



Inclusive Mathematics Education Applied in Science through Assistive Technology: Advancing SDG 4 for Deaf Students in Indonesia

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Abstract: The integration of assistive technology is a key pillar in creating an inclusive mathematics education ecosystem for deaf students. This Systematic Literature Review (SLR) analyzed 49 reference sources to map the trends and effectiveness of learning media at secondary school levels. Findings show the primary focus on practical solutions utilizing students' visual cognitive strengths. Geometry is the most frequent topic (39%) due to its visualization nature that suits deaf visual learners. The reviewed literature indicates that integrating digital media—such as Augmented Reality (AR), Android applications, and subtitled videos—yields average validity scores ranging from 86.50%. This study concludes that transforming physical teaching aids into an interactive digital ecosystem is a crucial solution to bridge verbal communication barriers and mathematical abstraction in secondary schools.

Keywords: Assistive Technology, Deaf, Mathematics, High School, SLR

Introduction

Education plays a fundamental role in shaping high-quality and dignified human resources and driving national development. (Alawyah et al., 2024). In the Indonesian context, education is guaranteed as a basic right for every citizen as stated in Article 31, paragraph (1) of the 1945 Constitution and is strengthened through Law Number 20 of 2003 concerning the National Education System, which emphasizes that every citizen has the right to quality education services without discrimination, including those with disabilities. This commitment is further reinforced by Law Number 8 of 2016 concerning Persons with Disabilities, (Windayani et al., 2024) which mandates the implementation of inclusive education at all levels of education to provide equal rights and opportunities for effective

participation. Philosophically, education is not seen merely as a process of knowledge transfer but as a holistic effort to develop intellectual capacity, moral values, and life skills so that individuals can live independently and with dignity. However, despite having a strong legal and philosophical foundation, reality on the ground shows that gaps in educational access and quality still persist (Marentek, 2025).

Empirical data indicates that a large portion of children with special needs in Indonesia have not yet received adequate educational services. This gap is influenced by geographical factors, socio-economic status, and limited educational infrastructure, particularly between urban and rural areas (3T regions) and across different regions of Indonesia (Azhar et al., 2025). Furthermore, the process of identifying and classifying the characteristics of Students with Special

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Needs (PDBK), which has so far been manual and subjective, often hinders the accuracy of educational services. Consequently, the equitable distribution of inclusive education remains a serious challenge, especially for marginal groups such as deaf students who require adaptive pedagogical approaches and learning environments (Atika et al., 2025).

Deaf students, defined as individuals with partial to total hearing loss, face significant challenges in language acquisition and communication due to limited access to auditory information (Ermin et al., 2025). This condition directly affects their ability to understand verbal instructions, which remain the dominant method in learning practices where many teachers still rely on conventional lecture methods (Anggraeni, 2020). From an applied science perspective, this condition demands an evidence-based instructional design capable of translating theoretical understanding of sensory limitations into applicable educational solutions (Dewi et al., 2025). The learning difficulties experienced by deaf students are not caused by intellectual limitations but by limited linguistic input, which impacts their understanding of symbolic and abstract representations, particularly in mathematics learning. Mathematics, as the mother of science, often becomes a heavy burden because its objects are abstract, especially in materials like geometry and the fundamental laws of science, (Rahmayanti et al., 2025).

Research in cognitive psychology and educational technology shows that deaf students have a strong tendency toward visual-spatial processing (Rabiasa et al., 2024). Therefore, learning needs to be designed by optimizing these visual strengths through visual representations, interactive media, and contextual approaches. In practice, limited vocabulary and language structures often hinder the understanding of mathematical word problems, thus requiring multimodal learning environments that integrate sign language, visual scaffolding, and interactive digital media (Wulayalin et al., 2024).

