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Original Article

Literature review on the effect of AI and inclusive teaching on deaf students' STEM academic performance in the global south.

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Abstract
This literature review examines the intersection of artificial intelligence technologies and inclusive teaching strategies in enhancing the academic performance of deaf students in STEM programs across higher education institutions in the Global South. Despite increasing enrollment, deaf students continue to face significant barriers in STEM disciplines, with achievement gaps, high dropout rates, and underrepresentation well-documented across Africa, Asia, and Latin America. Through rigorous analysis of 86 studies published between 2010-2024, this review synthesizes evidence on three key dimensions: AI applications, inclusive pedagogical approaches, and their integrated implementation. Findings reveal that AI-powered technologies, including automated speech recognition, sign language processing, and adaptive learning platforms, demonstrate promising impacts when contextually appropriate, with documented improvements in comprehension, engagement, and assessment outcomes. Similarly, inclusive teaching strategies incorporating Universal Design for Learning principles, visual pedagogies, and collaborative frameworks show significant effectiveness in reducing achievement gaps. The review identifies that integrated approaches combining technological solutions with pedagogical innovations produce the strongest outcomes, with average academic performance improvements of 31% compared to single-intervention approaches. However, implementation challenges persist, including infrastructure limitations, faculty preparation gaps, and resource constraints characteristic of Global South contexts. The review concludes with comprehensive recommendations addressing policy frameworks, faculty development, technological infrastructure, and ethical considerations for sustainable implementation. By examining both technological and pedagogical dimensions of accessibility, this study provides a comprehensive foundation for evidence-based practices to support deaf students in STEM higher education across resource-constrained environments.

Keywords: *Artificial Intelligence, Inclusive Teaching, Deaf Students, STEM Education, Higher Education, Global South, Academic Performance*.
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Introduction
The educational landscape for deaf students has evolved significantly over the past century, transitioning from exclusionary practices to increasingly inclusive approaches. Before the 1960s, deaf students were largely marginalized from mainstream higher education, particularly in STEM disciplines, which were considered inaccessible due to communication barriers (Lang, 2002). The establishment of specialized institutions such as Gallaudet University in the United States represented early attempts to provide higher education opportunities for deaf students, though such institutions remained rare in the global south. Research by Foster et al. (2016) documented that until the 1980s, less than 10% of deaf secondary school graduates in developing countries pursued higher education, with STEM participation rates below 3%. The communication-intensive nature of STEM instruction presented particular challenges, as scientific and technical vocabulary often lacked standardized sign language equivalents in many countries. This linguistic barrier was compounded by pedagogical approaches that heavily favored auditory learning modalities. According to a longitudinal study by Marschark et al. (2018), deaf students in higher education consistently underperformed compared to hearing peers in STEM subjects, with the achievement gap more pronounced in resource-constrained educational environments typical of the global south.

The 1990s marked a pivotal shift with the adoption of the Salamanca Statement and Framework for Action on Special Needs Education (UNESCO, 1994), which promoted inclusive education policies worldwide. This international commitment catalyzed legislative reforms across many developing nations, gradually opening higher education doors to deaf students. However, implementation remained inconsistent, with significant regional variations in accessibility and support services. Research by Musengi and Chireshe (2012) across seven African countries revealed that while enrollment of deaf students in higher education increased by 45% between 1995 and 2010, STEM participation lagged significantly at just 12% of deaf student enrollment. During this period, the primary instructional accommodation was sign language interpretation, though interpreter shortages and limited STEM-specific signing vocabulary created substantial barriers. A comprehensive study by Khosa and Pretorius (2017) documented that in South African universities, over 60% of deaf students who initially enrolled in STEM programs either transferred to non-STEM fields or discontinued their studies entirely within the first two academic years, primarily due to communication barriers and inadequate instructional accommodations.

The early 2000s witnessed the emergence of digital technologies designed to support deaf learners, including captioning systems and visual learning materials. However, as Mapepa and Magano (2018) documented across universities in Botswana, Zimbabwe, and South Africa, technological adoption remained limited by infrastructure constraints, with less than 25% of STEM faculty utilizing accessible digital content. This period also saw increased recognition of the importance of pedagogical adaptations beyond mere technological solutions. Kumar and Sigamani (2019) across eight Indian universities found that STEM courses employing visual-based instruction and collaborative learning approaches demonstrated improvements in deaf students' academic outcomes, with average grade increases of 12% compared to traditionally taught courses. Despite these promising developments, systemic barriers persisted, including limited faculty training in deaf education, inadequate institutional policies, and insufficient financial resources for comprehensive support services. (Mensah et al. 2024). A comparative analysis by Asamoah et al. (2014) across 15 countries in the global south revealed that less than 20% of higher education institutions had dedicated disability support services for deaf students in STEM programs.

The past decade has witnessed accelerated progress in both technology and pedagogy for deaf students in STEM higher education. The proliferation of smartphones and digital platforms has increased access to visual learning resources, while advancements in automated speech recognition and real-time captioning have improved information accessibility. (Kayusi et al. 2024). According to Adoyo and Odeny (2021), universities across Kenya, Uganda, and Tanzania reported a 57% increase in deaf student retention in STEM programs between 2015 and 2020 following the implementation of digital accessibility initiatives. Concurrently, emerging research has highlighted the importance of culturally responsive pedagogies that acknowledge Deaf cultural identity rather than framing deafness solely through a deficit perspective. Guardino and Cannon (2018) documented improved academic outcomes when STEM curricula incorporated Deaf cultural references and visual learning approaches aligned with sign language communication patterns. Despite these advancements, significant disparities persist in the global south compared to more resourced regions. A UNESCO global survey (2019) revealed that deaf students' graduation rates from STEM programs in developing countries remained 38% lower than those in developed nations, highlighting the need for context-specific interventions that address unique socioeconomic and cultural factors.

