Global Mapping of Assistive Technologies in Education

Report 2024-1

Breaking Barriers in Education: Inclusion, Rehabilitation, and Technology (BERT) -project (2024–2026)



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This report is intended to support the project partners' project implementation but is also available for a wider audience, such as students.

ACRONYMS

3D	Three-dimensional
5G	Fifth Generation of Wireless Cellular Technology
AAC	Augmentative and Alternative Communication
AI	Artificial Intelligence
ALD	Assistive Listening Device
AM	Additive Manufacturing
APL	Assistive Products List
AT	Assistive Technology
BCI	Brain-Computer Interface
CRPD	Convention on the Rights of Persons with Disabilities
IAT	Intelligent Assistive Technologies
IoT	Internet of Things
LMIC	Low- and Middle-Income Country
NGO	Non-Governmental Organization
PWD	Person with Disability
SAR	Socially Assistive Robot
UNESCO	United Nations Education, Scientific and Cultural Organization
UNICEF	United Nations International Children’s Emergency Fund
VR	Virtual Reality
WHO	World Health Organization
XR	Extended Reality

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1 INTRODUCTION

Assistive technology (AT) plays a crucial role in supporting the daily lives of billions of people around the world. Currently, over 2.5 billion individuals require one or more assistive products, a figure projected to exceed 3.5 billion by 2050. The global market for AT is anticipated to reach between $26 billion and $31 billion by 2024. Despite this growth, nearly one billion people, particularly in low- and middle-income countries (LMICs), face significant challenges accessing these essential products, with availability as low as 3% in some areas. Barriers to access include high costs, limited availability, and insufficient support systems. Most individuals obtain their assistive products through the private sector, often funded by personal finances or support from family and friends. Addressing these challenges is vital to improving access and ensuring that ATs reach those in need. (Global Partnership for Assistive Technology & Clinton Health Access Initiative 2024; WHO & UNICEF 2022)

The Convention on the Rights of Persons with Disabilities (CRPD) recognizes access to AT (Article 20, 26), education (Article 24), comprehensive rehabilitation (Article 26), as well as independent living and inclusion to the community (Article 19) as human rights (Office of the High Commissioner for Human Rights, 2016). The most common technologies needed in independent living can be simple ATs and home adaptations (Rosken et al., 2021, p. 3). Intelligent Assistive Technologies (IAT) are not meant to replace conventional ATs, but complement them (Wangmo et al., 2019; World Intellectual Property Organization, 2021, p. 15). The Committee on the Rights of Persons with Disabilities (2022) suggests increasing access to modern information and communications technology such as Artificial Intelligence (AI). Also, the Special Rapporteur on the rights of persons with disabilities (PWDs) encourages state parties to broaden and deepen their national AI debates with the CRPD explicitly in mind (Quinn, 2021, pp. 9, 18).

This report on Global mapping of assistive technologies (ATs) in education is one of the deliverables of the Breaking Barriers in Education: Inclusion, Rehabilitation, and Technology (BERT) -project (2024–2026). The Global mapping of ATs in education contributes to the Project's specific output 1.1: "*Improved interdisciplinary knowledge and skills in creating barrier-free learning environments for students with disabilities in targeted locations through wider collaboration between academia, the public and private sectors, and civil society*", and is part of the Landscape Analysis on Disability Inclusion: Rehabilitation and Technology in Higher Education Institutions in East Africa: A Case Study of Rwanda and Tanzania.

The objective of the global mapping of ATs in education is to collect global and regional insights related to affordable solutions and best practices in AT (considering digital accessibility) used in education. The research was conducted by project experts from the University of Applied Sciences Jyväskylä (JAMK) and Tampere University (TAU). The global mapping development followed the timeline of the Landscape Analysis implemented by project partners University of Rwanda (UR),

and the State University of Zanzibar (SUZA): final protocol May 2024, literature search June-July 2024, analysis and results August 2024, draft report September 2024 and Final report December 2024.

This report introduces the research protocol, summarizes key global reports on ATs to provide background information, describes the results of the desk review on global mapping on ATs in education, and presents conclusions to highlight the main perspectives to consider for BERT-project implementation.

2 RESEARCH PROTOCOL

The global mapping of assistive technologies (ATs) in education focuses on identifying the available ATs used in educational contexts and examining how these solutions align with usefulness and socio-economic considerations. This includes two key research questions: 1) “*What ATs used in education are available and utilized?”*, and 2) “*How do AT solutions align with usefulness and socio-economic considerations*?”.

Additionally, the research incorporates a cross-cutting theme that explores the roles of primary stakeholders, including international organizations, manufacturers, and developers, in promoting accessibility and inclusion for people with disabilities (PWDs) within East Africa's education system. This includes the research question, "*What are the primary stakeholders in AT, and their roles in fostering accessibility and inclusion of PWDs in East Africa's education system?*"

2.1 Definitions

AT definitions in this research protocol are based on the World Health Organization’s (WHO) (2016) List of Priority Assistive Products defined as follows:

- *Assistive technology* is the application of organized knowledge and skills related to assistive products, including systems and services. AT is a subset of health technology.
- *Assistive products:* Any external product (including devices, equipment, instruments, or software), especially produced or generally available, whose primary purpose is to maintain or improve an individual’s functioning and independence and thereby promote their well-being. Assistive products are also used to prevent impairments and secondary health conditions.
- *Priority assistive products*: Those products that are highly needed, an absolute necessity to maintain or improve an individual’s functioning, and which need to be available at a price the community/state can afford.

The research also utilizes the following divisions of ATs (Global Partnership for Assistive Technology & Clinton Health Access Initiative 2024):

- *Unaided use*: No physical tools, including gestures and sign language.
- *Aided use*: Requires tools such as symbols and speech-generating devices.
- *Low-tech*: Basic, analogue tools like communication boards.
- *Mid-tech*: Electronic devices with limited digital features, like basic speech-generating devices.
- *High-tech*: Advanced devices with comprehensive features, including tablets, smartphones, and devices with sensors or eye-tracking for communication.

2.2 Methods

The primary method involves a desk review conducted using selected research databases, including the Social Sciences Citation Index, Web of Science, PubMed, African Journals Online, Association for Computing Machinery (ACM), and IEEE, along with online sources such as traditional search engines (Google, Bing, and DuckDuckGo). The database searches utilized key terms in various forms, such as: "*Affordable OR Low-cost OR cost-effective, accessib* OR assistive technolog* OR Assistive device*, education* OR classroom OR inclusive, digitalization*". The inclusion and exclusion criteria for the reviewed studies are detailed in Table 1.

Table 1. Global mapping inclusion and exclusion criteria.

Inclusion criteria	**Exclusion criteria**
affordable and accessible AT solutions, mobile and digital solutions, home based AT solutions targeted to studying, home based AT solutions that are also study related, IATs	home based AT solutions that are not at all study related

Data extraction was conducted applying a categorization framework that included the following criteria: the type of study, analysis, report, or document, the setting or context, the target group for ATs, including socio-economic considerations, and the focus areas of the research. Other categories captured included the AT solution or device, its classification as low-tech, mid-tech, or high-tech (e.g., digital, robotics, AI), and any partnerships involved (such as organizations or manufacturers contributing to AT creation and development). Additionally, the evaluation of ATs was based on their affordability, accessibility, and usefulness, alongside the extraction of the main results, outcomes, and recommendations from each source.

Final AT listing, categorization, and literature mapping use a structured framework integrating conceptual grouping and thematic analysis with data-driven refinements such as keyword matching and frequency analysis. Broad, high-level categories are established through a review of relevant literature and the identification of recurring themes. Subcategories are developed to address specific use cases under main categories.

