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Music Education for Students with Visual and Hearing Impairments: A Scoping Review of Adaptive Technologies

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Abstract: This study aims to map and synthesize how adaptive technologies are designed and implemented to support access, participation, and learning in music education for students with visual and hearing impairments. The study employed the Arksey and O'Malley scoping review framework, encompassing identification, screening, eligibility assessment, and data charting processes. Literature searches were conducted in Scopus, ERIC, and Google Scholar for articles published between 2016 and 2026. Fourteen studies met the inclusion criteria and were analyzed using thematic analysis. The findings identified five main categories of adaptive technologies: haptic and vibrotactile technologies, audio-based technologies, visual feedback technologies, Braille music technologies, and multimodal or multisensory technologies. These technologies were implemented through individual and collaborative music learning activities, structured training sessions, tactile and auditory instruction, and multisensory learning experiences. The reviewed studies demonstrated positive contributions to accessibility, musical participation, rhythm and pitch comprehension, musical performance, confidence, communication, and social participation among students with disabilities. However, most interventions remained exploratory, involving small samples and short implementation periods. Music educators should integrate adaptive technologies into curriculum-based instruction, technology developers should prioritize user-centered and sustainable designs, and policymakers should strengthen teacher training and accessibility support.

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Introduction

The rising global population of individuals with sensory disabilities highlights a systemic challenge that necessitates a response through educational policy. Global health data from 2021 reported that approximately 295 million people experienced moderate to severe visual impairment, while 43 million people were living with total blindness (Pesudovs et al., 2024; Que et al., 2025; S. Zhang et al., 2024). Most cases are concentrated in low- and middle-income countries and are projected to increase between 2035 and 2050. Contributing factors include population aging, population growth, age and gender disparities, as well as regional variations in areas with low Sociodemographic Index (SDI) scores (Bourne et al., 2021). In addition to visual impairment, hearing loss also represents a substantial global burden. In 2021, there were 46,776,140 recorded cases of hearing loss among children aged 0–19 years, with the most affected age group being adolescents aged 15–19 years. By 2050, the number of individuals with hearing loss worldwide is projected to rise dramatically to 2.45 billion people(Jiang et al., 2023; Que et al., 2025; J. Zhang et al., 2025). Similar to trends in visual impairment, the sharpest increase in hearing loss cases is expected to occur in

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regions with low SDI, particularly South and Southeast Asia, where cases are projected to increase by up to 135% (Y. Zhang, 2025). Without well-planned interventions, there is a significant risk of widening disparities in access to education, technology, and social participation, which may negatively affect individuals' quality of life and well-being if educational systems are not prepared to respond proactively.

Students with visual and hearing impairments face major challenges in accessing conventional music education(Lu et al., 2023a). Students with visual impairments often struggle because music instruction depends heavily on visual elements such as reading notation and following teacher demonstrations (Lu, 2022a; Payne & Hurst, 2023; Somani et al., 2023). Meanwhile, students with hearing impairments face difficulties understanding auditory elements such as pitch, timbre, rhythm, and dynamic expression through traditional methods alone (Chenette, 2021; Mitchell et al., 2024). These challenges create disparities in musical competence because music education systems still do not accommodate diverse sensory modalities. Article 24 of the United Nations Convention on the Rights of Persons with Disabilities (CRPD) affirms the right to equal educational opportunities. Therefore, unequal access to music learning reflects both a pedagogical and structural issue. Music education also strengthens students' self-esteem by encouraging self-expression, participation, and recognition of their abilities (Rauduvaitė & Yao, 2023; L. Zhang & Hu, 2026)

Previous studies have developed music learning approaches that respond to the needs of students with sensory disabilities. Research involving students with visual impairments has focused on auditory and tactile modalities, including rhythm imitation, direct sound exploration, and tactile music notation (Pino, 2021; Pino, Rodríguez-Rossell, & Vallverdú, 2022). Studies on students with hearing impairments have mainly applied visual and kinesthetic approaches, such as visual cues, body movement, and vibration-based musical experiences(Cavdir, 2023; Chen et al., 2024; Shin et al., 2025). Despite these developments, researchers still rarely implement adaptive technologies systematically in music education. Existing studies mainly explore tactile devices for understanding musical notation and structure, haptic feedback systems for rhythm and synchronization, and interactive technologies that support real-time transfer of musical motor skills (Liu et al., 2024a; Nishida et al., 2022b; Turchet et al., 2021). Most studies remain exploratory and do not clearly identify which technologies are effective, the contexts in which they work best, or their limitations.