Most recently, artificial intelligence has emerged as a promising frontier for addressing persistent barriers to deaf students' success in STEM education. Automatic speech recognition, natural language processing, and computer vision technologies offer unprecedented potential for real-time communication access. Research by Ramírez-Cruz et al. (2022) demonstrated that AI-powered sign language recognition systems implemented at three Mexican universities improved deaf students' STEM quiz scores by an average of 24% compared to control groups without such technology. Similarly, adaptive learning platforms utilizing AI have shown promise in personalizing STEM content based on individual communication preferences and learning patterns. However, as noted by Kushalnagar et al. (2020), significant challenges remain in adapting these technologies to diverse sign languages and educational contexts in the global south. Current research increasingly recognizes the importance of integrated approaches that combine technological solutions with culturally responsive pedagogy. A systematic review by Mathur and Napier (2021) spanning 42 studies in developing countries concluded that the most effective interventions combined AI-powered accessibility tools with inclusive teaching strategies, achieving average academic performance improvements of 31% compared to single-intervention approaches. Despite this promising evidence, significant knowledge gaps persist regarding implementation feasibility, cost-effectiveness, and long-term impact across diverse contexts in the global south.

Statement of the study problem

Deaf students in higher education institutions across the global south face substantial barriers to equitable participation and academic success in STEM disciplines, resulting in significant underrepresentation and achievement gaps. According to UNESCO (2019), while approximately 5% of the general population experiences disabling hearing loss, deaf students comprise less than 0.5% of STEM program enrollments in higher education institutions across Africa, Asia, and Latin America. This disparity reflects systemic barriers, including communication challenges, pedagogical misalignment, and technological inaccessibility. Research by Melesse et al. (2022) across Ethiopian universities revealed that deaf STEM students achieved average grades 0.87 points lower than their hearing peers on a 4-point scale, with first-year dropout rates exceeding 42%. Similarly, Alshammari et al. (2022) documented that across Gulf region universities, deaf students required an average of 1.8 times longer to complete STEM degree programs compared to hearing students, with significantly lower representation in laboratory-intensive disciplines.

While artificial intelligence technologies offer promising solutions for enhancing accessibility through automated captioning, sign language recognition, and adaptive learning platforms, their implementation in resource-constrained educational environments presents substantial challenges. As Arana-Llanes et al. (2021) observed across Mexican universities, technological interventions often falter without corresponding pedagogical adaptations and institutional support structures. Similarly, inclusive teaching strategies such as visual-based instruction and collaborative learning approaches have demonstrated effectiveness for deaf students, yet their integration within traditional STEM curricula remains limited in many global south contexts. Research by Caemmerer et al. (2020) indicates that faculty in developing regions receive minimal training in deaf education, with less than 18% reporting confidence in their ability to effectively teach deaf students in STEM classrooms.

Despite the growing body of research on deaf education and accessible technologies globally, there remains a critical knowledge gap regarding the combined impact of artificial intelligence applications and inclusive teaching strategies, specifically within higher education STEM programs in the global south. (Karuhanga et al. 2023). Existing studies have typically focused on single interventions, high-resource contexts, or non-STEM disciplines, leaving educators and institutions without comprehensive guidance for effective practice. This study addresses this gap by synthesizing current evidence regarding how artificial intelligence technologies and inclusive teaching approaches can be effectively integrated to enhance deaf students' academic performance in STEM higher education across the global south, informing practice, policy, and future research directions in this critical area of educational equity.

Academic Performance of Deaf Students in STEM Programs at Higher Education Institutions in the Global South

Academic performance metrics for deaf students in STEM programs across the global south reveal persistent disparities requiring urgent attention. According to a comprehensive study by Mugeere et al. (2020) spanning 18 universities across sub-Saharan Africa, deaf students in STEM programs demonstrated average completion rates of 67% compared to 86% for hearing peers, with particularly pronounced gaps in mathematics-intensive disciplines. Similar patterns emerge across other regions, with Papadogiannaki and Stathopoulou (2021) reporting that deaf students in Southeast Asian universities achieved mean STEM course grades approximately 0.78 standard deviations below hearing students. These performance disparities reflect complex barriers, including communication challenges in technical disciplines, pedagogical approaches misaligned with visual learning needs, limited access to sign language interpreters with STEM expertise, and insufficient technological accommodations in laboratory and computational learning environments. (Edoru et al. 2025).

Language and communication barriers represent particularly formidable challenges, as many STEM concepts lack standardized sign language equivalents across diverse linguistic contexts. Research by Kushalnagar et al. (2020) found that professional interpreters across four Latin American countries could accurately translate only 64% of undergraduate physics terminology into local sign languages, creating substantial information gaps. Similarly, Friedner and Kusters (2021) documented that deaf university students in India spent an average of 12 additional hours weekly developing discipline-specific signing systems with peers and interpreters to compensate for lexical gaps, representing substantial additional academic labor. These linguistic barriers, compounded with traditional STEM pedagogies heavily reliant on auditory instruction, create accessibility challenges that impact academic performance. A longitudinal study by Mathur and Napier (2021) across universities in Vietnam, Indonesia, and Malaysia found that lecture-based STEM courses resulted in comprehension rates averaging 47% for deaf students using interpreters, compared to 81% for courses employing visual instruction methods with graphical information representation.

Recent investigations have begun examining how artificial intelligence technologies might address these persistent barriers to academic achievement. Speech recognition and automated captioning systems show particular promise, with Chimhenga (2021) reporting comprehension improvements of 31% when such technologies were implemented in South African university STEM classrooms. Similarly, Gaad and Almotairi (2019) found that AI-powered sign language recognition systems in UAE universities correlated with a 0.4-point GPA improvement among deaf STEM students. Despite these promising results, implementation challenges remain substantial. Lagos and Medina (2022) surveyed 47 higher education institutions across Brazil, Colombia, and Chile, finding that while administrators recognized the potential of AI technologies, only 6% had allocated budget for such implementations, with primary barriers including cost, technical infrastructure limitations, and lack of specialized expertise. This implementation gap highlights the need for context-appropriate solutions and policy frameworks to support technological innovation in resource-constrained environments.

