

## The Effectiveness of Augmented Reality in Enhancing Learning for Deaf Students: A Systematic Review

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**Abstract:** Deaf students frequently experience communication barriers that affect learning interaction and access to instructional content in inclusive education settings. Augmented Reality (AR) has emerged as a promising assistive technology capable of providing visual-interactive learning environments aligned with the learning characteristics of deaf learners. This study aims to systematically examine the effectiveness and research trends of AR implementation in deaf education. A Systematic Literature Review (SLR) was conducted following the PRISMA guidelines. Articles published between 2015-2025 were retrieved from Scopus, Google Scholar, PubMed, and IEEE Xplore databases using predefined search strings and eligibility criteria. After screening and eligibility assessment, six studies were included in the final synthesis. Bibliometric analysis using Bibliometrix was applied to identify research patterns and thematic development. The synthesis revealed four major themes: (1) AR-supported visual communication enhancement, (2) improved learning interaction and engagement, (3) accessibility and interface customization needs, and (4) device usability challenges related to comfort and affordability. Findings indicate that AR contributes positively to learning participation and conceptual understanding among deaf students; however, technological accessibility and ergonomic limitations remain critical concerns. In conclusion, AR demonstrates substantial potential as an inclusive learning support technology for deaf education. Nevertheless, limited empirical studies and device-related constraints highlight the need for user-centered design and broader implementation research in inclusive educational contexts.

**Keywords:** Augmented Reality (AR); Deaf Students; Learning Enhancement; Educational Technology; Inclusive Education.

### INTRODUCTION

Education is a crucial aspect in shaping the quality of human life (Domains et al., 2025) (Yuwono et al., 2025). For children with disabilities, particularly those with hearing impairments, the challenges in the learning process are often more significant than those faced by their typically developing peers (Gudyanga, 2014)(Efrina & Kusumastuti, 2020). One of the factors that can help overcome these challenges is the use of technology, specifically Augmented Reality (AR) (Alalwan et al., 2020). AR, which blends real-world elements with virtual objects, provides a more immersive and interactive learning experience, particularly beneficial for students with disabilities. Previous studies related to the application of AR in the education of deaf students have shown its potential in enhancing understanding and engagement in learning (Salim et al., 2025).

In the context of inclusive education, deaf students often face difficulties in communicating with teachers and peers (Hankebo, 2018). This communication barrier can hinder their academic and social development (Efrina et al., 2018)(Studies, 2018). The use of AR as an assistive tool can help address this issue by offering deeper visual and haptic features, allowing deaf students to interact more effectively with learning materials (Deb, 2018). However, while some studies show positive results, challenges still exist in AR implementation, such as the comfort of using the devices and the need to customize interface designs for easier accessibility by students with disabilities (Rahmatrisilvia, 2015)(Artigas & Falc, 2021).

Previous research has shown that AR can increase student engagement in the learning process and help them grasp challenging concepts, as highlighted in the study by (Ferino et al., 2023), which identified the positive impact of AR on motivation and interaction among deaf students in educational settings (Pamungkas et al., 2024). Despite these positive outcomes, issues such as the comfort of using head-mounted displays and limitations in the design of AR applications need to be addressed to enhance its effectiveness in this context (Febriyanti et al., 2024; Lee et al., 2020).

This research aims to further explore the use of AR in improving the quality of education for deaf students, with a focus on developing AR application designs that are more tailored to their needs. The study will also examine the challenges and limitations that may arise in implementing AR in inclusive schools, as well as identify factors that support the success of this technology in the education of deaf students.

The gap in existing research lies in the need for a deeper understanding of how AR can be effectively applied in the education of deaf students, particularly in terms of device comfort and interface design. While several studies show positive outcomes, there has been limited research specifically addressing the design challenges and comfort issues associated with using AR in the education of deaf students in Indonesia. Therefore, this study will fill this gap by exploring the design elements of AR that are most suitable for use in this context and identifying factors that can improve the comfort and effectiveness of this technology for deaf students.

