverage of varied language and cultural contexts. These gaps highlight the need for more long-term and context sensitive research on technology supported inclusion.

The findings indicate that digital and assistive technologies can help learners with hearing impairment access, engage, and participate in learning. However, their effectiveness can vary widely. It depends on how well they are integrated, their accessibility, and the level of

institutional support. These results form the basis for further discussion on their role in inclusive education practice and policy.

5. Discussion of Findings

This systematic literature review synthesised evidence from 15 studies to examine the role of emerging digital and assistive technologies in supporting learners with hearing impairment in special and inclusive education. Three key arguments consistently emerge from the literature. First, while technology can facilitate language access and participation, it does not independently ensure inclusion. Second, the educational benefits of technology are contingent upon its integration into pedagogy and the accessibility of the language of instruction; technology alone is insufficient. Third, effective implementation of these technologies requires robust systemic and institutional support structures. These arguments are identified as consistent patterns across the entire evidence base reviewed, rather than being derived from individual studies.

5.1 Technology as a Means of Access, Not Inclusion in Itself

The reviewed studies indicate that digital and assistive technologies are primarily utilised to enhance access to instruction and communication, rather than to fundamentally transform pedagogy. Tools such as captioning, speech-to-text services, and sign language embedded learning materials are consistently identified as essential for participation, particularly in online and blended learning environments (Alshawabkeh et al., 2021; Sivunen, 2025). A consistent pattern across studies is that accessibility is achieved when language and interaction supports are embedded, whereas participation remains limited when platforms and instructional practices are predominantly speech- and audio-based. Furthermore, findings demonstrate that technology alone does not ensure accessibility; in the absence of sign language support or reliable visual communication features, digital platforms often perpetuate existing educational barriers (Ferreiro-Lago & Osuna-Acedo, 2017). Collectively, these studies reinforce concerns within inclusive education that digitalisation should not be equated with inclusion. Technology serves as an enabler only when accessibility is systematically integrated into design, practice, and classroom assessment processes.

5.2 Educational Outcomes Depend on Linguistic and Pedagogical Alignment

The review demonstrates that positive educational outcomes, such as engagement, comprehension, and participation, are contingent on pedagogical integration and linguistic accessibility, while technological sophistication is of secondary importance. Studies incorporating sign language resources, visual scaffolding, and multimodal supports reported more consistent learning benefits, especially when materials were tailored to learners' visual communication needs (Hashim et al., 2020; Ibrahim et al., 2016). Interactive methods, including augmented reality and digital storytelling, further enhanced motivation and conceptual understanding when aligned with learners' visual strengths (Ploylim & Michel, 2023; Hazaymeh, 2025). Collectively, the evidence indicates that learning gains are most likely when technology is combined with accessible language input and intentional instructional design, rather than being used as an isolated tool. Conversely, technology implemented without adequate attention to instructional quality or language access yielded limited educational value. This pattern aligns with broader educational research, which underscores that outcomes result from the interplay of pedagogy, content, and learner needs, rather than technology alone.

5.3 Centrality of Language Access

Effective language access is fundamental to the success of digital and assistive technologies. Learners with hearing impairment face educational barriers primarily due to communication challenges, not cognitive limitations (Karthigadevi & Thangarasu, 2021). In addition, external evidence suggests that early and sustained access to an accessible language is a stronger predictor of educational outcomes than language modality alone (Coppola & Walker, 2025). Technologies such as AI-based speech-to-text and sign language recognition are designed to reduce access barriers and facilitate communication (Sreemathy et al., 2023; Madahana et al., 2022). However, the reviewed studies collectively indicate that technology is most effective when it supports accessible language environments and participation opportunities, rather than attempting to compensate for delayed language exposure. These tools are therefore most beneficial as supplements to, rather than replacements for, language-rich and inclusive educational settings.

5.4 Emerging Technologies: Potential and Caution

Building on these foundational elements, the review identifies growing interest in AI-enabled and immersive technologies, such as sign language recognition, augmented reality, and hologram based tools. Although several studies report promising technical performance and increased learner engagement (Sreemathy et al., 2023; Hazaymeh, 2025), the evidence remains largely preliminary. A consistent pattern is that emerging technologies are often assessed in small scale or short term studies, which limits the ability to draw conclusions about long-term educational impact, scalability, and sustainability. Additionally, research centred on deaf perspectives cautions that technologies developed without ongoing input from deaf communities may inadvertently perpetuate marginalisation, even when intended to be inclusive (O'Boyle et al., 2024). These findings underscore the importance of participatory, context-sensitive design and rigorous evaluation of educational effectiveness in diverse real-world settings.

5.5 Systemic and Implementation Constraints

Systemic factors beyond technology design significantly influence effectiveness. Teacher readiness consistently emerges as a major challenge; limited proficiency in sign language, inclusive pedagogy, or technology integration constrains the quality and consistency of implementation (Ibrahim et al., 2016; Alshawabkeh et al., 2021). Institutional barriers, such as inadequate infrastructure, inconsistent accessibility policies, and resource disparities, are also prominent, particularly in low and middle income contexts (Ferreiro-Lago & Osuna-Acedo, 2017; Madahana et al., 2022). The evidence base demonstrates that even well designed technologies are less effective when educators and institutions lack the necessary training, standards, and resources to implement accessibility in daily teaching and assessment. These findings highlight that inclusive education requires comprehensive system-wide commitment, and that digital and assistive technologies must be integrated within supportive policies, professional development, and accessibility standards to achieve sustained impact.