Researchers have introduced various adaptive technologies to support music learning for students with sensory disabilities, including Braille music notation, vibrotactile devices, sound visualization software, and multimodal applications (Lu et al., 2023a; Petry et al., 2018a). However, the development and use of assistive and adaptive technologies in this field reflect diverse approaches and objectives, ranging from providing access to musical notation to delivering musical information through alternative sensory modalities. Although the literature has grown considerably, few studies systematically map the types of technologies used, their implementation patterns, and the assumptions underlying their development This mapping is particularly critical at present because research on adaptive technologies for visual impairment and hearing impairment has developed along separate, fragmented tracks rather than a unified evidence base, and because most available evaluations originate from engineering and computer science perspectives that assess technical functionality rather than pedagogical impact in actual classroom settings. Without this mapping, practitioners and policymakers encounter challenges in identifying technologies that are genuinely effective and inclusive. To address this gap,this study conducts a systematic scoping review to map

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and synthesize how adaptive technologies are designed and implemented to support students' access, participation, and learning in music education for those with visual and hearing impairments. This review contributes by synthesizing adaptive technologies according to their sensory affordances, implementation patterns, and effects on musical competencies, while identifying the pedagogical and implementation gaps that must be addressed to move adaptive music technologies from experimental prototypes toward sustainable inclusive practic.

Research Method

This study employs a Scoping Review method to systematically map the scope, characteristics, and depth of literature within a particular field, as well as to identify key concepts, sources of evidence, and existing research gaps (Anderson et al., 2008; Arksey & O'Malley, 2005). Through this approach, knowledge in the field of music education for students with visual impairments and students with hearing impairments can be comprehensively examined, allowing gaps in knowledge and their implications within the literature to be analyzed, while also providing a foundation for the development of relevant ideas and theoretical approaches for future research. This scoping review followed the framework originally proposed by Arksey and O'Malley (2005), refined by Levac et al (2010) and adapted to the PRISMA-ScR reporting standards, which consists of six systematic stages in the process of identifying, selecting, analyzing, and reporting the literature, including:

a) Identify the research question

The focus of this study was formulated systematically using the Population, Concept, and Context (PCC) framework. This framework was employed to guide the literature exploration process comprehensively.

Table 1. Formulating research questions using the PCC framework

Population	Students with visual impairment; students with hearing impairment
Concept	The use of technology, adaptive technology (assistive/adaptive technology), digital interfaces, or digital learning tools specifically designed to support the learning process.
Context	Inclusive education settings at various level.

b) Identify relevant research

The researchers developed a structured literature search strategy for students with visual and hearing impairments based on the PCC framework to identify relevant studies using Boolean string operators (Table 2).

Table 2. Search Terms and Boolean Strings

PCC Components	Boolean Strings
Population	*("visual impairment" OR "visual disability" OR "blindness" OR "low vision" OR "sight loss")*
	("hearing impairment" OR "hearing loss"OR "deaf" OR "hard of hearing" OR "hearing disability")
Concept	*("assistive technology" OR "adaptive technology" OR "accessibility technology" OR "accessible technology") AND*
Context	*("music education" OR "music learning" OR "music instruction")*

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c) Article selection

Keywords were developed based on the PCC framework and combined using Boolean operators (AND, OR) to identify relevant studies. Searches were conducted in Scopus, ERIC, and Google Scholar for English-language publications from 2016 to 2026. The researchers established inclusion criteria based on publication characteristics, research focus, participants, language, and publication period. Eligible studies examined the use or implementation of adaptive, assistive, or accessible technologies in music education involving students with visual or hearing impairments. Following title and abstract screening, 61 articles were assessed through full-text review, resulting in 14 studies that met the eligibility criteria for final synthesis. The study selection process is presented in the PRISMA flow diagram (Figure 1).