Additionally, this research aims to develop practical guidelines for educators and educational technology developers to create more inclusive and effective AR applications for deaf students, which can be used in everyday learning at inclusive schools.

## **METHOD**

### ***Research Design***

This study uses a Systematic Literature Review (SLR) design, following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method to evaluate and analyze relevant articles on the application of Augmented Reality (AR) technology in the education of deaf students (Zhang et al., 2020). Additionally, bibliometric analysis is applied using Bibliometrix to provide deeper insights into trends, publication patterns, and relationships between the articles involved in this research (Kumar, 2025). A systematic search strategy was developed to identify relevant studies on the application of Augmented Reality in deaf education. The search process employed predefined keywords combined using Boolean operators. The primary search string used was:

(“Augmented Reality” OR “AR technology”) AND (“deaf students” OR “hearing impairment” OR “deaf education”) AND (“learning” OR “education” OR “inclusive education”).

Searches were conducted across four international databases: Scopus, Google Scholar, PubMed, and IEEE Xplore. Only peer-reviewed articles published in English between 2015 and 2025 were included.

### ***Time and Location of the Study***

This research is conducted during the year 2025, focusing on studies published between 2015 and 2025 that are related to the use of AR in the education of deaf students. The research is not conducted in a specific physical location, as it utilizes literature available in international databases.

### ***Research Subjects***

The subjects of this research are articles published in international journals that focus on the topic of Augmented Reality (AR) in education for deaf students, as well as the application of AR technology in inclusive education settings. The sample consists of articles that meet the inclusion and exclusion criteria established in this study. The selected samples are based on results from searches in several academic databases, such as Scopus, Google Scholar, PubMed, and IEEE Xplore.

### ***Inclusion and Exclusion Criteria***

The inclusion criteria for this research are:

- 1) Articles discussing the use of AR in the education of deaf students.
- 2) Articles published between 2015 and 2025.
- 3) Studies with valid and clear research designs, published in indexed journals.

The exclusion criteria are:

- 1) Articles not addressing AR in an educational context.
- 2) Articles that do not meet the quality standards set by PRISMA.

The methodological quality of the included studies was evaluated using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist. Each article was assessed based on research design clarity, data collection procedures, validity of findings, and relevance to the educational context of deaf students. Studies that did not meet minimum methodological quality standards were excluded from the final synthesis to ensure reliability and rigor of the review findings.

### ***Data Collection Techniques***

Data for this study are collected through a systematic search in academic databases as mentioned earlier. Articles that meet the inclusion criteria are filtered based on titles and abstracts, followed by further analysis. The article selection process involves two stages:

- 1) Title and Abstract Screening: This stage identifies articles relevant to the research topic.
- 2) Full-Text Screening: After identifying relevant articles, their full texts are reviewed to ensure alignment with the inclusion criteria.

The study selection process followed PRISMA guidelines involving identification, screening, eligibility, and inclusion stages. The screening process was conducted independently by two reviewers to minimize selection bias and improve reliability. Any disagreements regarding article eligibility were discussed and resolved through consensus. This procedure ensured transparency and consistency throughout the article selection process.

### ***Research Instruments***

The instrument used in this research is the PRISMA Flow Diagram to illustrate the process of article search and selection. This diagram shows the stages of identification, screening, eligibility, and synthesis of articles used in the research. Additionally, bibliometric analysis is performed using Bibliometrix to allow the researcher to analyze publication trends, citations, and author collaborations, as well as the relationships between the selected articles.

### **PRISMA Stages**

The following table illustrates the PRISMA stages used in this research, showing the article selection and screening process:

**Tabel 1. PRISMA stage**

PRISMA Stage	Number (n)
Identification	296
After Removing Duplicates	296
Title & Abstract Screening	237
Full-Text Eligibility	131
Included in Final Synthesis	6

### **Data Analysis Techniques**

The data obtained from the literature search will be analyzed using two main approaches:

- 1) **Qualitative Analysis:** Each article included in this study will be analyzed thematically to identify key findings related to the use of AR in the education of deaf students, as well as its benefits and challenges.
- 2) **Bibliometric Analysis:** Using Bibliometrix, the data will be analyzed to assess publication trends, the number of articles published, and citation analysis, which can reveal the impact and development of research in this field.