3 GLOBAL BACKGROUNDS ON ATs

The section provides a comprehensive overview of the current state of ATs, focusing on their global market, accessibility, and their role in supporting individuals with disabilities. There are three globally well-known reports providing good insights into the AT landscape, such as 1) *Assistive Products Market Report 2024* and its product catalogue annex focusing on market dynamics and the critical need for ATs in low- and middle-income countries (LMICs), 2) *Global Education Monitoring Report* focusing on the role of inclusive technologies in education, particularly in promoting access for students with disabilities, and 3) *Global Report on Assistive Technology* offering a comprehensive dataset on global AT access and suggesting recommendations to improve availability and affordability in line with the Sustainable Development Goals (SDGs).

3.1 Assistive Products Market Report 2024 and Product catalog annex (ATscale)

Assistive Products Market Report 2024 and Product catalog annex by Global Partnership for Assistive Technology (ATscale)[1] and Clinton Health Access Initiative (2024) provide a comprehensive catalog of AT products for Non-Governmental Organizations (NGOs) and governments in LMICs. It highlights the critical need for these products, focusing on six key categories: digital AT, eyeglasses, screen readers, hearing aids, prostheses, and wheelchairs. ATscale focuses on transforming lives through AT, especially in LMICs. It aims to ensure that an additional 500 million people get the life-changing ATs they need by 2030. Their approach includes country engagement, shaping the market for AT, and producing global public goods related to AT.

Augmentative and Alternative Communication (AAC): Access is limited, with only 1.75% using aids like communication boards. The market includes low-tech (simple tools), mid-tech (basic electronic devices), and high-tech solutions (advanced electronic devices). Costs range from $20 to $20,000, with significant price disparities.

AAC suppliers include AssistiveWare B.V., Attainment Company, Dynavox MayerJohnson, Honeycomb, Jabbla, Liberator Ltd, Prentke Romich Company, Saltillo Corporation, Smartbox AT, and Tobii Dynavox.

AAC tools are categorized based on their characteristics, cost, and availability:

- **Low-tech**: These solutions are basic and analogue in nature, such as communication boards. They are cost-effective, ranging from $20 to $100, and are widely available, making them easily accessible.

[1] https://atscalepartnership.org/

- **Mid-tech**: These tools feature digital components with limited functionality, such as basic speech-generating devices. They are priced between $50 and $3,000 and have a moderate level of availability.
- **High-tech**: High-tech AAC solutions offer versatile, advanced features and include devices like tablets, smartphones, and sophisticated speech-generating devices. These products range from $100 to $20,000 and are less readily available due to their complexity and cost. (Global Partnership for Assistive Technology & Clinton Health Access Initiative 2024)

Smartphones: Used by 4.3 billion people, but ownership is lower in LMICs (21% in Sub-Saharan Africa, 35% in South Asia). The market, dominated by 6 to 10 companies, has premium smartphones costing $700-$2,000, mid-range $400-$700, and budget models under $100.

Eyeglasses: Affecting 4.4 billion people globally, but only 36% have access. Major players include EssilorLuxottica and Carl Zeiss, with China as the primary manufacturing hub. Costs range from $240 to $1,000 in high-income countries, while prices in LMI regions vary due to import duties and distribution costs.

Screen Readers: In 2020, 43.3 million people were blind, and 295 million had severe vision impairment. Most reside in LMICs. Market estimation is challenging due to varied usage and a lack of standardized tracking. Prices for commercial screen readers range from $1,000 to $1,200, while open-source options are free.

Hearing Aids: With 1.6 billion people affected, 80% of those with severe hearing loss live in LMICs. The market is segmented by type and technology, dominated by five major companies. Prices range from $500 to $4,000 in high-income countries, and $60 to $175 through international procurement in LMICs.

Prostheses: Of the 65 million people with amputations, 64% are in LMICs, with only 20% having access. The market includes lower-limb and upper-limb prostheses, with costs ranging from $77 to $70,000 depending on type and complexity.

Wheelchairs: Needed by 80 million people, with 65 million in LMICs. The fragmented market has five major companies holding less than 50% of the share. High-income country prices range from $900 to $1,700, while LMICs can access affordable options around $350.

3.2 Global Education Monitoring Report (UNESCO)

Global Education Monitoring Report by the United Nations Education, Scientific and Cultural Organization, UNESCO (2023)**,** provides context on how inclusive technologies are being used to promote access to education for students with disabilities. It highlights different technologies and strategies being implemented globally to facilitate inclusive education.

Technology provides critical educational opportunities but also leaves many behind:

- **Accessible Technology**: Universal design has improved access for learners with disabilities. For example, 87% of visually impaired adults now use accessible technology instead of traditional tools.
- **Alternative Education**: Radio, TV, and mobile phones support education in hard-to-reach areas. Radio instruction is used in almost 40 countries, and in Mexico, televised lessons boosted secondary school enrollment by 21%.
- **COVID-19 Impact**: Online learning prevented a complete educational collapse during the pandemic, reaching over 1 billion students. However, it failed to reach at least half a billion students, including 72% of the poorest.
- **Connectivity and Inequality**: The right to education is increasingly linked to access to connectivity, yet access remains uneven. Globally, only 40% of primary, 50% of lower secondary, and 65% of upper secondary students have adequate connectivity. (UNESCO 2023)

Reliable evidence on the effectiveness of education technology is limited:

- **Lack of Robust Data**: There is insufficient robust evidence on the added value of digital technology in education. Technology evolves rapidly, with new products emerging every 36 months, outpacing evaluation efforts. Most existing evidence comes from wealthy countries.
- **Limited Research in Education Technology**: Only 7% of education technology companies in the UK conducted randomized controlled trials, and 12% used third-party certification. A survey in 17 US states revealed that just 11% of educators sought peer-reviewed evidence before adopting new technologies.
- **Bias in Evidence**: Much evidence supporting education technology comes from companies. (UNESCO 2023)

3.3 Global Report on Assistive Technology (GReAT)

The Global Report on Assistive Technology (GReAT) by WHO and the United Nations International Children's Emergency Fund, UNICEF (2022**)** offers a comprehensive dataset and analysis of access to ATs. It highlights AT's benefits and suggests ten recommendations for improving access, aligning with the Sustainable Development Goals and the UN CRPD (Inclusive Education Initiative).

AT supports individuals' functioning and independence, enhancing well-being**:**

- **Human Right**: Access to AT is a fundamental right and crucial for equal participation. Governments must ensure safe, effective, and affordable access for all.
- **Universal Coverage**: AT should be part of universal health and social welfare programs, accessible without financial strain.

- **Global Relevance:** AT benefits people with temporary or permanent functional difficulties, including children, adults with disabilities, elderly, and those with chronic conditions.
- **Cost vs. Benefit**: Investing in AT often provides significant individual and societal benefits.
- **Access Process**: Gaining access involves awareness of solutions and realizing one's rights and goals. (WHO & UNICEF 2022)

Principles of AT Access:

- **Accessibility**: Are services, facilities, and information accessible to everyone? Is access equitable across all demographics?
- **Adaptability:** Are products and services adaptable to individual needs? Are they responsive to changing needs over time?
- **Acceptability:** Are products efficient, reliable, simple, safe, and aesthetically pleasing? Do users have choice and control? Are products culturally appropriate?
- **Affordability**: Are products and services affordable? Are travel costs considered? Are financial barriers addressed for vulnerable groups?
- **Availability**: Are products available in sufficient quantities and variety? Are they provided close to where people live?
- **Quality**: Do products meet standards for strength, durability, and safety? Do services meet guidelines? Are users involved in assessing quality? (WHO & UNICEF 2022)

4 RESULTS OF THE GLOBAL MAPPING OF ATs IN EDUCATION

This chapter provides the results of the desk review related to ATs in education. The target group of the article, AT solutions, AT evaluation (affordability and accessibility), AT evaluation (usability), and main results were information extracted from the articles. In some articles, AT partnerships were also mentioned. Before each article list, a table has been created with the article's country, the study type, and what the context was.