Various technological innovations, such as Android-based Augmented Reality (AR), have proven effective in constructing the understanding of abstract concepts into more tangible forms for deaf students. Additionally, the use of digital Flipbooks, interactive animation videos, and Electronic Student Activity Sheets (e-LAPD) based on Liveworksheets are capable of accommodating various visual-kinesthetic learning styles of students. The integration of learning models such as Realistic Mathematics Education (RME/PMR), which starts from real-world problems, the STEM model to enhance collaboration, Project-Based Learning (PjBL) for independence, and Problem-Based Learning (PBL) for critical thinking in 3T regions is crucial in an inclusive education system (Azzahra et al., 2025;

Hariyadi et al., 2023). Without interventions based on scientific approaches and technological aids like the Adaptive Neuro-Fuzzy Inference System (ANFIS) for accurate classification, deaf students are at risk of academic difficulties, low learning engagement, and social exclusion. Therefore, integrating applied science approaches through the development of Inclusive Mathematics E-Learning (such as Google Sites-based platforms with Sign Language Interpreter (JBI) videos and text narration) is key to designing learning systems that are inclusive and responsive to the needs of deaf students to achieve the Sustainable Development Goals (SDGs) (Windayani et al., 2024)

Mathematics is widely recognized as a foundational discipline that underpins scientific and technological advancement and plays a crucial role in developing critical and analytical thinking skills (Azzahra et al., 2025; Purba et al., 2024). Despite its importance, mathematics is often perceived as difficult, abstract, and unengaging by many students, particularly those with special educational needs (Azzahra et al., 2025; Feliarosa et al., 2021). For deaf students, the challenges are compounded by the dual demands of processing abstract concepts and overcoming communication barriers, which significantly impact their conceptual understanding (Januarti et al., 2024). These students often have a lower understanding of mathematical concepts due to limitations in language and verbal communication. Concepts such as algebra, fractions, and geometry require a high level of abstraction and symbolic reasoning, which can be difficult to grasp without adequate visual support (Fauzan et al., 2023; Razi et al., 2020). Specifically, in the element of geometry, deaf students frequently struggle with the characteristics of flat shapes and area formulas because they lack the ability to maximize intelligence from verbal sources.

In many Indonesian special and inclusive schools, instructional practices remain predominantly teacher-centered, relying heavily on lecture methods and standardized textbooks that are not specifically designed to meet the needs of deaf learners. These materials often lack visual richness and fail to provide contextualized explanations that facilitate conceptual understanding (Syafudin et al., 2019). As a consequence, students tend to become passive recipients of information, leading to decreased engagement and limited knowledge construction. Furthermore, the limited integration of digital technology in classroom practices exacerbates these challenges, as it restricts opportunities for interactive and student-centered learning. In the context of the Merdeka Curriculum, which emphasizes flexibility, creativity, and student-centered approaches, the lack of adaptive instructional media represents a significant gap that needs to be

addressed to ensure inclusive and effective mathematics education. Deaf students require media that can maximize their visual and motor intelligence to overcome their communication limitations.

The rapid advancement of digital technology in the era of Society 5.0 presents new opportunities to transform traditional learning environments into more inclusive and interactive ecosystems (Basmalah et al., 2025). Assistive technologies such as Augmented Reality (AR), Android-based applications, and interactive multimedia have demonstrated significant potential in enhancing the learning experiences of students with disabilities, particularly deaf learners (Alawyah et al., 2024). These technologies enable the visualization of abstract mathematical concepts through dynamic and immersive representations, thereby facilitating deeper understanding and cognitive engagement. For example, AR technology allows students to interact with three-dimensional geometric objects in real-time, supporting the transition from concrete to abstract thinking as described in cognitive development theories such as Van Hiele's model (Zaahirah et al., 2025). Similarly, digital platforms like website-based applications that incorporate subtitles, animations, and immediate feedback mechanisms can enhance comprehension and motivation by replacing auditory input with accessible visual information.

In addition, the integration of technology supports the development of self-regulated learning (SRL), enabling students to learn at their own pace and according to their individual needs. Research has shown a significant relationship between SRL and mathematical achievement among deaf students, as those who can plan and focus their learning thoughts tend to achieve better results. Despite these advantages, the implementation of assistive technology in Indonesian classrooms remains uneven and often lacks systematic evaluation. Many schools still face challenges such as lack of specialized facilities, limited teacher training in specific digital content, and a reliance on conventional media like whiteboards (Ibnurhus et al., 2025). Therefore, there is a pressing need to examine the effectiveness, trends, and pedagogical implications of such technologies in supporting inclusive mathematics education for deaf students to bridge the gap between their potential and their academic achievement.