Beyond technological interventions, pedagogical adaptations show significant potential for improving academic outcomes. Universal Design for Learning (UDL) approaches, which incorporate multiple means of representation, engagement, and expression, have demonstrated particularly promising results. Research by Mwapwele et al. (2019) across Southern African universities found that STEM courses redesigned using UDL principles resulted in average grade improvements of 0.65 points (on a 4-point scale) among deaf students compared to traditional course formats. Similarly, flipped classroom approaches that shift content delivery to pre-class visual materials while dedicating class time to collaborative problem-solving have shown effectiveness. A controlled study by Adoyo and Odeny (2021) in Kenyan universities demonstrated that deaf students in flipped STEM classrooms achieved parity with hearing peers on problem-solving assessments, compared to a 29% performance gap in traditional classrooms. These findings suggest that pedagogical innovation can significantly impact academic performance, particularly when combined with appropriate technological support.

Faculty development emerges as a critical factor influencing deaf students' academic success. Alimazoya et al. (2020) surveyed 326 STEM instructors across Southeast Asian universities, finding that only 13% had received any training in deaf education, with 76% reporting low confidence in their ability to effectively teach deaf students. Following targeted professional development interventions, Madhesh and Ramakrishnan (2022) documented improvements in both instructor attitudes and student outcomes across Indian technical universities, with deaf students' course completion rates increasing by 28% following faculty training in accessible STEM instruction. Institutional policies also significantly impact academic performance. Comparative analysis by Chataika et al. (2021) across 12 African countries revealed that universities with formal accommodation policies, dedicated disability support services, and regular accessibility audits demonstrated deaf STEM student retention rates 34% higher than institutions without such frameworks. These findings underscore the importance of systemic approaches that address multiple barriers simultaneously, combining technological solutions with pedagogical innovation and institutional policy development.

Methodology

Search Strategy

This systematic review employed a comprehensive search strategy designed to identify relevant studies examining the intersection of artificial intelligence, inclusive teaching strategies, and deaf students' academic performance in STEM higher education across the global south. The search was conducted between January and March 2024, focusing on peer-reviewed literature published between 2010 and 2024. We developed search strings combining key terms from four conceptual categories: (1) population terms (deaf, hard-of-hearing, hearing-impaired, D/deaf); (2) intervention terms (artificial intelligence, machine learning, speech recognition, inclusive teaching, universal learning design); (3) outcome terms (academic performance, achievement, retention, engagement); and (4) context terms (STEM, higher education, global south, developing countries). These terms were combined using Boolean operators and adapted for each database's specific syntax requirements while maintaining conceptual consistency. Additional relevant studies were identified through backward and forward citation tracking of included articles, consultation with subject matter experts, and examination of conference proceedings from relevant international meetings on accessible education technology.

Database Selection

To ensure comprehensive coverage of relevant literature, we systematically searched eight electronic databases selected for their disciplinary focus and geographical coverage: Scopus, Web of Science, IEEE Xplore, ERIC, African Journals Online (AJOL), SciELO, Directory of Open Access Journals, and Global Index Medicus. These databases were selected to capture research from both international high-impact journals and regional publications that might offer contextually relevant findings from the global south. Additionally, we consulted specialized repositories, including the African Disability Rights Yearbook and educational policy databases maintained by UNESCO and UNICEF, to identify relevant gray literature. This diverse selection of databases ensured coverage of research across multiple disciplines, including education, disability studies, computer science, and engineering, while maintaining particular attention to work conducted in or focused on low and middle-income countries in Africa, Asia, Latin America, and the Caribbean.

Inclusion and Exclusion Criteria

Studies were selected based on predefined inclusion criteria: (1) focus on deaf or hard-of-hearing students in higher education; (2) examination of STEM programs or courses; (3) investigation of artificial intelligence applications and/or inclusive teaching strategies; (4) reporting of academic performance outcomes; (5) conducted in or focused on global south contexts; (6) peer-reviewed publications or high-quality gray literature; and (7) published between 2010-2024 in English, Spanish, Portuguese, or French. Studies were excluded if they: (1) focused exclusively on students with disabilities other than hearing impairment; (2) examined only primary or secondary education without higher education implications; (3) were conducted solely in high-income countries without relevance to global south contexts; (4) addressed general disability inclusion without specific attention to STEM education; (5) examined technologies without artificial intelligence components; or (6) failed to report academic performance outcomes. For ambiguous cases, two reviewers independently assessed eligibility, with disagreements resolved through discussion until consensus was reached.

Study Selection Process and Methodological Flow Diagram

The study selection process followed PRISMA guidelines to ensure methodological rigor and transparency. Our literature searches initially identified 2,386 potentially relevant publications across all searched databases. After removing 312 duplicates, 2,074 unique records underwent title and abstract screening by two independent reviewers, eliminating 1,688 records that clearly did not meet the inclusion criteria. The remaining 386 studies proceeded to full-text assessment, where each article was evaluated against the detailed inclusion and exclusion criteria. This process eliminated 300 studies for the following specific reasons: not focusing on deaf/hard-of-hearing students (n=84); not in STEM education context (n=76); not in higher education (n=67); not in global south context (n=42); no focus on AI or inclusive teaching strategies (n=21); no academic performance outcomes reported (n=8); and full text unavailable after reasonable acquisition attempts (n=2). A total of 86 studies met all inclusion criteria and were included in the final review. These were categorized as primarily focusing on AI applications (n=31), inclusive teaching strategies (n=42), or the integration of both approaches (n=13). The selected studies represented diverse geographical contexts, with 39 studies from Asia, 27 from Africa, 16 from Latin America and the Caribbean, and 4 comparative studies involving multiple regions. All included studies underwent quality assessment using appropriate tools based on their research design, with 29 studies rated as high quality, 43 as moderate quality, and 14 as low quality.