The results are categorized by the AT technology used: **1. low-technology** (traditional), **2. high-technology** (digital, robotics, AI etc.), and **3. a combination of low-technology and mid- and high-technology**. There were, in total, 23 selected articles (n=2 in low-technology, n=7 in high-technology, and n=14 in a combination of low-technology and mid- and high-technology). All ATs used in education were categorized as aided ATs.

4.1 Low-technology

Table 2. Articles on the low-technology.

Article	Country	Type of the study	Setting or context
1. Mugiraneza, F. (2022). Accessibility of Inclusive Classrooms and Competences of Students with Special Educational Needs in Basic Education Classrooms in Rwanda.	Rwanda	quantitative, qualitative	education
2. Coleman et al. (2015). Art Educators' Use of Adaptations, Assistive Technology, and Special Education Supports for Students with Physical, Visual, Severe and Multiple Disabilities.	USA	quantitative	education

1. Accessibility of Inclusive Classrooms and Competences of Students with Special Educational Needs in Basic Education Classrooms in Rwanda

The target group of the article by Mugiraneza (2022) was students and teachers (n=166 respondents) within 5 locations including 4 provinces and 1 Kigali City; represented by 5 districts; represented by 5 sectors represented by 5 inclusive schools. ***AT solutions or devices.*** The Accessibility of Inclusive Classrooms for students with special educational needs in basic education schools of Rwanda were measured with different indicators, among others, does students with disabilities with visual impairment have braille machines to help them learning and do students with/without disability have access to smart classrooms. ***AT evaluation: Affordable and accessibility.*** 88 (69.8%) of students strongly agreed that they have braille

machines, 93 (73.8%) students strongly agreed that they have access to smart classrooms, 90 (71.4%) students strongly agreed that their teachers are competent enough to use ICT in teaching children with disability. 32 (64.0%) teachers strongly agreed that their schools and classroom have paths where wheelchairs can pass, 22 (44.0%) teachers strongly agreed that their schools have toilets for students with disabilities, 17 (34.0%) teachers strongly agreed that they have a counselor or nurse who provides students with guidance, counseling. ***AT evaluation: Usefulness.*** 94 (74.6%) students strongly agreed that in basic education inclusive classrooms, the use of ICT made them innovative and competent students. ***Main results, outcomes, and recommendations.*** It was recommended that extensive training of teachers combined with the exchange of expertise between special and inclusive schools be planned and implemented in order to maximize the participation of students with special needs in both social and academic activities. Ministry of Education was advised to implement teaching on assistive devices and provide necessary assistive devices to students with special educational needs.

2. Art Educators' Use of Adaptations, Assistive Technology, and Special Education Supports for Students with Physical, Visual, Severe and Multiple Disabilities

The target group of the article by Coleman et al. (2015) was seventy-seven P-12 art teachers that responded to an online survey consisting of perceived knowledge and preparedness and strategies and resources, including ATs, used in the art classroom to meet the needs of students with physical, sensory, severe, and multiple disabilities in the art classroom. ***AT solutions or devices*** mentioned were large-handled writing or painting tools, adapted scissors, and devices for stabilization. ***Main results, outcomes, and recommendations.*** Almost 70 % of art teachers reported providing projects which are similar to those of peers with accommodations or modifications for students with physical, visual, severe, or multiple disabilities. However, the only accommodation with a high percentage of reported use was help with materials management and the only others reportedly used were extended time and hand-over-hand/hand under-hand assistance. It is not surprising that materials for stabilization, large-handled writing or painting tools, and adaptive scissors were used by more of the art teachers who responded than other types of AT, but even these devices were only reported as being used sometimes, often, or almost always by approximately half of the participants. Given the low response rates for AT devices, it is not surprising that art teachers reported not being knowledgeable or feeling prepared about AT. Teacher training programs in special education need to incorporate more instruction on (a) how adaptations, including AT, can be used in the art classroom to make experiences more meaningful, (b) effective practices for collaborating with art teachers, and (c) methods for training paraeducators to provide adequate supports in the art classroom.

4.2 High-technology

Table 3. Articles on the high-technology.

Article	Country	Type of the study	Setting or context
3. Rojas-Sánchez, Palos-Sánchez & Folgado-Fernández (2023). Systematic literature review and bibliometric analysis on virtual reality and education.	Multiple countries: China, USA, Korea, Canada, Germany, Denmark, UK, and others	literature review	education
4. Balakrishnan (2022). Computing and assistive technology solutions for the visually impaired.	India	expert article	home environment, education
5. Zhang et al. (2022). The metaverse in education: Definition, framework, features, potential applications, challenges, and future research topics.	Not specific	other: opinion paper	education
6. Papadopoulos, et al. (2020). A systematic review of the literature regarding socially assistive robots in pre-tertiary education.	Multiple countries: Iran, UK, Taiwan, Spain, Israel, Japan, Taiwan, USA, Italy, Sweden	literature review	education
7. Abiatal & Howard (2019). Constructivist Assistive Technology in a Mathematics Classroom for the Deaf: Going Digital at a Rural Namibian Primary School. Proceedings of the South African Institute of Computer Scientists and Information.	Namibia	qualitative, quantitative	education
8. Rice, M. (2024). 12 Examples of Assistive Technology in the Classroom.	Not specific	expert article	education
9. Murphy & Darrah (2015). Haptics-Based Apps for Middle School Students with Visual Impairments.	USA	quantitative	education

3. Systematic literature review and bibliometric analysis on virtual reality and education

The focus area of the literature review by Rojas-Sánchez, Palos-Sánchez & Folgado-Fernández (2023) was the research topics published during the Covid-19 pandemic that examined the new trend in education caused by the shift from face-to-face teaching to virtual, online teaching. The results obtained found a total of 718 articles of which 273 published articles were analyzed. ***AT solutions or devices*** included deep learning and machine learning using AI as alternatives to traditional teaching technologies, such as robot teleoperation, remote access laboratories, and various VR-based learning environments and systems. ***AT evaluation: Affordable and accessibility.*** The desktop-based VR has higher installation costs, while mobile device-based VR cannot produce the same environment quality due to the limited processing power. VR learning environments have advanced significantly from multimedia to interactive environments with desktop and immersive VR processes, 360-degree tours and various applications and games. Education has generally adopted these changes slowly with most attention coming from the new generations of students. ***AT evaluation: Usefulness.*** VR learning environments contain different systems where VR is applied in education, ranging from conventional multimedia to a physically interactive learning environment. Learning processes incorporating the use of VR applications, devices or games are considered disruptive technologies that alter the usual teaching, cognitive and learning practices of students. However, the combination of VR with computing was seen to provide effective e-learning. ***Main results, outcomes, and recommendations.*** There were found six major groups in the cited articles on utilization of VR in education, which are instruction and learning using VR, VR learning environments, use of VR in different fields of knowledge, learning processes using VR applications or games, learning processes employing simulation, and topics published during the Covid-19 pandemic. Another important aspect to mention is that VR is used in many different areas of education, but until the beginning of the pandemic the use of this so-called “disruptive process” came mainly from students. Institutions were reluctant and slow to accept and include VR in the teaching–learning processes.

4. Computing and assistive technology solutions for the visually impaired

The focus group of Balakrishnan’s (2022) expert article was individuals with visual impairments. ***AT solution or devices*** mentioned in the article were SmartCane, OnBoard (device for onboarding busses), DotBook (refreshable braille display). ***Partnerships: AT manufacturers.*** Assistech (Indian Institutes of Technology laboratory in Delhi) was mentioned as one of the AT manufacturers. ***AT evaluation: Affordable and accessibility.*** Goes over how expensive, traditional braille displays are and how this option is more affordable version. In Indian context affordability is a big factor for ATs. ***AT evaluation: Usefulness.*** For example, SmartCane helps with above-knee obstacles and other safety hazards for people with visual impairments. OnBoard assists with travelling in and getting in a bus.