d) Data charting

At this stage, the researchers analyzed articles that passed the screening and eligibility stages through a data charting process. They extracted information on the authors, publication year, country, study objectives, research methods, participant characteristics, types of adaptive or assistive technology, and main findings (Table 3). The researchers conducted this process systematically to ensure consistent and comprehensive data analysis.

e) Compile, summarize, and report results

Literature searches across databases yielded 774 records, which were screened and presented in a PRISMA flow diagram (Figure 1). A total of 14 studies met the inclusion criteria. Most included studies involved small sample sizes (typically under 15 participants), comprising blind and low-vision (BLV) students, deaf and hard-of-hearing students, teachers, and musicians. Methodologies varied, including qualitative, quantitative, experimental, mixed-methods, R&D, and co-design studies. Using thematic analysis, extracted data were coded and synthesized into recurring themes reflecting the types of adaptive technologies used, their implementation patterns, and their impact on students' musical competencies.

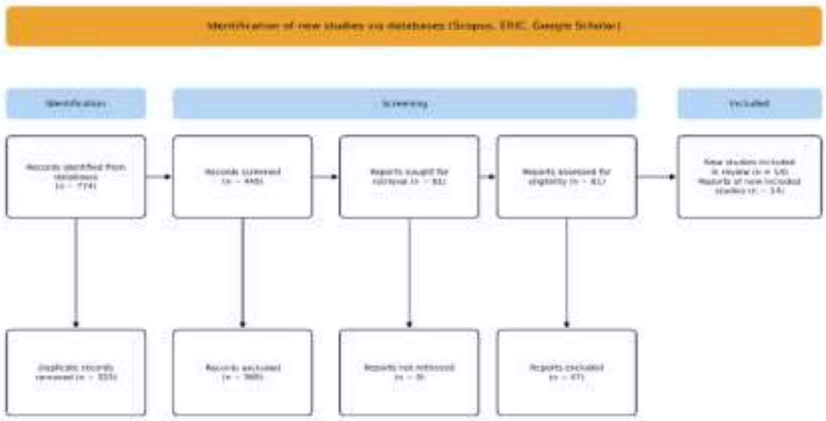

Figure 1. Prisma Flowchart

Table 3. Data Synthesis

Author, Year, Country	Adaptive Technology & Method	Key Findings
Chao-Fernandez et al. (2017), Spain	Interactive ICT storytelling app linking illustrated characters to rhythm/notation via musicograms; quasi-experimental, 23 students (1 with HI).	Improved engagement, self-confidence, and social integration among students with hearing impairments.