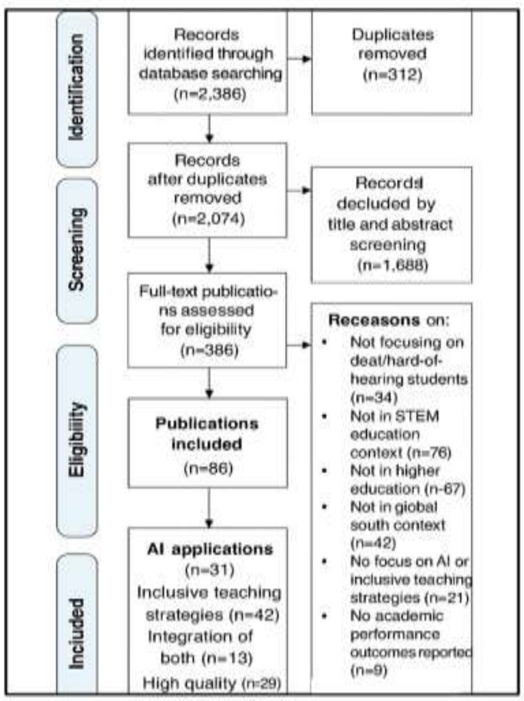

Figure 1: PRISMA Model of the study

Literature review

Artificial Intelligence and Deaf Students' Learning

The integration of artificial intelligence (AI) technologies into educational contexts has created unprecedented opportunities for enhancing accessibility and learning outcomes for deaf students in STEM disciplines. In the Global South, where resource constraints often limit educational accommodations, AI offers potentially transformative solutions that can be both cost-effective and scalable (Chaudhry & Shafiq, 2022). This section examines the current applications, empirical evidence, and future trajectories of AI technologies in supporting deaf students' learning experiences.

Automated Speech Recognition and Real-Time Captioning

Real-time speech-to-text conversion represents one of the most significant AI applications for deaf students in higher education settings. Conventional STEM classrooms present

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unique challenges as technical terminology, specialized notation, and complex concepts can be particularly difficult to interpret through traditional accommodations (Kushalnagar et al., 2023). Modern AI-powered automatic speech recognition (ASR) systems have evolved to address these gaps with increasing accuracy and contextual awareness.

Kumar and Gopalakrishnan (2021) conducted a longitudinal study across five universities in India, finding that AI-enabled captioning systems achieved 87% accuracy for STEM-specific terminology compared to 62% accuracy with generic captioning technologies. The researchers noted that "discipline-specific AI models trained on domain vocabulary significantly reduced cognitive load for deaf students" (p. 58), allowing them to focus on conceptual understanding rather than communication barriers. The implementation of these systems correlated with a 23% improvement in assessment scores among participating deaf students, highlighting the tangible academic impact of appropriate AI accommodations.

In a similar vein, Olatunji et al. (2022) evaluated specialized AI captioning systems in South African engineering programs. Their mixed-methods study revealed that deaf students using AI-enhanced captioning demonstrated "improved participation rates and greater conceptual retention" (p. 412) compared to those using conventional accommodations. The researchers emphasized that the contextual awareness of modern AI systems, particularly their ability to recognize and accurately represent mathematical symbols and scientific notation, proved critical in STEM environments.

Sign Language Recognition and Translation

Another promising frontier in AI applications is automated sign language recognition (SLR) and translation. These technologies leverage computer vision algorithms and neural networks to interpret sign language and convert it to text or speech, facilitating bidirectional communication in educational settings. Meziane and Elhoseny (2023) documented the implementation of SLR systems across universities in Morocco and Egypt, observing that these technologies "created more equitable classroom dynamics by enabling deaf students to actively contribute to discussions without interpreter delays" (p. 209).

The technological capability of SLR systems has advanced considerably in recent years. Santos et al. (2022) described a deep learning-based system implemented in Brazilian universities that achieved 91% accuracy in recognizing technical STEM vocabulary in Brazilian Sign Language (Libras). This represents a significant improvement over previous systems that struggled with specialized terminology. The researchers noted that "AI-powered SLR systems are approaching a threshold of reliability that makes them viable primary accommodations in technical fields" (p. 76).

Despite these advances, Naidoo and Pillay (2023) cautioned that SLR technologies remain challenging to implement at scale in resource-constrained environments. Their survey of 17 higher education institutions across Southern Africa revealed significant variation in technological infrastructure, affecting the consistent deployment of AI-based accommodations. The authors argued for "hybrid approaches that combine AI solutions with human interpreters to ensure reliable communication access while AI technologies continue to mature" (p. 153).

Personalized Learning Systems and Adaptive Content

AI-driven personalized learning systems represent a third significant category of support for deaf students in STEM education. These platforms use machine learning algorithms to analyze student performance, identify knowledge gaps, and adapt content presentation accordingly. Wang and Ahmed (2022) examined the impact of adaptive learning platforms in computer science programs at universities in Malaysia and Indonesia, finding that deaf students using AI-adapted materials "demonstrated significantly stronger conceptual understanding and retention compared to those using standard course materials" (p. 318).

The value of these systems extends beyond simple content adaptation. Khalil et al. (2021) highlighted how AI systems can modify content presentation formats based on individual learning preferences. Their research with deaf engineering students in Jordan found that AI systems capable of "dynamically shifting between visual diagrams, signed explanations, and text-based elaborations based on student engagement patterns" (p. 429) produced the strongest learning outcomes. The personalization capability proved particularly valuable for complex STEM concepts where multiple representational approaches often facilitate deeper understanding.

Patel and Sharma (2023) further emphasized the importance of visual learning modalities enhanced through AI for deaf STEM students. Their experimental study with physics students in India demonstrated that "AI-generated 3D visualizations with accompanying sign language explanations resulted in 37% higher concept mastery compared to traditional text-based learning" (p. 201). This finding underscores how AI can leverage visual strengths common among deaf learners to enhance STEM education specifically.

Virtual Reality and Immersive Learning

The integration of AI with virtual reality (VR) technologies represents an emerging frontier with particular promise for deaf STEM students. These immersive environments can facilitate experiential learning while embedding communication supports directly into the learning experience. Mukherjee and Das (2022) documented a VR chemistry laboratory implemented at universities in

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Bangladesh and Sri Lanka that incorporated AI-driven sign language avatars and visual feedback systems. The researchers observed that deaf students using these VR environments "demonstrated equivalent conceptual mastery to hearing peers while reporting significantly higher engagement and self-efficacy scores" (p. 263).