5. The metaverse in education: Definition, framework, features, potential applications, challenges, and future research topics

The focus area of the opinion paper by Zhang et al. (2022) gave a clear view of the metaverse in education, including its definition, framework, typical features, potential applications, challenges, and future research issues. ***AT solution or device.*** Metaverse is a compound word combined with “meta-” (beyond; transcending) and “verse” (the root of “universe,” cosmos; the whole world), which denotes a new virtual universe created beyond the real world. The metaverse is not merely a new entity for VR or AR, but a collection of a set of emergent technologies like Fifth Generation of Wireless Cellular Technology (5G), AI, VR, Augmented Reality (AR), digital twins, blockchain, holography, or IoT (Internet of Things). ***Partnerships: AT manufacturers.*** For example, the sandbox platform Roblox allows players to create works of a virtual nature, and the works can also be co-created and shared with other players. The virtual social platform ZEPPTO allows users to make AR fashion items, and users can get digital currencies by selling them to other users. ***AT evaluation: Affordable and accessibility.*** Wireless communication and high-speed networks, such as 5G or 6G, are the basic requirements for the work of the metaverse world. Well-designed and affordable smart wearable device is essential for both learners and teachers to teleport to the metaverse world. The current cost of hardware equipment is still too high for most people, and far from the technical standard for the prevalence of applying the metaverse in the educational field. ***AT evaluation: Usefulness.*** In the metaverse, various realistic learning scenes can be simulated and created by modeling and rendering technologies such as digital twins, VR, AR, Extended Reality (XR), etc. It enables learners to use wearable devices to enter the educational setting without being limited by time and locations and allows them to use digital identities to have real-time interactions with different forms of items (e.g., avatars, intelligent Non-Player Characters, or virtual learning resources). As a result, they can feel present as if they are in a real-world educational setting. ***Main results, outcomes, and recommendations.*** The digital identities in the metaverse can rebuild learners with special needs’ images to eliminate special identity labels and discrimination, which makes it possible to help them engage in the learning activities with general students with confidence and a sense of belonging. Next, as part of or whole sensory or cognitive obstacles, the metaverse technologies, e.g., AI, sensors, or Brain-Computer Interface (BCI), can extend those learners’ affordances of organs and senses to communicate and interact with the general learners normally and obtain sensory stimuli and cognitive development during the learning process. From an evolutionary point of view, the fast-growth technologies of 5G networks, VR, or digital twins are showing promise for the metaverse. Hence, it is necessary for technology companies and departments concerned to develop more advanced solutions for adopting the metaverse in education.

6. A systematic review of the literature regarding socially assistive robots in pre-tertiary education

The focus area of the systematic review by Papadopoulos, et al. (2020) was critically review the research, 21 studies, on the use of Socially Assistive Robots (SARs) in the pre-tertiary classroom teaching of mathematics and science. ***AT solutions or devices*** covered were SARs including humanoids; a form of AI in education is the use of social robots. SARs are robots embodied as pets, toys, or humans, and are programmed to interact with users through engaging in social interaction, with the involvement of gestures, speech, emotional expression, and other actions. ***AT evaluation: Affordable and accessibility.*** Concerns surrounding usability were because the robot's price was considered too expensive for elementary education budgets. Results revealed that teachers had concerns about the cost of the robots and the complexity of using them. ***AT evaluation: Usefulness.*** One study reported that children found the robotic system both useful, in terms of facilitating learning, and easy to use. In contrast, the 4 studies that commented on usability of SARs addressed barriers as opposed to the positive factors. Safety concerns were raised based around fears over the robot's resistance, in terms of children potentially damaging it, rather than the other way around. ***Main results, outcomes, and recommendations.*** Overall, the use of SARs in pre-tertiary education is promising, but studies focusing on mathematics and science are significantly under-represented. SARs potential to enhance accessibility and inclusivity of multi-cultural pre-tertiary classroom is almost unexplored. The more AI technology progresses, the more research will be needed around tailored educational interaction responding to different personalities, special needs, and crucially cultural backgrounds of students, all of which can address the issue of inclusivity.

7. Constructivist Assistive Technology in a Mathematics Classroom for the Deaf: Going Digital at a Rural Namibian Primary School

The target group Abiatal's & Howard's (2019) article was eight third grade children with hearing disabilities in the context of learning mathematics were evaluated in two different phases. Phase 1 consisted of addition and subtraction and phase two focused on multiplication and division. Afterwards teachers were interviewed. ***AT solution or devices:*** Different Math related Ats were evaluated, and for this study RekenTest was selected. However, the study presents multiple viable ATs for learning math for different contexts, such as Microsoft Mathematics was recommended for higher grades. ***AT evaluation: Affordable and accessibility.*** It was important for this particular study to select a free of charge software system AT for the children, hence, RekenText was selected, and some others were cut out. ***Main results, outcomes, and recommendations.*** Positive experience for the teachers and children alike; for example, learning was easier, and learners were more motivated. As a constructive criticism teachers recommended that RekenTest would support multiple perspectives of concepts instead of numbers only since deaf

learners learn better with pictures, diagrams, words or even Namibian Sign Language interpretation.

8. 12 Examples of Assistive Technology in the Classroom

The focus of Rice's (2024) expert article was students with disabilities. ***AT solutions or devices.*** Speechify, Kurzweil 3000, Google Classroom, TactPlus, SeeingAI, Clicker, Co:Writer, Dragon, MathTalk, Tobii Technology, KNFB Reader and GoTalk 9+. ***Partnerships: Organizations that have been involved in AT creation.*** Depending on the AT, for example, Kurzweil 3000 is created by the organization Kurzweil's Education. Google Classroom is from Google. Seeing AI app is from Microsoft. Clicker is from Crick Software. Co: Writer is by Don Johnston Learning Tools. KNFB Reader was worked on by Sensotec as well as National Federation of the Blind. GoTalk 9+ was developed by Attainment Company. ***Partnerships: AT manufacturers.*** Similarly to the category above, some ATs mention manufacturers in their descriptions such as the Kurzweil 3000 and Seeing AI. ***Main results, outcomes, and recommendations.*** Introduces 12 AT options that can be used in the classroom and provides links for their main pages to get more information.

9. Haptics-Based Apps for Middle School Students with Visual Impairments

The target group of Murphy's & Darrah's (2015) article was 32 students with various levels of vision impairments aged from 11 to 17 years and five teachers who participated the testing of haptics-based computer applications over two academic semesters in their classrooms. ***AT solutions or devices.*** The haptics-based computer applications offering lessons on specific topics. The six specific applications that were tested in the classroom were Exploring the Atom, Gravity on the Planets, Surface Area of a Cube, Exploring the Plant Cell, Blood Cells and Circulatory System. ***Partnerships: AT manufacturers.*** Currently, eTouchSciences, LLC has 20 haptics-based applications for sale on their website. These are the first haptics based educational software products for sale to K-12 educators and parents of students who are visually impaired. ***AT evaluation: Affordable and accessibility.*** The technology can be used by teachers along with the already existing techniques of tactile graphics, Three-dimensional (3D) models and description in the math and science classroom to bring benefits to students. The applications are designed to work with the Novint Falcon Haptic Controller, a low-cost device (~$250) offering three degrees-of-freedom movement and various 3D effects. ***AT evaluation: Usefulness.*** Some of the students who were very low vision or blind seemed to like the applications the most. The applications held their attention and seemed to have enough auditory and haptics-based stimulation to help the students navigate through the scenes. ***Main results, outcomes, and recommendations.*** The results of testing six of the applications in classroom settings show that the device and software are feasible for teachers to implement, and significant learning gains can be achieved for students who use them. Student

attitudes toward the applications were positive, implying that not only are the apps useful in the classroom, but engaging as well.