This study addresses a critical gap in the existing body of knowledge by focusing specifically on the integration of assistive technology for deaf students in senior high school or vocational high school (SMA/SMK) mathematics education, an area that remains significantly underrepresented in current research. While previous studies have explored various forms of educational technology and inclusive practices, most have concentrated on general education settings or

lower educational levels, with limited attention to the unique challenges faced by deaf learners in advanced mathematics contexts. Furthermore, the development and evaluation of adaptive technologies tailored to the visual learning characteristics of deaf students at the senior secondary level are still scarce, particularly within the Indonesian educational landscape. The novelty of this research lies in its comprehensive application of a Systematic Literature Review (SLR) approach to analyze 49 scholarly sources, providing a structured synthesis of technological trends, methodological approaches, and effectiveness outcomes. This study not only identifies existing gaps but also offers evidence-based insights that can inform the design of more inclusive and adaptive learning environments. The importance of this research is underscored by the urgent need to ensure equitable access to quality education for all students, including those with disabilities. By bridging theoretical perspectives and practical applications, this study contributes to the advancement of inclusive education and supports the realization of a more equitable, technology-enhanced educational system in Indonesia.

Method

The method in this study was designed systematically using the Systematic Literature Review (SLR) approach. This method was chosen to identify, review, evaluate, and interpret all available research related to the phenomenon of assistive technology integration in mathematics learning for deaf students. The main focus of this procedure is to map the types of technology used and their potential in increasing mathematical engagement in inclusive secondary schools and Special Schools (SLB).

The following is a detailed explanation of the stages of the research method used:

Formulation of Research Questions

The research questions were formulated using a relevant framework to map special education trends in Indonesia. These questions include what are the most widely used research methods in the development of assistive technology for deaf mathematics?, how is the distribution of mathematical materials integrated with this technology?, what is the geographical distribution of research locations throughout Indonesia?, What are the classifications of assistive media that have been developed and what is their level of effectiveness for secondary school students?

Literature Search Strategy

A comprehensive literature search was conducted on several reputable digital databases, including Google Scholar, Scopus, and Semantic Scholar. The

identification process uses supporting applications such as Publish or Perish to maximize the discovery of relevant articles.

Researchers use search keywords combining Boolean operators (AND, OR) to refine search results, with the following keywords: (a) "Mathematics" AND "Deaf" AND "Assistive Technology"; (b) "Mathematics"

AND "Hearing Impairment" AND "Secondary School"; (c) "Learning Media" AND "Deaf Students" AND "Inclusion".

Inclusion and Exclusion Criteria (Eligibility)

To ensure the validity of the data analyzed, researchers established strict selection criteria.

Table 1. Literature Selection Criteria

Criteria	Inclusion (Accepted)	Exclusion (Rejected)
Time span	Latest publications (main focus 2020-2024)	Articles outside the scope of current ICT developments
Subject	Deaf/hearing disabled students at secondary school level (SMP, SMA, SMK)	Regular elementary school students or non-human subjects
Main Topics	Integration of assistive technology, digital media, or mathematical teaching aids	Articles that do not discuss technology or fields other than mathematics/STEM
Document Type	Scientific journal articles, national seminar proceedings,	literature review or pure textbook
Language	Indonesian and English	Languages other than these two languages

Selection Stages (Development Procedures) The selection procedure is carried out through four main stages based on the PRISMA model: Identification, collecting raw articles from databases, Screening (filtering articles based on title and abstract to see initial relevance), Eligibility (conducting an assessment of the full text to ensure the article meets all inclusion criteria). Included (the final articles for further in-depth analysis.)

Data Analysis Techniques

The collected data was processed using qualitative and quantitative descriptive analysis techniques. Researchers extracted information based on predetermined parameters: Conducting a trend analysis of the use of the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model 4D (Define, Design, Develop, Disseminate), Plomp model and SAM model (Successive Approximation Model), measuring effectiveness through Gain Score (N-Gain) results, validity levels from media/material experts, and positive student responses and grouping technology media based on the type of input, such as Visual-Digital Media (Subtitled Video), Interactive Media (Android

Applications), and Immersive Media (Augmented Reality).

Through the integration of all the stages above, this method section provides a solid foundation for researchers to present a factual and sharp trend analysis regarding the development of assistive mathematics technology in Indonesia.

Result and Discussion

Based on a comprehensive analysis of 49 literature sources, various fundamental findings were identified that map the trends and effectiveness of assistive technology integration in inclusive mathematics learning in Indonesia. The results of this study are systematically described to provide a factual overview of the current dynamics of special education.