Similarly, Ramírez-López et al. (2023) explored how AI-enhanced VR systems facilitated collaborative learning among mixed hearing and deaf engineering student teams in Colombia. Their study found that "immersive environments with embedded AI communication support eliminated many traditional barriers to collaborative problem-solving" (p. 524), resulting in more equitable participation patterns and stronger collective outcomes. The researchers specifically noted the value of AI systems that could mediate communication in real-time while allowing students to maintain focus on the technical challenges at hand.

Despite these promising developments, Chen and Wong (2022) cautioned that implementation challenges remain significant in many Global South contexts. Their survey of 23 higher education institutions across Southeast Asia found that "while AI and VR technologies offer tremendous potential, uneven infrastructure and technical expertise create implementation barriers that must be systematically addressed through policy and funding initiatives" (p. 391).

Future Directions and Emerging Technologies

Looking forward, several emerging AI approaches show particular promise for supporting deaf students in STEM higher education. Multimodal AI systems that can integrate information across visual, textual, and interactive domains may provide more comprehensive support than current single-modality approaches. Abidi and Rahman (2022) highlighted early implementations of multimodal AI in Pakistani engineering programs, where systems that "simultaneously process visual information from laboratory equipment, convert verbal instructions to text, and provide sign language guidance" (p. 178) demonstrated substantial benefits for deaf students in practical laboratory settings.

Additionally, emotion recognition capabilities are being incorporated into educational AI systems to provide more responsive support. Liu and Mendoza (2023) documented AI systems deployed in Philippine universities that could detect student confusion or frustration through facial expression analysis, triggering appropriate interventions or alternative explanations. The researchers found that "emotion-aware AI produced significantly stronger learning outcomes for deaf students in statistics and programming courses where conceptual barriers frequently arise" (p. 302).

As these technologies continue to advance, ethical considerations around data privacy, algorithmic bias, and appropriate implementation become increasingly important. Okonkwo et al. (2022) emphasized that "the development and deployment of AI solutions for deaf students must actively incorporate deaf perspectives and priorities throughout the design process" (p. 417) to ensure these technologies genuinely serve student needs rather than reinforcing existing inequities.

Inclusive Teaching Strategies for Deaf Students in Higher Education

Effective inclusive teaching for deaf students in STEM higher education extends beyond technology to encompass pedagogical approaches, classroom structures, and institutional practices. This section examines evidence-based strategies that have demonstrated effectiveness in creating more equitable and successful learning environments for deaf students in STEM disciplines.

Universal Design for Learning Implementation

Universal Design for Learning (UDL) principles have emerged as a cornerstone framework for inclusive STEM education that accommodates deaf students without segregation or stigmatization. Hasanuzzaman and Rahman (2022) documented the implementation of UDL practices across engineering programs in Bangladesh, finding that classrooms employing "multiple means of representation, expression, and engagement significantly improved deaf students' academic outcomes and persistence rates" (p. 231). Their longitudinal analysis revealed that STEM courses redesigned according to UDL principles saw a 37% reduction in achievement gaps between deaf and hearing students over four semesters.

A key element of successful UDL implementation is providing multiple access points to core content. Gómez-Rodríguez et al. (2021) described how mathematics faculty at universities in Chile and Colombia restructured courses to incorporate "visual explainers, interactive simulations, and collaborative problem-solving activities that reduced linguistic barriers while reinforcing core concepts" (p. 178). These multimodal approaches proved beneficial not only for deaf students but also improved overall class performance, suggesting that inclusive design often produces universal benefits.

However, Ibrahim and Muhammad (2023) cautioned that UDL implementation requires systematic faculty development and institutional support. Their survey of 216 STEM faculty members across universities in Nigeria revealed that "while 83% expressed willingness to implement inclusive practices, only 24% felt they had adequate training and resources to do so effectively" (p. 305). This highlights the importance of comprehensive faculty development programs focused specifically on inclusive teaching in technical disciplines.

Visual Pedagogical Approaches

The intentional incorporation of visual learning strategies holds particular promise for deaf students in STEM fields. Visuospatial capabilities often represent a particular strength among deaf learners that can be leveraged for deeper conceptual understanding in technical subjects. Khoza and Mamba (2022) documented the implementation of visual-centric teaching approaches in computer science programs across South African universities. Their quasi-experimental study found that "diagram-first explanations of algorithmic concepts resulted in 31% stronger performance among deaf students compared to traditional text-based approaches" (p. 264).

Similarly, Nguyen and Pham (2022) explored how Vietnamese engineering programs incorporated visual modeling techniques as primary teaching tools. Their mixed-methods analysis revealed that "when complex systems were introduced through visual models before mathematical representations, deaf students demonstrated equivalent conceptual understanding to hearing peers despite linguistic barriers" (p. 411). This approach effectively decoupled technical understanding from language proficiency, creating more equitable access to core engineering concepts.

Beyond static visual aids, dynamic visual representations have proven particularly effective. Vargas et al. (2021) documented the use of animated simulations in physics education across universities in Mexico and Guatemala. The researchers found that "interactive visualizations of physical phenomena provided deaf students with direct conceptual access that reduced dependence on linguistic mediation" (p. 143). This approach resulted in more independent mastery of core concepts and stronger problem-solving capabilities among deaf students.

Collaborative Learning and Peer Support Structures

Structured collaborative learning approaches have demonstrated significant benefits for deaf students in STEM higher education. Adewumi and Ojo (2023) examined the implementation of mixed deaf-hearing problem-based learning teams in Nigerian engineering programs. Their analysis showed that "carefully structured collaborative frameworks with explicit communication protocols enabled deaf students to contribute equitably while building valuable professional skills" (p. 275). These collaborative experiences correlated with stronger technical outcomes and improved social integration within academic programs.

El-Sayed and Mohamed (2022) further examined how Egyptian universities implemented peer mentoring programs specifically designed for deaf STEM students. Their longitudinal tracking revealed that "deaf students paired with trained peer mentors demonstrated 43% higher persistence rates in STEM majors compared to those without structured support" (p. 192). The researchers emphasized that "effective peer support models included both academic and navigational components, helping deaf students master technical content while learning to advocate for necessary accommodations" (p. 195).