Bibliometric analysis was conducted using the Bibliometrix package implemented in *RStudio* to examine research development patterns related to Augmented Reality in deaf education. The analysis included annual scientific production, most relevant sources, keyword co-occurrence networks, thematic evolution mapping, and collaboration patterns among authors. These analytical parameters enabled visualization of research trends and thematic concentrations within the selected studies.

### **Research Procedure**

This research follows the PRISMA procedure, which involves four main stages:

- 1) **Identification:** Collecting all relevant articles from various academic databases using predefined keywords.
- 2) **Screening:** Filtering articles based on the inclusion and exclusion criteria established.
- 3) **Full-Text Eligibility:** Reviewing the full text of articles that pass the screening process to ensure they meet quality and relevance standards.
- 4) **Synthesis:** Analyzing and synthesizing the results from the selected articles to gain a deeper understanding of the application of AR in the education of deaf students.

By following this approach, this research is expected to provide valuable insights into the application of AR technology in inclusive education, as well as offer practical recommendations for developing more effective AR applications for deaf students in inclusive schools.

Potential bias in this review may arise from database selection, language restrictions, and publication availability. Only English-language studies indexed in selected databases were included, which may limit representation of regional research findings. Furthermore, the relatively small number of studies included in the final synthesis ( $n = 6$ ) reflects the emerging nature of Augmented Reality research specifically addressing deaf education contexts. These limitations were considered during interpretation of the findings.

## FINDING AND DISCUSSION

### Finding(s)

This study analyzes various articles discussing the application of Augmented Reality (AR) in the education of deaf students. The results of the analysis highlight key findings obtained from the literature selected using the PRISMA method and bibliometric analysis. The key findings regarding the use of AR in the education of deaf students are as follows:

**Table 2. Key Findings from Articles Included in the Synthesis**

Author & Year Title	Title	Desain	Focus RQ	Key Findings
(Ridha & Shehieb, 2021)	Assistive Technology for Hearing-Impaired and Deaf Students Utilizing Augmented Reality	Development and Evaluation of AR System for Deaf Students	How AR assists hearing-impaired students in integrating into mainstream education.	AR glasses with features like real-time transcription, speech emotion recognition, and sound indication helped students overcome communication barriers.
(Chamberlain, 2025)	Exploring Deaf and Hard of Hearing Peoples' Perspectives on Tasks in Augmented Reality	Empirical study exploring DHH users' interaction with AR tasks in a game.	How Deaf and Hard of Hearing people interact with 3D AR objects and instructions.	DHH participants preferred interaction based on context and visual or haptic cues. Design recommendations included customizable UI and haptic feedback.
(Fernandes et al., 2024)	Augmented Reality in Education for People Who Are Deaf or Hard of Hearing	Systematic Literature Review (SLR) on AR in DHH education	What design elements and impacts influence AR applications for DHH education?	AR in education for DHH students showed positive impacts on motivation, interaction, and learning, but issues with comfort (e.g., head-mounted displays) were noted.
(Cabanillas-carbonell et al., 2022)	Mobile Application with Augmented Reality to Improve the Process of Learning Sign Language	Development and evaluation of a mobile AR app for learning Peruvian Sign Language (PSL).	How does AR improve learning time and information retention for Sign Language?	The AR mobile app significantly improved learning time and information retention, with students reducing learning time by 65%.
(Pieriboni et al., 2026)	STEM Education and ICT-Enhanced Tools for Students with Disabilities	Five-year review of ICT tools for STEM education for students with disabilities	How do ICT-enhanced tools impact STEM education for students with disabilities?	ICT and AI tools in STEM education showed significant improvements in accessibility, learning engagement, and motivation for students with disabilities.
(Carter, 2026)	Let's CHAT About Artificial Intelligence for Students With Disabilities: A Systematic Literature Review and Meta-Analysis	Meta-analysis of AI-based interventions for students with disabilities	What is the overall effect of AI on students with disabilities' learning outcomes?	AI-based interventions showed medium positive effects on students with disabilities' learning outcomes, especially in areas of academic performance and engagement.