Research Methodology Analysis

Educational research in mathematics specifically for deaf students in Indonesia shows a very strong tendency towards creating practical solutions through product development.

Table 2. Percentage Distribution of Research Methods (n=49)

Research methods	Description	Frequency	Percentage
Research & Development (R&D)	ADDIE, 4D, Hannafin & Peck, Plomp, SAM models	26	52.1%
Single Subject Research (SSR)	Individual experiments with AB or ABA designs	9	18.7%
Descriptive Qualitative	Case studies, in-depth interviews, observations	7	14.6%
Systematic/Scoping Review	Systematic literature analysis and evidence mapping	7	14.6%

R&D methods (52.1%) reflects the urgent need in the field for standardized learning media for children with special needs (ABK). Researchers have widely adopted the ADDIE and 4D models because of their systematic evaluation structure, involving validation by material experts and media experts to ensure

accessibility for deaf students. On the other hand, the SSR method (18.7%) is a crucial instrument for measuring changes in learning behavior specifically in deaf individuals who have unique characteristics and cannot be generalized.

Analysis of Material and Middle School Level

The cognitive characteristics of deaf students who rely heavily on visual modalities significantly influence the selection of materials and levels of intervention in secondary schools.

Geometry material is a favorite research topic (38.8%) due to its ease of concrete visualization through

Augmented Reality (AR) technology and software such as GeoGebra (Hariyanti et al., 2025) (Hariyanti et al., 2025) . The SMPLB level (48.9 %) is considered a crucial phase for improving conceptual understanding that is often left behind at the basic level before students move on to the more complex vocational level (SMK).

Table 3. Analysis of Material and School Level

Analysis Aspects	Category	Percentage	Key Findings
School Level	Special Junior High School	48.9%	Focus on strengthening basic concepts of geometry and fractions.
	Special High School/Vocational High School	36.7%	Emphasis on functional and vocational mathematics (fashion/design).
	Others (PT/General)	14.4%	Adaptation of LMS and interactive communication technology at a high level.
Main Material	Geometry	38.8%	Flat shapes and spaces best suit the power of visual perception.
	Number Operations	28.6%	Addition, multiplication, and fractions are the main obstacles to abstraction.
	Literacy/Language	22.4%	Improvement of sentence structure (SPOK) and vocabulary through visual media.
	Vocational	10.2%	Application of mathematics in practical skills (screen printing/clothing patterns).

Classification of Assistive Technology and Geographic Distribution

The transformation of learning media from physical teaching aids to an immersive digital ecosystem shows rapid progress. Geographically, Java (73.5%) remains the center of assistive technology development due to the

availability of ICT infrastructure and more concentrated research institutions. However, positive trends are emerging in areas outside Java (26.5%), such as Bali and Sumatra, which are integrating local wisdom (ethnomathematics) into digital media development.

Table 4. Classification of Assistive Media and Research Locations

Media Classification	Examples of Innovation	Validity/Effectiveness	Main Location
Digital-Interactive	AISITARU, Quizizz, Unity 3D	83% - 94%	Semarang, Malang, Bali
Visual Assistive	Subtitled Video, Fotonovela	Very Worthy	Yogyakarta, Jakarta
Immersive (AR)	SmartMath, Candi AR	87.6%	Jember, Sleman
Digital Manipulative	Shapes 3D, Web-Learning	100% (Visual)	Jakarta, Surabaya
Vocational-Digital	Fashion Design/Screen Printing Tutorial	96.6% (Practical)	Padang, Probolinggo

However, the main obstacle that remains a critical concern is students' limited vocabulary. Most of the developed media (75%) emphasized the importance of speech-to-text transcription and simplified language instructions to prevent misconceptions in math story problems. In conclusion, the integration of assistive technology that focuses on the power of visuals is essential for the success of inclusive mathematics education in Indonesia.

An understanding of basic mathematics, such as arithmetic operations (addition, subtraction, multiplication, and division) and geometry, is the main foundation for science learning. This relationship can be seen in the following aspects: mathematics as the Language of Science: Science requires complex logical and conceptual skills, where many scientific principles are expressed in mathematical models. For example, in

studying the Periodic Table of Elements (Chemistry), students must understand the structure and sequence based on mathematical logic. Hadi et al. (2019), measurement and Calculation: Scientific activities are inseparable from the process of measurement. Mathematical skills in calculating the area or volume of plane figures are essential in physical and chemical experiments. And logical Thinking Skills: Mathematics trains critical, systematic, and analytical thinking skills. Students with a good understanding of mathematics tend to find it easier to formulate problems and draw conclusions using the scientific method.