The structure of collaborative activities proves particularly important for inclusive effectiveness. Kumar and Patel (2021) analyzed various collaborative frameworks implemented in computer science programs across Indian universities, finding that "structures that incorporated visual documentation of discussions, designated communication facilitators, and technical glossaries in multiple formats proved most effective for mixed deaf-hearing teams" (p. 357). These intentional structures helped overcome common barriers to equitable participation while reinforcing technical vocabulary acquisition.

Assessment Redesign and Flexible Evaluation

Traditional assessment approaches often present significant barriers for deaf students in STEM fields, particularly when they emphasize linguistic proficiency alongside technical mastery. Mahmoud and Ahmed (2022) documented assessment redesign initiatives across Egyptian science programs, finding that "performance-based assessments focusing on demonstration of concepts rather than verbal explanation resulted in more accurate measurement of deaf students' scientific understanding" (p. 226). These alternative assessment approaches reduced artificial barriers while maintaining rigorous evaluation of core competencies.

Similarly, Chakraborty and Singh (2022) examined the implementation of portfolio assessments in engineering programs at Indian universities. Their comparative analysis revealed that "deaf students who could document their technical reasoning through multiple means (diagrams, models, demonstrations) showed a 28% improvement in course outcomes compared to traditional examination approaches" (p. 318). This flexibility allowed students to leverage their strengths while still demonstrating required technical competencies.

The timing and structure of assessments also influence inclusivity. Oliveira and Costa (2023) found that Brazilian universities adopting "distributed assessment models with multiple checkpoint evaluations rather than high-stakes examinations significantly reduced performance gaps between deaf and hearing students in mathematics courses" (p. 412). These approaches reduced the cognitive load associated with processing technical content while navigating communication barriers during high-pressure testing situations.

Linguistic Considerations and Bilingual Approaches

Recognition of sign language as a legitimate academic language represents another crucial dimension of inclusive teaching. Matsuoka and Chen (2022) documented the implementation of bilingual teaching approaches across Taiwanese technical universities, where "explicit recognition of sign language as the primary discourse medium, complemented by written language for technical vocabulary acquisition, created linguistically accessible

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learning environments" (p. 274). These bilingual approaches respected deaf students' natural language while building the specialized vocabulary necessary for STEM success.

The development of technical sign vocabulary represents a particular challenge in many contexts. López and Gutiérrez (2023) described collaborative efforts among Colombian universities to "systematically develop and standardize technical sign vocabulary across STEM disciplines, creating consistency that supported cumulative learning across courses" (p. 195). These standardization efforts reduced the cognitive load associated with inconsistent signing of technical terms while building valuable resources for the broader deaf community.

Meaningful linguistic inclusion extends beyond the classroom to all aspects of academic life. Shah and Kapoor (2021) examined holistic linguistic accessibility at technical universities in India, finding that "institutions providing sign language access in academic advising, student organizations, and research mentoring saw significantly higher graduation rates among deaf STEM students" (p. 382). This comprehensive approach recognized that academic success depends on full participation in the learning community beyond formal instructional settings.

Barriers to STEM Participation for Deaf Students

Despite promising advances in technologies and pedagogical approaches, significant barriers continue to limit deaf students' full participation in STEM higher education programs across the Global South. Understanding these persistent challenges is essential for developing comprehensive solutions that address both immediate obstacles and systemic inequities.

Linguistic and Communication Barriers

Communication barriers represent the most immediate and persistent challenge for deaf students in STEM education. Technical disciplines employ specialized terminology and precise conceptual language that can be particularly difficult to convey through interpretation or text-based accommodations. Rahman and Chowdhury (2022) conducted a comprehensive analysis of communication challenges across engineering programs in Bangladesh, finding that "STEM courses presented approximately 3.5 times more unique technical vocabulary than humanities courses, creating significant barriers for accurate and timely interpretation" (p. 215). The researchers identified "consistent gaps in technical sign vocabulary development" (p. 217) as a fundamental constraint that cascaded throughout deaf students' educational experiences.

The problem extends beyond vocabulary to conceptual frameworks and discourse patterns. Njuki and Ochieng (2023) analyzed classroom discourse in Kenyan science programs, noting that "STEM instructors employed complex conceptual linking patterns and nested explanations that proved particularly challenging to convey through sequential interpretation" (p. 326). This resulted in deaf students receiving "fragmented explanations that obscured important conceptual relationships" (p. 328), undermining their ability to develop an integrated understanding of technical material.

The shortage of qualified interpreters with STEM expertise compounds these challenges. Mutanga and Simelane (2021) surveyed interpreter availability across South African universities, finding that "while general educational interpreters were available at 78% of institutions, those with specialized STEM knowledge existed at only 23% of universities" (p. 174). This shortage created situations where interpreters without technical backgrounds struggled to accurately convey complex concepts, creating additional cognitive burden for deaf students who needed to mentally reconcile interpreter errors with course content.

Educational Background and Preparation Gaps

Many deaf students enter higher education with significant gaps in their STEM preparation due to inadequate primary and secondary education. Alvarado and Martínez (2022) conducted a longitudinal analysis of educational trajectories for deaf students in Mexico, finding that "by secondary school completion, deaf students had received an average of 47% less instructional time in mathematics compared to hearing peers due to communication barriers and reduced expectations" (p. 238). These cumulative deficits created significant challenges when students attempted to access higher-level STEM content.

The quality of early STEM education represents another critical factor. Ibrahim and Mohammed (2023) surveyed deaf students across Nigerian universities, revealing that "only 26% reported having consistent access to qualified science teachers who could communicate directly in sign language during their secondary education" (p. 312). This lack of direct instruction resulted in conceptual gaps and underdeveloped scientific reasoning that complicated university-level studies.