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Author, Year, Country	Adaptive Technology & Method	Key Findings
Petry et al. (2018), Singapore	MuSS-Bits++ prototype using vibration/light feedback; mixed-method experiment, 11 deaf children, 7 sessions.	Improved rhythm comprehension, confidence, and synchronization.
Gorbunova & Govorova (2018), Russia	Speech synthesizers, Braille displays, MIDI keyboards; descriptive study with blind students.	Improved accessibility, independent learning, and interaction.
Silvestri & Falk (2022), United States	UDL-based multimodal learning (movement, sign language, tactile cues, SUBPAC); collaborative study, deaf/deafblind/deaf-disabled students.	Improved inclusive access via visual, kinesthetic, tactile, and sign-language experiences.
Nishida et al. (2022), United States	DigituSync dual-user exoskeleton glove (real-time haptic feedback); R&D study, piano learners, deaf-blind users.	Showed potential to improve music learning accessibility for deaf-blind users.
Lu et al. (2023), Canada	Musical Haptic Wearables (“Clockwise” prototype); co-design study, 10 BLV participants.	Supported tactile communication and multisensory learning experiences.
Yongkamol (2023), Thailand	Braille music and GoodFeel software; single-case study, 12 weeks, 7 musicians with visual impairments.	Improved accessibility, independence, and music theory comprehension.
Lu et al. (2024), Canada	Multimodal Assistive Technologies (audio, vibration, Braille); co-design workshop, 9 BLV participants.	Improved music reading and memorization through multisensory interaction.
Chen et al. (2024), China	Auditory, Braille music, and MIDI-based piano teaching model; mixed-method study with blind students in China.	Improved inclusive and effective piano learning.
Liu et al. (2024), China	NoteBlock: tactile blocks with sensors and audio feedback; prototype/feasibility study, preschool BLV children.	Supported basic musical concepts; increased interest among young BLV children.
Lu et al. (2025), Canada	TapTap wearable haptic device (rhythm/tempo cues); 10-week longitudinal study, 7 BLV students.	Improved rhythm, synchronization, and focus.
Chai et al. (2024), China	Tactile devices, Braille notation, DAISY talking books, AI audio description; cross-national study, 12 countries.	Improved access to notation, rhythm, memorization, and inclusive participation.
HyunYi et al. (2025), South Korea	Visual feedback app (pitch tracking, note animation, sign-language guidance); experimental study, 10 deaf participants.	Improved pitch understanding, vocal control, and independent singing ability.
Dewi et al. (2025), Indonesia	Genjek Bali audiobook via MP3 player (vocal training, tempo, dynamics); R&D study using ADDIE model, 12 blind students.	Improved vocal ability, intonation, coordination, creativity, and motivation.

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Results and Discussion

Thematic Analysis

The synthesis revealed a differentiated pattern in how adaptive technologies mediate access to music learning across sensory impairments. For students with visual impairments, haptic and vibrotactile technologies translated musical information into tactile cues, whereas audio-based and multimodal technologies provided alternative channels for accessing musical content. For students with hearing impairments, visual feedback and vibrotactile technologies similarly transformed auditory information into perceivable visual or tactile representations. Across these contexts, adaptive technologies were integrated into individual practice, collaborative learning, and movement-based activities, suggesting that their pedagogical function extends beyond compensating for sensory limitations to reshaping how musical information is accessed, practiced, and experienced. The convergence of these approaches indicates that accessibility is achieved not through a single technological modality, but through the alignment of technological affordances with learners' sensory and pedagogical needs.

The reported outcomes further indicate that adaptive technologies may contribute to both musical development and participation in inclusive learning environments. Across the reviewed evidence, recurring outcomes included enhanced accessibility and participation, improved understanding of rhythm and pitch, development of musical performance skills, and greater confidence and social inclusion. These patterns suggest that the educational significance of adaptive technologies lies in their capacity to reduce sensory barriers while enabling sustained engagement with musical processes. Nevertheless, the heterogeneity of technologies, instructional contexts, and research designs limits direct comparison across studies and cautions against interpreting the reported outcomes as definitive causal effects. Taken together, the evidence supports adaptive technology as a potentially important component of inclusive music education, while also underscoring the need for more systematic investigation of its pedagogical effectiveness across diverse learner populations and educational settings.

Discussion

Adaptive technologies for students with visual impairments

For students with visual impairments, the effectiveness of adaptive technologies is closely associated with their ability to translate musical information into sensory modalities that remain accessible without visual input. Haptic and vibrotactile technologies are particularly relevant for rhythm, tempo, timing, and movement because they provide real-time tactile cues that can be perceived through bodily sensation (Baker et al., 2019; Fletcher, 2021; Lu, 2022). In contrast, audio-based technologies, including speech synthesizers, screen readers, and accessible digital music resources, are more suitable for accessing musical notation, verbal instructions, and sequential musical information, thereby supporting independent practice (Gorbunova & Govorova, 2018; Pino et al., 2022; Yongkamol, 2023). Multimodal technologies further extend accessibility by combining auditory, tactile, and Braille-based information, allowing students to access musical concepts through complementary sensory channels (Chai et al., 2024). These differences suggest that the effectiveness of adaptive technology is not determined solely by its technical sophistication, but by the extent to which its sensory affordances correspond to the specific musical task and learner needs.