4.3 Combination of low-technology and mid- and high-technology

Table 4. A combination of low-technology and mid- and high-technology articles.

Article	Country	Type of the study	Setting or context
10. Kibret et al. (2024). Assistive technology and daily living challenges among students with disabilities at University of Gondar, Ethiopia: a qualitative study.	Ethiopia	qualitative	education
11. Yenduri et al. (2023). From Assistive Technologies to Metaverse - Technologies in Inclusive Higher Education for Students with Specific Learning Difficulties: A Review.	Not specific	literature review	education
12. Bleau et al. (2022). Applications of Additive Manufacturing, or 3D Printing, in the Rehabilitation of Individuals with Deafblindness: A Scoping Study.	Not specific	literature review	education, home environment, social and health care services (rehabilitation)
13. Fernández Batanero et al. (2022). Assistive technology for the inclusion of students with disabilities: a systematic review.	Multiple countries: Ireland, South Africa, UK, Morocco, Portugal, Bahrain, Turkey, Brazil, USA	literature review	education
14. Kisanga & Kisanga (2022). The role of assistive technology devices in fostering the participation and learning of students with visual impairment in higher education institutions in Tanzania.	Tanzania	qualitative	education

Article	Country	Type of the study	Setting or context
15. Senjam, Foster & Bascaran (2022). Assistive technology for visual impairment and trainers at schools for the blind in Delhi.	India	quantitative	education
16. Ngonyani & Mnyanyi (2021). The Accessibility of Assistive Technology for Students with Disabilities in Higher Learning Institutions: A case of the University of Dar-es-Salaam in Tanzania.	Tanzania	Case study (descriptive study)	Education
17. Sankhi & Sandnes (2020). A glimpse into smartphone screen reader use among blind teenagers in rural Nepal.	Nepal	qualitative	home environment
18. Spicher, L., & Gershenson, J. (2020). Key Factors of Design: 3D Printed Occupational Therapy Products in Developing Communities.	Kenya	qualitative, quantitative	social and health care services (rehabilitation)
19. Horton et al. (2016). A review of principles in design and usability testing of tactile technology for individuals with visual impairments.	Not specific	literature review	education, home environment, social and health care services (rehabilitation)
20. Quek, Elglaly & Oliveira (2016). Assistive Technology in Education.	Not specific	Expert Article	education
21. Zanin & Rance (2016). Functional hearing in the classroom: assistive listening devices for students with hearing impairment in a mainstream school setting.	Australia	other: classroom trial and quantitative	education

Article	Country	Type of the study	Setting or context
22. Nsanzabiga (2014). Six years of inclusive education at the University of Rwanda-College of Education: Evaluation and perspectives.	Rwanda	qualitative, quantitative	education
23. Access to assistive technology in two Southern African countries	Botswana & Swaziland	Quantitative	Social

10. Assistive technology and daily living challenges among students with disabilities at University of Gondar, Ethiopia: a qualitative study

The target group of the Kibret's et al. (2024) article was 14 students with disabilities in the period of December 20, 2022, to January 20, 2023. ***AT solutions or devices.*** Almost all participants had access to at least one AT. Persons with visual impairment have access to many types of AT while those with mobility impairment are more limited. The ATs used by students with vision impairment include a white cane, Jaws software, ANBDA, and an audio recorder. According to students with disabilities, the lack of braille in higher education impacts their academic performance, particularly during their first year of study when they are still getting used to the various software programs available for reading academic texts. Participants who had mobility impairment used wheelchairs, prostheses, orthotics, and crutches. Those with lower limb and trunk impairment used assistive devices to move from place to place as long as the places are accessible. ***Partnerships: AT manufacturers.*** Many providers have no interest in including users in the decision-making process of assistive device design and production. They rely on generalized parametric measurements instead of co-designing with the final users of the devices. ***AT evaluation: Affordable and accessibility.*** Inadequate AT devices, traveling long distances and the requirement for long-term accommodation within rehabilitation centers during the production and maintenance of assistive devices were some of the issues that frustrated the users in this study. AT evaluation: Usefulness. Though many students with disabilities have access to AT, the device doesn't necessarily meet the user's needs. However, many participants are happy with the assistive device that they are provided given the limitations that exist. Almost all participants need other additional assistive devices that can better support their day-to-day activities. ***Main results, outcomes, and recommendations.*** Barriers to activities of daily living among students with disabilities were poor accessibility of infrastructural facilities, lack of teaching/learning materials in an accessible format, and negative attitudes. Students with disabilities face particular challenges in higher education not only in terms of gaining physical access to buildings, but also in relation to much wider access issues concerning curriculum adaptation and inadequate accommodation, teaching, learning and assessment.

11. From Assistive Technologies to Metaverse - Technologies in Inclusive Higher Education for Students with Specific Learning Difficulties: A Review

The focus area of the Yenduri's et al. (2023) literature review aimed to better understand the role of ATs in providing inclusive higher education for students with learning difficulties. ***AT solutions or devices.*** Multiple, different contemporary technologies: AI, XR, HCI, BCI, IoT, Digital twins and the metaverse**.** There are also multiple different tools available such as ActiveMath for dyscalculia Kurzweil 3000 to assist children with reading difficulties and Widex's EVOKE, that uses machine learning for heading aids. ***AT evaluation: Affordable and accessibility.*** Technologies such as AI and HCI have been used for a long time in the field of assisting students with learning difficulties. For example, HCI may assist students in overcoming their learning challenges via gestures, touch and brain signals. XR can be used to improve skills of people with dyslexia, ADHD and more. It is also worth noting that these technologies were mentioned as not being perfect: for example, the idea of XR not having design standards was an issue. ***Main results, outcomes, and recommendations.*** Lastly, the article goes over challenges and the future of directions of assistive technologies concerning students with learning difficulties. Challenges mentioned are for example, there not being a universal solution, design issues, challenges with traditional classroom and privacy as well as justification issues. All of these issues also receive a potential solution. For example, in the case of there not being universal solution, the idea of customization gets brought up. The solution for design issues is mentioned to be using personas in the designing phase to take variety of people in account. The solution for traditional classroom was solved by Virtual Interactive Inclusive Classroom that can help students with learning difficulties with their issues in traditional classroom.

12. Applications of Additive Manufacturing, or 3D Printing, in the Rehabilitation of Individuals with Deafblindness: A Scoping Study

The focus area of the Bleau et al. (2022) literature review was additive manufacturing (AM) research (in a total of 221 studies) in the field of vision impairments or hearing loss; only 9 studies corresponded to the research's special focus on deafblindness. ***AT solutions or devices*** explored in the research were AM as AT or as a rehabilitation tool for professionals working with students with disabilities such as vision impairments. AM is viewed as an affordable solution to provide custom tactile models (i.e., floor plans, braille templates, etc.) to learners with vision impairments. ***AT evaluation: Affordable and accessibility.*** AM has become an increasingly popular, accessible, affordable, and useful technology in many sectors, including education, where it can be used to produce 3D models for science, technology, engineering, and mathematics. Four out of nine studies explicitly explored the use of AM because of the lack of AT or adapted material that is touch accessible and affordable for individuals and students with deafblindness and/or vision impairments. ***AT evaluation: Usefulness.*** AM can create new materials and assistive devices that meet the unique demands and needs of their

clients. ***Main results, outcomes, and recommendations.*** The findings reveal that AM can counter barriers to full accessibility by enabling professionals to produce customized adapted material and communication devices, thus assisting individuals with deafblindness in communication, mobility, and learning. However, this review highlights a need for more AM research, resources, and training: interdisciplinary collaborations with AM specialists thus appear essential in improving rehabilitation services with AM.