### *Thematic Synthesis of AR Implementation in Deaf Education*

The findings from the six selected studies were synthesized using a thematic analysis approach to identify recurring research patterns and conceptual relationships regarding the implementation of Augmented Reality in deaf education. Instead of analyzing studies individually, the synthesis integrates common findings across studies to generate broader analytical themes.

Four major themes emerged from the synthesis: (1) AR-supported visual communication, (2) enhanced learning interaction and engagement, (3) accessibility and interface customization, and (4) device usability and technological constraints. These themes represent dominant research directions and practical considerations in implementing AR for deaf learners within inclusive educational environments.

### ***AR for Visual Communication Support***

Across the reviewed studies, AR technology primarily functions as a visual communication facilitator for deaf students. Features such as real-time captioning, sign-language visualization, gesture recognition, and visual cues enable students to access instructional information more effectively. These visual augmentations reduce dependence on auditory instruction and support inclusive classroom participation.

### ***Learning Interaction and Engagement Enhancement***

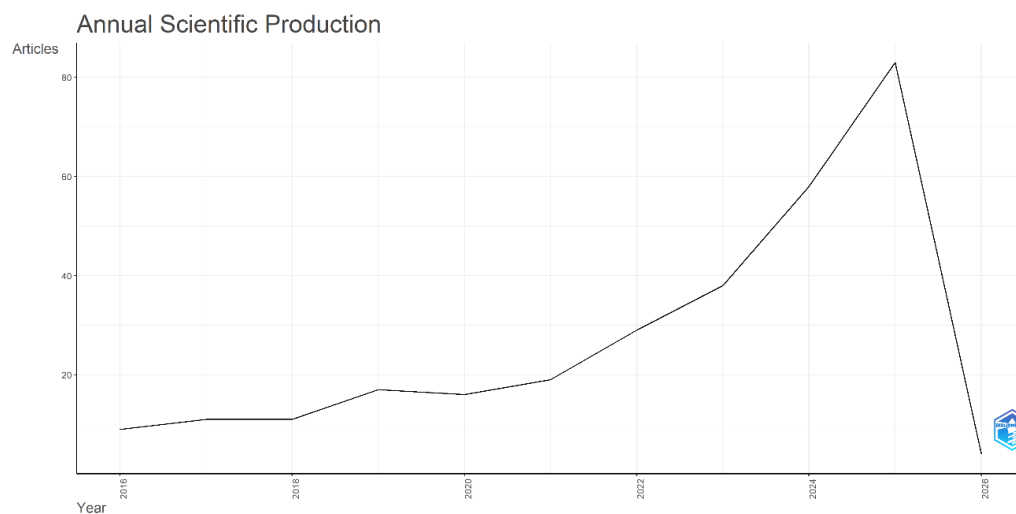
The synthesis indicates that AR environments significantly increase student engagement through immersive and interactive learning experiences. Visual simulation and contextual interaction promote active participation and improve conceptual understanding, particularly for abstract learning materials that traditionally pose challenges for deaf learners.

### ***Accessibility and Interface Customization***

Several studies emphasize the importance of adaptive interface design to accommodate diverse learner needs. Customizable visual layouts, haptic feedback, and user-controlled interaction settings were identified as essential components supporting accessibility and learner autonomy in AR-based educational applications.