Collectively, these thematic findings indicate that decision makers should prioritise language accessibility, pedagogical integration, and institutional support over a primary focus on technological innovation. Although new technologies provide additional tools, ongoing challenges persist in accessibility design, teacher preparedness, and policy implementation. The review therefore advocates for a deliberate shift toward learner centred, language inclusive educational systems, in which digital tools facilitate genuine equity and participation rather than merely representing technological progress.

6. Conclusion

By supporting learners with hearing impairment within special and inclusive education contexts, the review demonstrates that digital and assistive technologies have the potential to enhance access to instruction, communication, and participation for deaf and hard-of-hearing learners. However, the findings also make clear that technological innovation alone is insufficient to ensure educational inclusion. Instead, the effectiveness of these technologies is shaped by their alignment with linguistic accessibility, inclusive pedagogy, and systemic support structures.

Across the reviewed studies, technologies such as captioning systems, speech-to-text tools, sign language embedded learning materials, and AI-based communication supports were primarily used to address access related barriers. When these tools were integrated thoughtfully into teaching and learning processes, they contributed to improved comprehension, engagement, and participation (Hashim et al., 2020; Alshawabkeh et al., 2021). Conversely, when technologies were implemented without consideration of sign language access, instructional design, or teacher readiness, their impact was limited and, in some cases, counterproductive (Ferreiro-Lago & Osuna-Acedo, 2017; Sivunen, 2025). These findings reinforce the argument that inclusive education requires a shift from accommodation-based models toward proactive, language-accessible learning environments.

Importantly, the review highlights the centrality of language access in mediating educational outcomes for learners with hearing impairment. Evidence consistently shows that learning challenges faced by DHH learners stem from communication barriers rather than cognitive limitations (Karthigadevi & Thangarasu, 2021). Large scale research further indicates that early and sustained access to an accessible language, particularly sign language, plays a decisive role in shaping developmental and educational outcomes (Coppola & Walker, 2025). This underscores the need to situate digital and assistive technologies within broader educational ecosystems that prioritise linguistic inclusion from the earliest stages of learning.

While emerging technologies such as AI-based sign language recognition, speech-to-text translation, augmented reality, and immersive applications show promise, the review reveals that much of the existing evidence remains exploratory. Many studies are limited in scale, duration, or contextual diversity, highlighting the need for cautious interpretation of their potential impact. Without attention to inclusive design principles, cultural linguistic appropriateness, and real world implementation conditions, technological innovations risk reinforcing existing inequities rather than addressing them (O'Boyle et al., 2024; Madahana et al., 2022).

7. Implications

For educators, the findings emphasise the importance of integrating digital and assistive technologies within inclusive pedagogical frameworks. Teachers should prioritise instructional designs that embed sign language, visual supports, and multimodal resources, rather than relying solely on retrofitted accommodations. Professional development initiatives should focus on building teachers' competencies in inclusive technology use, sign language awareness, and accessible instructional strategies to ensure that technologies are used effectively to support learning. Educational institutions have a critical role in establishing system-level support for inclusive technology implementation. This includes investing in accessible digital infrastructure, ensuring the availability of qualified interpreting and

captioning services, and adopting accessibility standards for learning platforms and materials. Institutional commitment to inclusion must extend beyond policy statements to encompass sustained resource allocation and accountability mechanisms.

From a policy perspective, the findings highlight the need to align inclusive education policies with enforceable accessibility requirements and clear implementation guidelines. Policymakers should recognise language access as a fundamental educational right and ensure that digital education initiatives incorporate sign language and visual accessibility from the outset. In addition, targeted funding and capacity building initiatives are needed to support the adoption of inclusive technologies in low and middle income contexts, where resource constraints may otherwise limit access. Policies should also encourage participatory and deaf centred approaches to technology development and evaluation. Engaging deaf learners, educators, and communities in decision making processes can help ensure that digital and assistive technologies reflect real educational needs and cultural linguistic contexts.

The review identifies several directions for future research. First, there is a need for longitudinal, large scale studies examining the sustained educational impact of digital and assistive technologies on learners with hearing impairment. Second, more research is required to explore implementation processes, including teacher training models, institutional readiness, and policy effectiveness. Third, future studies should prioritise diverse geographical, linguistic, and socio-economic contexts to address current gaps in global representation. Finally, research should increasingly foreground the perspectives of DHH learners to ensure that technology enhanced inclusion is evaluated from the standpoint of lived educational experiences.

In conclusion, this literature review adds to social science and education by synthesising emerging digital and assistive technologies for learners with hearing impairment. Based on the findings, we recommend the following: prioritise linguistic accessibility for all learners, intentionally design pedagogy to support diverse needs, and commit systemically to inclusion. By adopting learner centred, language inclusive, and evidence-based methods, educators, institutions, and policymakers can more effectively leverage digital and assistive technologies to build equitable, sustainable, and inclusive education systems.

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Conflict of Interest Statement
The author declares that there is no conflict of interest regarding the publication of this manuscript. The author confirms that the review was conducted independently and that no financial or personal relationships influenced the research process, interpretation of findings, or reporting of results.

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