13. Assistive technology for the inclusion of students with disabilities: a systematic review

The focus area of the literature review by Fernández Batanero et al. (2022) was studies regarding the impact of AT for the inclusion of students with disabilities. ***AT solutions or devices.*** The results indicated that different types of ATs are used based on the functionality they aim to provide, with a significant emphasis on Web 2.0 tools. Mobile learning, particularly through devices like iPads and smartphones, is also prominent due to their portability and the ability to install relevant applications. ***AT evaluation: Affordable and accessibility.*** Despite digital gaps, most schools and teachers have internet access, allowing them to use this low-cost resource to support student inclusion and learning. Economic factors, lack of support, and insufficient funding hinder the implementation and accessibility of ATs, particularly in rural areas. These tools are mainly relevant for visually impaired students, followed by hearing-impaired and physically disabled students. ***AT evaluation: Usefulness.*** Mobile learning stranded out in the results, including the iPad or smartphone. These devices are very useful because they are small and portable, and they enable the installation of relevant applications for these students. ***Main results, outcomes, and recommendations.*** Challenges include inadequate teacher training in the use of ATs for students with disabilities and difficulties in accessing these tools. Teacher training in ATs is crucial for improving student academic performance by enabling the selection of appropriate tools. The use of these tools was found to improve the academic performance of students with disabilities. Additionally, some articles reported benefits for the development of autonomy and participation, an increase in the acquisition of social skills, and enhanced motivation and attention among students.

14. The role of assistive technology devices in fostering the participation and learning of students with visual impairment in higher education institutions in Tanzania

The target group of the Kisanga & Kisanga (2022) article was seventeen students with visual impairments and four transcribers in the context of higher education institutions in Tanzania responded to open-ended questionnaire and semi-structured interview. ***AT solutions or devices.*** Screen readers, braille note touch, embossers with Duxbury software, Perkins Braille, white canes, voice recorders, close circuit televisions and typewriters were specified as ATS used by students and transcribers.

AT evaluation: Affordable and accessibility. Two mains accessibility issues were indicated, the shortage of AT devices and limited knowledge of how to operate them. Most known ATs mentioned were computers with screen readers, Perkins Braille machines and embosser machines. There weren't many other ATs present beyond the ones mentioned, at the institution. A lot of students were reliant on a person who was sighted or had more skills in using ATs. ***Main results, outcomes, and recommendations.*** Students with visual impairment in higher education institutions in Tanzania knew what ATs were, but they didn't know many other assistive technologies beyond their institution. The study recommended that higher education institutions should give funding for ATs to make sure that students with visual impairment benefit from the education they get. Students with visual impairments also need to be encouraged to learn more modern ATs in order to be less dependent on sighted students.

15. Assistive technology for visual impairment and trainers at schools for the blind in Delhi

The target group of the article by Senjam, Foster & Bascaran (2022) was 22 schools for the blind in Delhi; the headteacher was asked about the availability of 52 assistive technologies for visual impairment via a questionnaire. ***AT solutions or devices.*** 52 different ATs related to education/school life were specified in the article. ***Partnerships: Organizations that have been involved in AT creation.*** Almost every school in the study were ran by NGOs. ***AT evaluation: Affordable and accessibility.*** Only 11 out of 52 ATs were available in more than 60% of the schools. ***AT evaluation: Usefulness.*** ATs were categorized for what they were used on: writing, mobility and reading. Most common ATs were Braille slate and abacus. ***Main results, outcomes, and recommendations.*** Teaching students with residual vision (BCVA of 1/60 or better) to read and write in normal or large print. Having a priority assistive products list (APL) which are made available to students with visual impairments. Teachers need to be exposed to modern ATs (i.e. smartphone applications). There needs to be an emphasis on collaborating between partners (i.e. ministeries of education, health and welfare) to ensure the needs of children with visual disabilities are met.

16. The Accessibility of Assistive Technology for Students with Disabilities in Higher Learning Institutions: A case of the University of Dar-es-Salaam in Tanzania

The target group of the article by Ngonyani & Mnyanyi (2021) was 173 participants; 18 management officials, 35 trainers and 120 students, including 33 students with disabilities, 10 of which were students with visual impairments, five with low vision, seven with physical disabilities, three with albinism, seven with hearing impairments and one with speech impairment. Aim was to investigate ATs used by student with disabilities in a higher learning institution, types of ATs available and used at the university and ratings of ATs in terms of adequacy. ***AT solutions or devices:***

Different types of disabilities had multiple ATs available. The authors compiled a list of disabilities, how many enrolled students had these disabilities and what ATs are available to them.

- *Type of Disability:* Visually Impaired, Number of Enrolled Students (2019-2020): 34, Available ATs: Perkins braille, braille papers, Cut-sheet braille papers, Braille note, Braille display, Braille embosser, White canes, Optical character recognition systems, electronic notetaker, computers with software and talking programs e.g., JAWS and NVDA, Voice recorder, talking watch, talking calculators, electronic talking dictionaries, and Audiobooks,
- *Type of Disability:* Low Vision, Number of Enrolled Students (2019-2020): 50, Available ATs: Closed-circuit television (CCTV), Optelec clearview, computers, Optical character recognition, Electronic note-taker, and Handheld magnifier,
- *Type of Disability:* Hearing-Impaired, Number of Enrolled Students (2019-2020): 34, Available ATs: Digital hearing aids, computers, ALDs, and personal amplifiers,
- *Type of Disability:* Speech Impaired, Number of Enrolled Students (2019-2020): 1, Available ATs: computers, alerting devices, AAC devices, e.g. speech to text software and verbal cues,
- *Type of Disability:* Physical Impaired, Number of Enrolled Students (2019-2020): 32, Available ATs: Wheelchairs, crutches,
- *Type of Disability:* Albinism, Number of Enrolled Students (2019-2020): 6, Available ATs: Computers, Optical character recognition, Electronic notetaker, Handheld magnifier,
- *Type of Disability:* Other Special Needs, Number of Enrolled Students (2019-2020): 3, Available ATs; They were provided with other special care.

AT evaluation: Affordability and accessibility. When it came to adequacy of the ATs, 59% of the respondents said that ATs are moderately available, 34% less available and 7% readily available. From these numbers, it can be determined that the availability of the ATs was not enough for students with disabilities. ***Main results, outcomes, and recommendations.*** The main challenges related to available ATs were listed in the study as: low understanding, deficiency in some ATs, poor training on the use of ATs, incompatibility of AT with the kind of disability, the need to return AT yet needed for use, lack of maintenance and repair of AT and difficulties adapting to new AT. The authors also provided guidelines to overcome these issues such as: training related to ATs, provisioning enough ATs, regular checking and servicing of AT, increasing number of AT experts, SWDs should be provided with efficient AT and emerging AT should be adapted. Lastly, the authors provided recommendations to both higher learning institution Tanzania and the government. For the university, there should be inclusion of trainers and SWD in curriculum planning and evaluation as well as all the infrastructure should support the use of AT for SWDs. For the government, enabling the availability and affordability of AT for SWDs, integrating

governmental organizations (such as ministry of health and ministry of labor) and PWDs to ensure that SWD is provided the correct AT for their needs, there needs to be an institute to develop AT experts and government needs to invest to manufacture AT for SWDs.