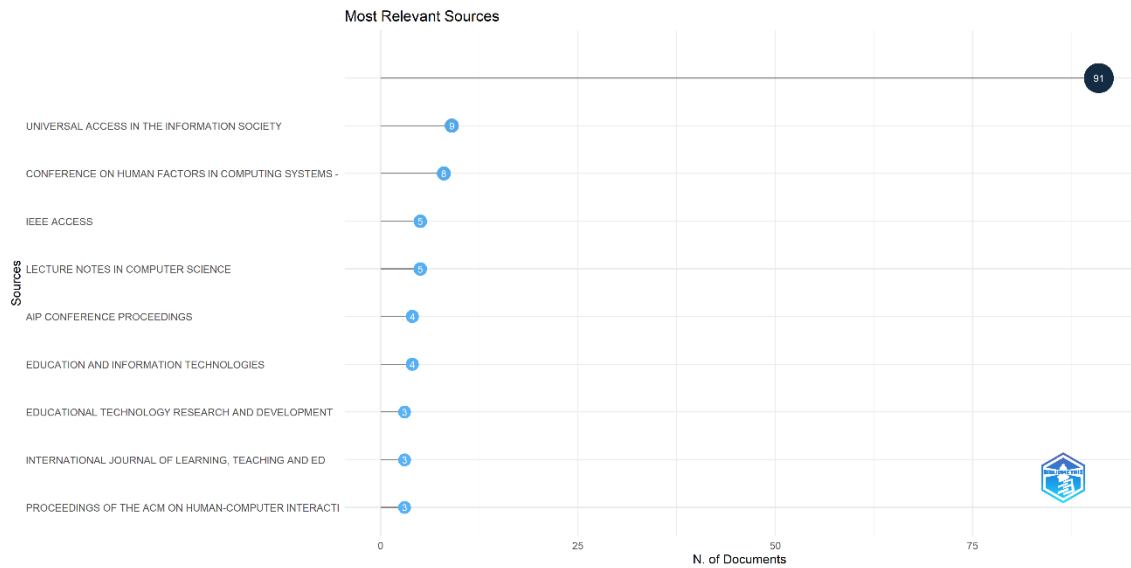
### ***Device Comfort and Technological Constraints***

Despite positive educational outcomes, technological limitations remain evident. Issues related to device weight, prolonged headset usage, cost of hardware, and infrastructure requirements were consistently reported across studies. These constraints highlight the necessity of user-centered and ergonomically optimized AR design for sustainable classroom implementation.



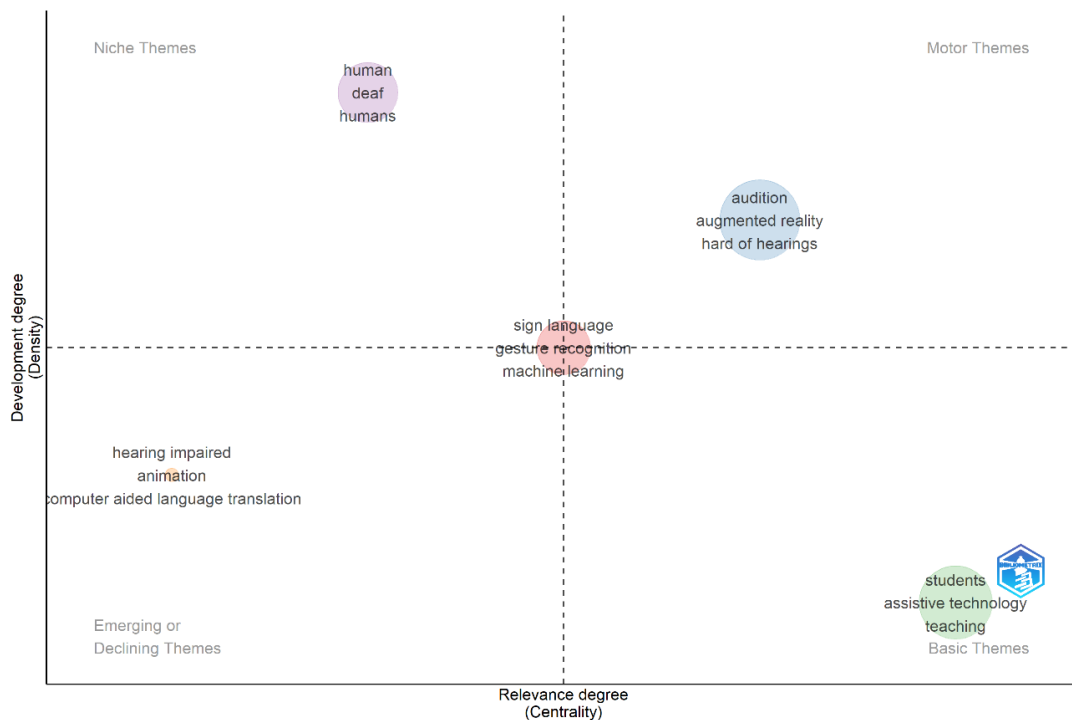
**Figure 1. Annual Scientific Production**