Learning Challenges for Deaf Students

Although mathematics and science are essential, many deaf students find these subjects difficult due to their abstract nature. Some of the main inhibiting factors

include: deaf students have a limited vocabulary, which hinders their understanding of complex word problems or scientific terms, deaf students face a greater cognitive load because they must intensively process visual information to replace auditory information, the use of conventional textbooks with excessive text without adequate visual illustrations has proven ineffective for them.

Innovative Interactive Learning Media as a Bridge

To overcome these obstacles, innovative learning media are needed that maximize the visual and motor intelligence of deaf students. Some technological solutions that have been developed include:

Augmented Reality (AR) and 3D Visualization

AR technology, as implemented in the "OxyTech" and "SmartMath Pop-Up Book" media, has proven highly effective. AR helps visualize abstract chemical concepts or geometric shapes into realistic 3D forms that can be interactively manipulated. The implementation of OxyTech in inclusive schools has shown an increase in students' average grades from 48.5 to 84.3, demonstrating its high effectiveness in the science subject understanding category.

Multimedia and Video Tutorials

Learning videos equipped with Indonesian Sign Language (Bisindo or SIBI), subtitles, and moving images significantly assist deaf students in absorbing information. The use of audio-visual media, such as video tutorials on screen printing or clothing pattern making, helps students understand technical procedures involving mathematical calculations through systematic visual examples. The Role of Self-Regulated Learning

In addition to media, internal factors such as Self-Regulated Learning (SRL) also significantly influence achievement in mathematics and science. SRL is a student's ability to focus their thoughts, feelings, and actions on achieving learning goals. Deaf students with high SRL tend to be more active in asking questions, seeking additional resources, and employing better learning strategies, thereby improving their academic achievement.

Holistic Inclusive Education Strategy

The implementation of educational services for deaf students must be carried out through a special, adaptive learning program. This includes: conducting screening to identify the specific characteristics and needs of each student to tailor lesson plans and media used, combining sign language, writing, facial expressions, and gestures as the primary communication channels in the classroom, support from

Special Assistant Teachers (GPK): The availability of GPK is crucial in inclusive schools to facilitate communication between subject teachers and deaf students.

Conclusion

Based on a systematic synthesis of 49 peer-reviewed studies published between 2020 and 2024, this review concludes that the integration of assistive technology has become a critical driver of effective and equitable mathematics learning for deaf secondary students in Indonesia. The findings indicate that geometry dominates the research focus (38.8%), reflecting its strong compatibility with the visual-spatial learning characteristics of deaf students, while interactive digital media such as Augmented Reality, GeometryLab, SmartMath applications, GeoGebra, and Unity 3D-based tools consistently outperform conventional lecture-based and textbook-centered instruction. Importantly, AR should not be interpreted merely as a sophisticated technology, but as a cognitive-visual aid that enables deaf learners to access and manipulate abstract mathematical objects that lie beyond auditory perception, thereby supporting progression across Van Hiele's levels of geometric thinking. The synthesis of reported learning outcomes across studies indicates consistent improvements in students' conceptual understanding, engagement, self-confidence, and self-regulated learning, particularly when media are designed with strong visual representations, immediate feedback, and sign-language or subtitle support. Therefore, future research is recommended to expand assistive technology studies into diverse mathematical domains, underrepresented regions, and long-term learning impacts, while integrating visual-spatial theory, self-regulated learning frameworks, and disability-friendly language design. Overall, this study underscores the urgent need for curriculum-technology alignment, strengthened digital literacy for special education teachers, and equitable ICT infrastructure investment to support inclusive mathematics education in line with SDG 4 (Quality Education) and SDG 10 (Reduced Inequalities).

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Author Contributions

S. and A. identified problems related to the availability of assistive technology to facilitate deaf students in secondary schools. S. conducted a literature review and analyzed relevant sources. Both authors contributed to writing the initial draft,

providing ideas, reviewing, and editing the manuscript. They also monitored the progress of the research and provided feedback throughout the study. All authors contributed equally to the content of this article. We have read and approved the published version of the manuscript.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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