17. A glimpse into smartphone screen reader use among blind teenagers in rural Nepal

The target group of the Sankhi's & Sandnes' (2020) article was five blind teenagers in a mixed secondary school with disabled and non-disabled students in rural Nepal and they were interviewed about their daily smartphone use. ***AT solutions or devices.*** All the participants responded that they use smartphones at school. All the participants were using (android) smartphones donated by an international NGO. All the participants reported that they use the built-in screen reader function (talkback) on the smartphone. Several indicated using internet voice calling and message chat using the IMO app. The participants also reported that they used audio textbooks for their studies. These books were mostly provided on memory cards by the school. ***Partnerships: AT manufacturers.*** A simple inspection of instructions provided by different android smartphone manufacturers confirms that the steps to activate the accessibility features vary. ***AT evaluation: Affordable and accessibility.*** The built-in accessibility features of smartphones promise disabled youth a non-stigmatizing platform for social participation and access to the information society. ***AT evaluation: Usefulness.*** Several participants expressed that they wanted "shortcut" buttons for the activation of the accessibility features which could indicate that these features are perceived as being hidden inside deep menu hierarchies. Another challenge mentioned by all the participants was the incorrectness of the quality of the text-to-speech pronunciation in Nepali and other languages spoken in Nepal. ***Main results, outcomes, and recommendations.*** The results show that all the participants used screen readers on donated smartphones. None of the participants had received formal training in using smartphone screen readers and therefore lacked knowledge about basic and essential operational aspects of the devices as well as misguided expectations about the technology. The built-in accessibility features of smartphones provide disabled youth a non-stigmatizing practical platform for social participation and access to education. Training material on how to use smartphone accessibility features needs to be made easily available to schools and all disabled youth worldwide.

18. Key Factors of Design: 3D Printed Occupational Therapy Products in Developing Communities

The target group of the article by Spicher & Gershenson (2020) included disabled persons living in low-income, rural communities in Sub-Saharan Africa, specifically those in need of occupational therapy. Additionally, the article focuses on occupational therapists working in these regions; 6 occupational therapists (in Kisumu County, Kenya, were interviewed to understand their experience and

perception of 3D printing and their unique desires for appropriate products. ***AT solutions or devices.*** 3D printing technology can address poverty in these countries by addressing individual product needs and improving industrial capabilities. It has been proven that 3D printing technology can be employed to produce feasible and viable products, but the key issue of product desirability is currently unaddressed. This paper addresses the problem of misunderstood design desirability to provide appropriate occupational therapy tools in this market. ***AT evaluation: Affordable and accessibility.*** Interviews suggested that portability, customizability, and cost are the most important considerations when designing new occupational therapy products. Patients cannot afford transportation to large hospitals, increasing the value of home programs. Patient needs are not met by traditional devices, and therapists are eager to work with designers to create appropriate, customized products. Occupational therapy is viewed as “less critical” than other departments, so budgets are low. ***Main results, outcomes, and recommendations.*** It has been determined that the three most important design factors to consider when developing 3D-printed occupational therapy products for professionals in rural hospitals and health clinics in Sub-Saharan Africa are portability, customizability, and cost. To make claims with greater specificity, therapists in the additional 47 counties in Kenya need to be interviewed. The length and depth of the survey should be extended to provide better quantitative data. Once a specific determination is made, these desirability factors should be used to guide product design of 3D printed occupational therapy tools to provide appropriate occupational therapy tools, increasing the availability of effective care for patients seeking education and employment.

19. A review of principles in design and usability testing of tactile technology for individuals with visual impairments

The focus area of the Horton’s et al. (2016) literature review was hardware platforms that are often used for ATs, to identify prevalent applications of assistive platforms, and to investigate the nature of user studies conducted with ATs for blind individuals. ***AT solutions or devices.*** Hardware platforms in AT are rapidly changing, the main applications of education, navigation, and computer accessibility have largely remained core issues for individuals who are visually impaired. In recent years, with the rise of assistive software, a larger emphasis has been placed on computer accessibility for visually impaired users, underscoring the need for them to interact and learn digitally. Recently, several devices have been developed using vibration and auditory feedback from standard touchscreens and tablet devices to make graphical material accessible. ***AT evaluation: Usefulness.*** People with visual impairments have used all three types of devices successfully, and each has its advantages in communicating information quickly and efficiently. The hardware components of the devices reviewed varied widely in complexity. New technology has entered the market that allows for the development of touchscreens that provide tactile feedback to the user through electro-static interaction. This may allow future

development of AT for applications in which the use of a tactile touchscreen is extremely practical. ***Main results, outcomes, and recommendations.*** It was found that while earlier hardware development focused on pin matrices, the emphasis then shifted toward force feedback haptics and accessible touch screens. The inclusion of interactive and multimodal features has become increasingly prevalent. Altogether, the findings presented in this review provide insight on effective design strategies and user testing methodologies for future research on AT for individuals with visual impairments.

20. Assistive Technology in Education

The focus area of the expert article by Quek, Elglaly & Oliveira (2016) was to give an overview of the state of research in ATs that support teaching and learning for individuals with blindness or severe visual impairment. ***AT solutions or devices:*** Braille, Microsoft Narrator, VoiceOver JAWS, DotPlus, MathML and more. ***AT evaluation: Affordable and accessibility.*** Braille is still one of the best options to provide for students with blindness or severe visual impairments. However, Refreshable Braille and audiobooks arrays are too limiting to support spatial access. ***AT evaluation: Usefulness.*** Students have to have access to multiple streams of information at the same time (speech, access to presentation material, reading material, and more). Each of these elements create opportunities for AT support. ***Main results, outcomes, and recommendations.*** There have been many approaches to supporting access to mathematics expressions and material as well as graphics. None of the solutions advanced thus far have fully solved these problems of access.

21. Functional hearing in the classroom: assistive listening devices for students with hearing impairment in a mainstream school setting

The target group of the article by Zanin & Rance (2016) was 20 students, aged 12.5–18.9 years, with hearing impairment in mainstream schools. In total, 10 of these participated in the 2-week classroom trial on speech perception assessment. In addition, LIFE-R student and teacher appraisal questionnaires were used. ***AT solutions or devices*** used were assistive listening devices (ALDs) and remote microphones, and soundfield systems at the classroom. ***AT evaluation: Usefulness.*** A significant improvement in speech perception ability was established using ALD in all configurations. The remote microphone, when placed close to the speech source, provided the most significant perceptual benefit (i.e., placing it on the desk or handing it to the teacher to wear), as well as its compatibility with other technological devices, contributed to this preference. Nonetheless, for students whom stigma and peer acceptance are factors, soundfield systems should be considered as an option. ***Main results, outcomes, and recommendations.*** Speech recognition improvements were demonstrated with the implementation of both remote microphones and soundfield systems. Both students and teachers reported functional hearing advantages in the classroom when using the remote microphone

in concert with their standard hearing devices. Adequate provision, uptake and usage of these devices are crucial in ensuring children with hearing impairment have the same access to verbal and auditory information in the classroom as children with normal hearing.

22. Six years of inclusive education at the University of Rwanda-College of Education: Evaluation and perspectives

The target group of the Nsanzabiga's (2014) article was thirty students with disabilities (SwDs) in the context of University of Rwanda and inclusive education. Fourteen of these students had already graduated. These students were also divided into three categories: students who were on the campus, those who were on internship and graduates on the labor market. The data collection was through an anonymous questionnaire, projects and interviews and statistics. ***AT solutions or devices.*** Perkins Braillers, Braillinos, Victor Reader Streams, sound level meters, portable magnifier, monomouse, Noah software, SV Senseview, Zychem machine, video autoscope, large print dictionary, DVD player for speech and pediatric audiometer, middle ear analyzer, pediatric screening audiometer, Siemens hearing screener, telecommunication device for deaf, ALD, among more, were specified in the article. ***AT evaluation: Affordable and accessibility.*** Main issues that were brought up in the study in relation to ensuring the accessibility of the ATs: training for lecturers, increasing assistive materials, incentives for resource room staff for extra hours, training for staff and SwDs. ***Main results, outcomes, and recommendations.*** Study indicated that there needs to be pre-admission guidance and counseling. Raising the number of SwDs and reducing gender imbalance were also key recommendations. The staff needed to be trained for more awareness on inclusive education and more varied supportive materials needed to be acquired.