Despite these advances, the existing evidence remains largely focused on overcoming immediate access barriers rather than establishing how adaptive technologies can be integrated into systematic music pedagogy. Most studies demonstrate that students can access

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musical information through alternative sensory channels, but provide less evidence regarding long-term skill development, curriculum integration, and the transfer of technology-supported learning to conventional music instruction. This creates a pedagogical gap between technological accessibility and sustainable music learning. In addition, the predominance of small-scale and exploratory interventions limits understanding of how these technologies can be implemented across diverse classroom settings and learner profiles.

Adaptive technologies for students with hearing impairments

For students with hearing impairments, adaptive technologies are effective when they transform auditory components of music into visual, tactile, or kinesthetic representations. Visual feedback technologies can represent rhythm, pitch, musical patterns, and timing through characters, colors, animations, and other visual cues, making otherwise abstract auditory information observable (Baglama et al., 2018; Chao-Fernandez et al., 2017; Hyun Yi et al., 2025). Vibrotactile technologies provide a complementary pathway by converting musical timing, rhythm, and synchronization into bodily sensations, which can support students in coordinating movement and musical responses (Petry et al., 2018; Silvestri & Falk., 2022). Multimodal approaches combine these modalities with movement and tactile interaction, potentially providing greater flexibility for students whose access to auditory information varies (Cheng & McGregor, 2024; McHugh et al., 2021). Thus, visual technologies may be particularly useful for representing musical structure and pitch, whereas vibrotactile technologies offer stronger affordances for temporal awareness and bodily synchronization.

However, the literature has not yet established how these sensory modalities should be selected or combined for specific musical learning objectives. Existing interventions tend to demonstrate that students can perceive and respond to transformed musical information, but provide limited evidence concerning how such technologies support higher-order musical development, sustained practice, musical expression, and learner autonomy. This represents a significant pedagogical gap because accessibility alone does not necessarily result in meaningful musical learning. Furthermore, many systems remain at the prototype or exploratory stage, making their feasibility in routine classroom environments uncertain.

Implementation of adaptive technologies for students with visual impairments

The implementation of adaptive technologies for students with visual impairments generally follows a gradual progression from technology familiarization to guided practice and increasingly independent musical activity. Haptic and vibrotactile systems can initially be introduced through familiarization with vibration patterns before being incorporated into instrumental practice, where real-time feedback supports rhythm, tempo, and motor coordination (Liu et al., 2024; Lu et al., 2025; Nishida et al., 2022)Similarly, audio-based approaches commonly progress from listening and imitation to repetition, memorization, and independent practice using accessible resources such as Braille Music and GoodFeel (Chai et al., 2024; Yongkamol, 2023). These approaches are pedagogically meaningful because they can gradually shift students from teacher-mediated instruction toward greater independence. Collaborative activities further demonstrate that tactile and auditory feedback can support ensemble synchronization and interaction with teachers and peers (Pino et al., 2022; Dewi et al., 2025). Nevertheless, the implementation evidence reveals a tension between individualized technological support and scalable classroom practice. Many interventions depend on continuous teacher or researcher guidance, individualized configuration, and real-time feedback, which may be difficult to sustain in ordinary music classrooms with multiple learners. Although these technologies can facilitate immediate participation, limited evidence exists regarding whether students can progressively self-regulate their practice once external

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guidance is reduced. Moreover, most studies are conducted in small-scale or controlled settings, leaving questions about technological reliability, teacher workload, accessibility of resources, and long-term classroom integration. The pedagogical challenge, therefore, is not merely to provide students with accessible technological tools, but to develop implementation models that enable technology to become a sustainable component of everyday music instruction.