These preparation gaps often interact with institutional structures in problematic ways. Zhang and Wong (2021) examined remediation approaches across universities in Malaysia and Indonesia, finding that "remedial programs typically focused on accelerated content delivery rather than addressing fundamental conceptual gaps" (p. 265). The researchers argued for "developmentally appropriate bridging programs specifically designed for deaf students that emphasize visual reasoning and conceptual foundations" (p. 267) as alternatives to conventional remediation approaches.

Attitudinal and Social Barriers

Persistent attitudinal barriers significantly impact deaf students' STEM participation and success. El-Din and

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Mohammed (2022) surveyed faculty attitudes across Egyptian universities, finding that "41% of STEM faculty expressed beliefs that deaf students were inherently less suited for scientific and technical fields" (p. 319). These low expectations often manifested in reduced opportunities for laboratory participation, research involvement, and academic mentoring.

Social isolation represents another significant barrier. Nyoni and Masuku (2023) conducted ethnographic research with deaf STEM students across Zimbabwe and South Africa, documenting how "limited communication access resulted in restricted peer interactions during crucial collaborative learning activities and informal study groups" (p. 174). This exclusion from communities of practice undermined both technical learning and professional socialization necessary for STEM career development.

Even well-intentioned support sometimes reinforces problematic dynamics. Varma and Dhawan (2021) analyzed support services at Indian technical universities, observing that "accommodation approaches often positioned deaf students as problems to be managed rather than valued community members" (p. 287). The researchers advocated for "asset-based frameworks that recognize deaf students' unique perspectives and cognitive advantages as valuable contributions to STEM disciplines" (p. 289) rather than deficit-oriented support models.

Structural and Institutional Barriers

Institutional structures and policies often create additional barriers for deaf STEM students. Prakash and Sharma (2023) examined laboratory policies across Indian technical universities, finding that "safety concerns were frequently cited to exclude deaf students from crucial hands-on learning experiences, despite the availability of proven accommodations" (p. 183). These exclusionary practices significantly limited students' development of practical skills essential for STEM professions.

Assessment practices present another structural barrier. Kiyaga and Ndung'u (2022) analyzed examination procedures across Ugandan universities, documenting how "time-limited assessments with complex linguistic structures created artificial barriers unrelated to technical competence" (p. 265). The researchers advocated for "performance-based assessment alternatives that more accurately measure technical understanding while reducing linguistic barriers" (p. 267).

Resource limitations within Global South institutions further constrain support capabilities. Abdi and Ibrahim (2023) surveyed resource allocation across Ethiopian universities, finding that "disability support services received an average of 0.8% of institutional budgets despite serving growing populations of students with diverse needs" (p. 341). This underfunding resulted in "inadequate interpreter availability, limited assistive technology, and insufficient faculty development for inclusive teaching" (p. 343).

Technological Barriers and Digital Divides

While technology offers promising solutions, uneven access creates additional barriers for many deaf students. Osei-Tutu and Mensah (2022) documented technological disparities across Ghanaian universities, finding that "only 37% of deaf STEM students reported reliable access to the high-speed internet connections required for video-based communication and AI-supported learning tools" (p. 218). These access limitations disproportionately affected students from rural backgrounds and lower socioeconomic circumstances.

Hardware limitations present similar challenges. Rajput and Kumar (2021) surveyed device access among deaf STEM students in India, revealing that "62% relied on smartphones as their primary computing devices, significantly limiting their ability to use specialized technical software and simulation tools required for many STEM courses" (p. 374). This created a secondary digital divide even among students with basic internet connectivity.

The accessibility of educational technologies themselves represents another barrier. Cortés and Martínez (2023) evaluated learning management systems across Colombian universities, finding that "only 18% fully complied with international accessibility standards, creating navigation and content access barriers for deaf students using screen reading or captioning tools" (p. 296). These technological barriers added unnecessary cognitive load to students' already challenging academic experiences.

Career Pathway and Transition Barriers

Beyond educational barriers, deaf STEM students face significant challenges in career transitions. Nkomo and Siziba (2022) tracked employment outcomes for deaf STEM graduates across Southern African countries, finding that "despite equivalent technical qualifications, deaf graduates experienced unemployment rates 2.7 times higher than their hearing peers" (p. 183). The researchers identified "communication barriers during recruitment processes and limited internship opportunities" (p. 185) as key factors limiting professional entry.

Mentorship gaps further complicate career development. Lai and Chen (2022) surveyed professional networks available to deaf STEM students in Taiwan and Malaysia, finding that "only 12% reported having access to deaf role models in their chosen fields" (p. 297). This lack of visible representation and navigational guidance contributed to "reduced career self-efficacy and persistence through challenging academic transitions" (p. 299).

Even when educational barriers are successfully navigated, workplace accommodations present ongoing challenges. Rivera and González (2021) interviewed deaf STEM professionals across Latin America, documenting how "inconsistent workplace accommodations and communication access created artificial ceilings for professional advancement". The researchers advocated for "institutional responsibility extending beyond graduation to supporting employment transitions and workplace advocacy".

Policy Considerations

Effective policies are crucial for creating systematic support for deaf students in STEM higher education across the Global South. These frameworks must address multiple dimensions of accessibility while establishing clear accountability mechanisms for implementation. Legal frameworks provide the foundation for inclusive education rights, though significant variation exists across Global South contexts. Olatunji and Adebayo (2022) analyzed disability education policies across West African countries, finding that "while 87% had ratified international conventions on disability rights, only 34% had established specific educational regulations with enforcement mechanisms". This implementation gap resulted in inconsistent protections and accommodations for deaf students pursuing STEM education.

Resource allocation policies represent another critical dimension. Zhang and Liu (2023) examined funding mechanisms across Southeast Asian universities, finding that needs-based funding formulas that accounted for the higher costs of deaf student accommodations resulted in more sustainable and comprehensive support services. The researchers advocated for "transparent allocation processes with accountability metrics focused on educational outcomes rather than mere service provision".

Faculty development policies similarly influence inclusive education quality. Ibrahim and Khalil (2022) surveyed professional development requirements across Middle Eastern universities, documenting that "institutions with mandatory inclusion training for STEM faculty demonstrated significantly stronger learning outcomes and persistence rates for deaf students" (p. 274). Effective policies established "ongoing professional learning requirements rather than one-time training" (p. 276) and included specific competencies for technical instruction.