This figure depicts the annual scientific production related to the use of AR in the education of deaf students from 2016 to 2026. There is a noticeable spike in publications in 2023, indicating increased interest in this topic. However, there is a sharp decline in 2026, which may reflect a temporary decrease in research output related to this area.



**Figure 2. Most Relevant Sources**

This figure shows the most relevant sources in publications discussing AR in the education of deaf students. The primary source with the highest number of articles is Universal Access in the Information Society, followed by conferences on human factors and computing systems. This indicates that much of the research on AR in deaf education is published in journals and conferences focusing on technology and accessibility.



**Figure 3. Development and Relevance Degree of Themes**



This figure provides an overview of the contribution of each source to document production related to the topic of AR in the education of deaf students. It is clear that the majority of publications come from conferences and technology journals, indicating a strong concentration of articles in these domains.

### ***Interpretation of Bibliometric Visualization***

The bibliometric visualizations provide comprehensive insights into the research development of Augmented Reality (AR) in deaf education. The dominance of keywords such as sign language, assistive technology, and inclusive interaction indicates that current research trends primarily emphasize visual communication enhancement as a central strategy for supporting deaf learners in educational environments. These findings confirm that AR technology is predominantly utilized to address communication accessibility challenges experienced by students with hearing impairments.

In addition, the concentration of publications within technology-oriented journals and conference proceedings demonstrates that advancements in this field are largely driven by technological innovation rather than pedagogical development. While this trend reflects rapid progress in AR technology, it simultaneously reveals limited integration between educational theory, inclusive instructional design, and special education practices.

The visualization patterns further suggest that future research should promote stronger interdisciplinary collaboration among educational researchers, special education practitioners, and technology developers. Such collaboration is essential to ensure that AR applications are not only technologically advanced but also pedagogically meaningful and aligned with learner-centered principles and the cognitive characteristics of deaf students in inclusive education settings.

### ***Interpretation of Results***

The results obtained from the analysis indicate that AR in the education of deaf students is steadily growing, with a significant surge in publications observed in 2023. This reflects the increasing recognition of AR as a valuable technology for enhancing learning experiences for deaf students. Various AR applications, such as AR glasses used to overcome communication barriers and AR-based Sign Language learning applications, have demonstrated positive effects on students with disabilities.

Key themes such as sign language, gesture recognition, and augmented reality show that AR technology is highly connected with visual and haptic-based interactions, providing solutions to the communication challenges often faced by deaf students. Additionally, findings from bibliometric analysis reveal that much of the research in this area is coming from technology and accessibility sources, further supporting the notion that AR is an essential tool in inclusive education.

The importance of assistive technology and teaching methods is also evident, highlighting that AR not only supports communication but also boosts engagement in the learning process. As AR technology continues to develop, it is expected that more tailored AR applications will emerge, providing even better learning experiences for deaf students in inclusive classrooms.

## Discussion

In this section, the results of the study will be further discussed in relation to the research objectives, and the findings will be linked to existing theories and previous research. This discussion will address the research questions, connect the results with relevant literature, and provide insights into the implications of the findings for inclusive education, particularly for deaf students.

This systematic review synthesizes current evidence regarding the implementation of Augmented Reality (AR) in deaf education and provides critical insights beyond individual study findings. The results indicate that AR technology plays a substantial role in improving learning accessibility through visually enriched instructional environments. From a special education perspective, this outcome is consistent with visual learning and cognitive accessibility theories, which emphasize that deaf learners primarily process information through visual modalities rather than auditory input. AR-based visualization, gesture representation, and contextual simulation therefore function as compensatory learning supports that facilitate comprehension and reduce communication barriers within instructional settings.