Implementation of adaptive technologies for students with hearing impairments

For students with hearing impairments, implementation typically combines visual representation, movement, tactile feedback, and collaborative music-making. Visual learning activities can represent rhythm, pitch, and musical structure through animation, musicograms, sign language, and other visual cues, while movement-based activities allow students to experience musical timing through bodily action (Chao-Fernandez et al., 2017). Vibrotactile systems complement these approaches by providing physical cues for rhythm and synchronization during music-making activities . The combination of sensory modalities is particularly relevant because music learning is not limited to auditory perception; it also involves timing, movement, coordination, expression, and interaction. Consequently, adaptive technologies may be most effective when embedded within active and collaborative pedagogies rather than used solely as compensatory devices. Despite this potential, current implementation remains largely dependent on structured activities led by teachers or researchers. Students frequently receive continuous visual, tactile, or movement-based cues, while relatively little evidence demonstrates how these supports can be gradually reduced to foster independent learning and self-regulation. This dependence represents a key pedagogical gap. In addition, many interventions remain short-term or prototype-based, with limited evidence regarding their integration into regular classroom routines, teacher training, technical maintenance, and long-term student development.

The Effects of Adaptive Technologies on Students' Musical Competencies

Across the reviewed studies, adaptive technologies were associated with improvements in accessibility and participation, rhythm and pitch understanding, musical performance, and confidence and social inclusion (Chai et al., 2024; Lu et al., 2025; Pino et al., 2022). These outcomes suggest that the primary contribution of adaptive technologies extends beyond providing access to musical information. By translating musical concepts into tactile, visual, or accessible auditory forms, these technologies can create opportunities for students to engage with musical tasks that might otherwise be inaccessible. However, the nature of the reported outcomes varies according to the technology and learning context. Tactile and vibrotactile systems appear particularly relevant to rhythm, timing, and synchronization, whereas audio and Braille-based technologies provide stronger support for music reading and independent practice. Visual and multimodal systems, meanwhile, facilitate the representation of musical structure and collaborative participation. This suggests that improvements in musical competence are likely to emerge from the interaction between technological affordances and appropriate pedagogical strategies rather than from technology alone. Importantly, the evidence base remains insufficient to determine whether these reported improvements are sustained beyond the intervention period. Most studies involve small participant groups, short-term interventions, or prototype and exploratory systems, with limited evidence regarding long-term musical development, transfer to conventional learning environments, teacher adoption, and independent use. The central research gap is therefore a shift from demonstrating technological feasibility to establishing pedagogical effectiveness and sustainability.

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Conclusion

This review highlights the current landscape of adaptive technology in music education for students with visual and hearing impairments. The findings show that haptic, vibrotactile, visual, audio-based, and multimodal technologies support music learning through structured training, collaborative participation, and sensory-based experiences. These technologies help address limitations in conventional music pedagogy and promote inclusive education. Across the 14 synthesized studies, this review identified a shift from conventional approaches centered on single-sensory substitution, such as converting visual notation into tactile or auditory equivalents, toward technology-enabled multisensory integration and inclusive collaboration, in which adaptive technologies combine haptic, visual, auditory, and kinesthetic channels simultaneously and position students with visual and hearing impairments as active co-participants alongside sighted or hearing peers rather than as recipients of substituted access. However, challenges related to technical reliability, scalability, teacher preparedness, and long-term implementation remain, and their integration into educational settings is still limited and unsustainable.

Recommendation

Future research should focus on more sustainable and integrated implementations of adaptive technology in inclusive music education. Studies with larger participant groups and longer implementation periods are also needed to better evaluate their impact on students' musical development. In addition, future research should expand AI-based and personalized adaptive technologies while strengthening collaboration among researchers, educators, developers, and disability communities to create more accessible and relevant inclusive music learning practices. Building on these findings, several stakeholder-specific actions are warranted. For educators and schools, adaptive tools should be integrated into regular classroom instruction rather than deployed as isolated interventions, paired with multisensory and collaborative activities, and supported by structured teacher training; critically, teachers should also plan for a gradual reduction of continuous cueing to help students develop independent learning and self-regulation. For technology developers, priority should shift from short-term prototypes toward field-ready, affordable systems that are reliable and scalable for everyday classroom use, designed by default as multisensory/multimodal tools rather than single-sensory substitutes, and developed through participatory co-design with visual- and hearing-impaired communities. For policymakers, sustained funding for larger-sample, longer-term implementation studies is needed, alongside teacher certification pathways, procurement or subsidy mechanisms that make these technologies affordable for schools, and cross-sector standards that connect researchers, educators, developers, and disability communities.

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