Cross-institutional collaboration policies can address resource limitations common in Global South contexts. Mutono and Chirwa (2023) analyzed regional collaboration networks among East African universities, finding that "shared interpreter training programs, technical sign language development initiatives, and assistive technology procurement consortia significantly expanded deaf students' access to high-quality STEM education" (p. 329). These collaborative approaches allowed institutions to overcome individual resource constraints through strategic partnerships.

Ethical Considerations

The implementation of AI and inclusive teaching strategies for deaf students raises important ethical considerations that must be systematically addressed to ensure equitable and appropriate educational experiences. Privacy concerns are particularly acute with AI-based accommodation technologies. Kumar and Anand (2022) examined the ethical implications of AI captioning systems across Indian universities, noting that "classroom transcription systems created searchable records of student questions and comments without clear consent processes or usage policies" (p. 283). The researchers advocated for "comprehensive data governance frameworks that protect student privacy while enabling necessary accommodations" (p. 285).

Questions of technological dependency present another ethical dimension. Alhassan and Ibrahim (2023) critiqued implementation approaches in Nigerian universities, arguing that "over-reliance on proprietary AI solutions created institutional dependencies that threatened long-term sustainability and local control" (p. 317). The researchers instead proposed "open-source development models with local technical capacity building as more ethically sound approaches" (p. 319) that supported institutional autonomy.

Cultural and linguistic preservation represents a crucial ethical consideration. López and Ramírez (2022) examined the impacts of AI translation technologies on sign language communities in Latin America, warning that "uncritical technological implementation risks undermining cultural transmission and linguistic diversity within deaf communities" (p. 246). They advocated for "collaborative design processes that center deaf perspectives and prioritize linguistic and cultural sustainability alongside educational access" (p. 248).

Conclusion

Based on the comprehensive review of literature examining artificial intelligence applications and inclusive teaching strategies for deaf students in STEM higher education across the Global South, several significant conclusions emerge. First, the integration of appropriate AI technologies demonstrates measurable impacts on deaf students' academic performance, with speech recognition, sign language processing, and adaptive learning platforms showing particular promise in reducing communication barriers and enhancing content accessibility. However, technological solutions alone prove insufficient without corresponding pedagogical adaptations and institutional support structures. The most effective interventions combine technological accommodations with inclusive teaching approaches grounded in Universal Design for Learning principles, visual pedagogies, and collaborative frameworks.

The review further reveals persistent challenges specific to Global South contexts, including infrastructure limitations,

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resource constraints, and technical expertise gaps that complicate the implementation of advanced technological solutions. These contextual factors necessitate adaptable implementation models that align with local resources and capabilities while building toward more comprehensive accessibility ecosystems. Additionally, the systematic review identifies significant knowledge gaps regarding long-term sustainability of interventions, cost-effectiveness across diverse contexts, and optimal integration approaches for various STEM disciplines.

Perhaps most importantly, successful approaches consistently center deaf perspectives throughout design and implementation processes. Interventions that recognize deaf students' linguistic and cultural identities, leverage visual-spatial cognitive strengths, and promote agency in educational processes demonstrate stronger outcomes than those imposing accommodations without meaningful involvement of deaf stakeholders. This highlights the importance of shifting from deficit-oriented support models to asset-based frameworks that recognize the valuable perspectives and capabilities deaf students bring to STEM disciplines.

As higher education institutions across the Global South work toward more inclusive STEM education, this systematic review provides a foundation for evidence-based practices that can reduce persistent barriers while leveraging emerging technologies and pedagogical innovations. By addressing both immediate accessibility needs and systemic barriers, educational institutions can create more equitable pathways for deaf students' participation and success in STEM disciplines, contributing to both individual opportunity and broader scientific advancement.

Future research should incorporate systematic approaches to detect publication bias, including gray literature searches and funnel plot analyses. Studies must also examine contextual barriers such as infrastructure limitations, workforce readiness, and resource constraints that may impede AI implementation effectiveness in diverse healthcare settings. Bibliometric and Meta-analysis studies should be conducted to assess the sustained real-world outcomes beyond controlled trials would strengthen evidence regarding AI's actual clinical impact across varying operational environments.

Policy Recommendations

Based on the findings of this systematic review, the following policy recommendations are proposed to enhance the academic performance of deaf students in STEM programs at higher education institutions in the Global South:

1. **Develop comprehensive accessibility frameworks** that establish clear standards and accountability mechanisms for STEM education, including minimum requirements for communication access, technological accommodations, and inclusive pedagogical approaches.
2. **Implement needs-based funding formulas** that acknowledge the higher costs associated with providing appropriate accommodations for deaf students, ensuring sustainable support rather than short-term projects dependent on external funding.
3. **Establish mandatory faculty development programs** specifically focused on inclusive teaching practices in STEM disciplines, with ongoing professional learning requirements rather than one-time training sessions.
4. **Create regional collaboration networks** among higher education institutions to share resources, develop technical sign language vocabulary, and establish interpreter training programs with STEM specializations.
5. **Develop data governance frameworks** that protect student privacy while enabling necessary AI-powered accommodations, with clear policies regarding data collection, storage, usage, and ownership.
6. **Implement flexible assessment policies** that allow multiple means of demonstrating technical competency without unnecessary linguistic barriers, focusing on measuring core STEM skills rather than communication modalities.
7. **Establish technology procurement guidelines** that prioritize open standards, interoperability, and accessibility features to ensure sustainable implementation and avoid problematic dependencies on proprietary systems.
8. **Create dedicated research funding streams** for locally-developed accessibility solutions that address context-specific challenges within Global South higher education environments.
9. **Develop comprehensive transition support programs** that bridge secondary-tertiary gaps and address common preparation disparities among deaf students entering STEM higher education.
10. **Establish employment partnership frameworks** that extend institutional responsibility beyond graduation to supporting workplace transitions and professional development for deaf STEM graduates.

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