The effectiveness of AR identified across studies can also be interpreted through inclusive education and Universal Design for Learning (UDL) frameworks. UDL principles advocate multiple means of representation, engagement, and action to accommodate learner diversity. The reviewed studies demonstrate that AR environments enable flexible interaction, real-time visualization, and experiential learning opportunities that support active participation among deaf students. This transition from teacher-centered delivery toward interactive learning environments strengthens learner agency and promotes equitable classroom participation in inclusive education contexts.

Despite these promising outcomes, this review reveals that existing AR research remains predominantly technology-oriented. A considerable proportion of studies prioritize system development and technical performance while providing limited discussion on pedagogical integration or instructional adaptation. Such imbalance indicates that technological innovation alone does not guarantee meaningful educational improvement. Effective implementation requires alignment between assistive technology design, instructional strategies, and learner characteristics specific to deaf education. Without pedagogical grounding, AR risks functioning merely as an engaging visualization tool rather than a transformative learning medium.

Another critical issue emerging from the synthesis relates to accessibility and sustainability. Although AR applications demonstrate positive effects on engagement and conceptual understanding, challenges associated with device comfort, hardware cost, and infrastructure requirements remain significant barriers. Head-mounted displays and advanced AR devices may cause physical discomfort during prolonged use, potentially limiting classroom applicability. Furthermore, unequal access to technological resources may widen educational disparities between institutions with differing levels of digital readiness. These findings highlight the importance of user-centered and ergonomically informed AR design tailored to educational environments.

Importantly, learner perspectives must be positioned at the center of AR development. Studies included in this review suggest that customizable interfaces, visual autonomy, and interactive control enhance motivation, confidence, and learning independence among deaf students. These outcomes align with constructivist learning theory, which posits that knowledge construction occurs through active interaction with learning environments. AR

therefore supports experiential learning processes by allowing students to manipulate visual information and engage directly with instructional content.

From a socio-educational standpoint, the integration of AR technology also reflects broader transformations within inclusive digital education policies. The adoption of assistive technologies corresponds with global commitments to equitable education access and digital inclusion. However, sustainable implementation requires institutional support, teacher professional development, and policy alignment to ensure that technological adoption translates into improved learning outcomes rather than temporary innovation initiatives.

This review further emphasizes the necessity of interdisciplinary collaboration among educators, special education experts, software developers, and policymakers. Future AR development should integrate pedagogical theory, accessibility standards, and contextual educational needs to ensure relevance for deaf learners across diverse learning environments. Consequently, AR should be conceptualized not merely as an emerging technology but as an inclusive pedagogical ecosystem capable of enhancing communication accessibility, social participation, and independent learning.

## CONCLUSION

This systematic literature review provides consolidated evidence regarding the role of Augmented Reality (AR) in supporting learning accessibility for deaf students within inclusive education environments. The synthesis of selected studies indicates that AR contributes positively to visual communication support, learner engagement, and conceptual understanding by transforming auditory-dependent instruction into visually accessible learning experiences. These findings confirm that AR has strong potential as an assistive pedagogical medium capable of reducing communication barriers and promoting active participation among deaf learners.

However, the findings should be interpreted with caution due to several limitations inherent in this review. First, the relatively small number of eligible studies included in the final synthesis reflects the emerging stage of AR research specifically focused on deaf education. Second, database and language restrictions may have excluded relevant studies published in non-English sources, introducing potential publication bias. Additionally, variations in research design and technological implementation across studies limit direct comparison of effectiveness outcomes.

From a practical perspective, future implementation of AR in deaf education should prioritize user-centered design, affordability of technological devices, and teacher readiness to integrate AR into instructional practices. Educational institutions and policymakers are encouraged to support sustainable adoption through inclusive digital infrastructure development and professional training programs for educators.

Future research should expand empirical investigations involving long-term classroom implementation, learner experience evaluation, and pedagogically grounded AR design frameworks. Strengthening collaboration between technology developers, special education researchers, and practitioners will be essential to ensure that AR development aligns with inclusive education principles and responds effectively to the learning characteristics of deaf students.

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