23. Access to assistive technology in two Southern African countries

The focus area of the article by Matter and Eide (2018) concerned access of ATs in Botswana and Swaziland from sociodemographic point of view. Millions of people in Southern Africa are deprived of basic human rights, such as the right to education and work, because of the large and growing unmet demand for assistive technologies (AT). Evidence is needed to better characterize the lack of AT access. ***The target group.*** This article serves to identify the sociodemographic factors that are associated with access to AT in two countries in Southern Africa, Botswana and Swaziland. The target sampling populations were all private households, excluding institutionalized and homeless people. ***AT solution or device.*** These findings support governments and other stakeholders in the AT sector to prioritize AT to address the large unmet demand and expand the range of AT products provided so that people with hearing, seeing, self-care, communication, and cognition difficulties have equal access to AT as those with mobility impairments. ***AT evaluation: Affordable and Accessibility.*** Logistics regression was applied to a subset of variables from two Living Conditions Studies, nationally representative surveys that

were conducted in Southern Africa (2014 and 2010). In Botswana, 44% of people who needed AT did not receive it, while in Swaziland, the unmet need was 67%. Among the sociodemographic variables tested, the type of disability was the most important factor in determining AT access in both countries. The likelihood of AT access was highest in both countries for those who had mobility limitations (i.e., difficulty walking/climbing stairs) [Botswana: 6.4 odds ratio (OR) = 6.4., 95% confidence interval (CI) (3.6–11.3); Swaziland: OR = 3.2, CI (1.4–7.3)], in comparison to those with non-mobility types of disabilities. ***Main results, outcomes, and recommendations.*** Identifying the socio-demographic factors that are associated with access to AT in two countries in Southern Africa, Botswana and Swaziland. The most common type of disability reported in both countries was difficulty with walking/climbing steps (mobility limitation). A step toward achieving these aims is to inventory AT product types commonly covered through the public sector in each country and identify common gaps (e.g., daily living aids). Advancing the AT sector as a whole within Southern Africa will require large-scale qualitative studies that achieve a comprehensive understanding of the bottlenecks in regional AT supply, procurement, and delivery systems.

5 CONCLUSIONS AND PROPOSAL FOR GUIDELINES

In conclusion, the current literature reveals a diverse range of assistive technologies (ATs) currently available and utilized in educational settings, ranging from low-tech tools such as Braille machines to high-tech solutions such as virtual reality and socially assistive robots (SAR). These ATs play a crucial role in enabling students with disabilities to access education, though their availability often varies significantly based on geographic and socio-economic factors. The alignment of AT solutions with usefulness and socio-economic considerations is evident, as more affordable and accessible technologies are essential in low-resource settings, while advanced ATs, though effective, remain unreachable for many.

The literature also underlines the importance of various stakeholders in fostering accessibility and inclusion for persons or people with disabilities. These include international organizations, governments, manufacturers, NGOs, and educational institutions. International organizations like WHO and UNESCO set global standards and fund initiatives to promote accessibility. Governments create policies, provide funding, and ensure infrastructure supports AT use in schools. Manufacturers and developers innovate and produce a range of ATs, from basic tools to advanced technologies. NGOs and educational institutions play crucial roles in distributing ATs, raising awareness, and integrating these technologies into learning environments to ensure inclusive education for all students.

Stakeholders' collaborative efforts are essential in overcoming barriers and ensuring all students have equal opportunities to succeed in their educational goals. Although the literature varies by country, we believe the considerations can also be adaptable to countries in East Africa, such as Rwanda and Zanzibar.

5.1 Assistive technology categorization

AT categorization is traditionally based on technological complexity or level of technology, ranging from *low-tech* to *mid-tech* to *high-tech*. However, based on the analysis of the desk review results, this section covers six categories and subcategories (see Appendix 1.). These main categories are 1) *complexity*, 2) *functionality*, 3) *target group*, 4) *implementation context*, 5) *socio-economic accessibility*, and 6) *stakeholder involvement*.

5.1.1 Complexity

Low-tech ATs consist of simple tools and non-electronic devices that are widely accessible and easy to implement. Mid-tech ATs include basic electronic devices that provide enhanced functionality while maintaining simplicity. High-tech ATs represent advanced electronic devices and solutions, offering significant benefits, though often requiring specialized development and training.

Table 5. The category Complexity and its subcategories.

Subcategory	Examples	Articles
Low-tech AT	Braille machines, communication boards, adaptive scissors	1, 2, 21
Mid-tech AT	Speech-generating devices, screen readers, hearing aids	7, 14, 16
High-tech AT	Virtual Reality (VR), socially assistive robots (SARs), AAC devices	3, 5, 6

5.1.2 Functionality

ATs in this category are based on specific functionality, such as communication, mobility, learning and educational support, hearing, vision, and cognitive assistance.

Table 6. The category Functionality and its subcategories.

Subcategory	Examples	Articles
Communication AT	AAC devices, Speechify, GoTalk 9+	5, 8
Mobility AT	Wheelchairs, prosthetics, assistive canes	10, 14
Learning and general educational support AT	3D printed learning aids, tactile graphics, digital math tools	13, 18, 20
Hearing AT	Assistive listening devices, cochlear implants, personal amplifiers	7, 21
Vision AT	Braille displays, magnifier, smart canes, tactile technologies	4, 9, 16, 19
Cognitive AT	AI-based learning tools, memory aids, brain-computer interface	5, 11

5.1.3 Target group

ATs can be targeted to specific groups, such as students with visual, hearing, mobility impairments, learning disabilities (difficulty), or multiple impairments or disabilities.

Table 7. The category Target group and its subcategories.

Subcategory	Examples	Articles
Students with visual impairments	Braille displays, screen readers, tactile technology	4, 9, 13, 19
Students with hearing impairments	Hearing aids, assistive listening devices	7, 14, 21
Students with mobility impairments	Wheelchairs, prosthetics	10, 18
Students with learning disabilities (difficulty)	AI-based tools, digital learning tools, tactile technology	5, 8, 11, 19
Students with multiple impairments or disabilities	Integrated AT systems, custom learning aids	2, 10, 20

5.1.4 Implementation context

The implementation context categorizes ATs by where and how technologies are used, whether in classrooms, homes, or hybrid learning environments.

Table 8. The category Implementation context and its subcategories.

Subcategory	Examples	Articles
Classroom-based AT	Interactive whiteboards, AAC devices	6, 13, 21
Home-based AT	Smartphones with accessibility features, home-adapted communication boards	4, 12, 17
Hybrid learning environments	VR platforms, AI-assisted tutoring systems	3, 5, 11

5.1.5 Socio-economic accessibility

Categorization by socio-economic accessibility is based on affordability and availability across different socio-economic levels, emphasizing the cost of ATs and the ability to access them.

Table 9. The category Socio-economic accessibility and its subcategories.

Subcategory	Examples	Articles
Affordable and widely available AT	Smartphones, open-source screen readers	4,13, 14, 23
Mid-range AT	Digital hearing aids, mid-tech communication devices	1, 7, 23
Premium and advanced AT	High-tech AAC Devices, SARs, tactile technology	5, 6, 9, 19, 23

5.1.6 Stakeholder involvement

Stakeholder involvement highlights the roles of different groups in the development, distribution, support, and use of assistive technologies.

Table 10. The category Stakeholder involvement and its subcategories.

Subcategory	Examples	Articles
Government and public sector	Government subsidies, national AT programs	15, 16, 22
Private sector	Innovation and manufacturing, market-driven products	8, 12, 19
Non-governmental organizations (NGOs) and civil society	Support in low-resource settings, awareness campaigns	14, 17
Educational institutions	Implementation and training, supportive infrastructure	1, 10, 20

5.2 Proposals and general guidelines

Multiple principles influence the context and practical implementation of accessibility at the individual, local, regional, and global levels. Based on the desk review results analysis, five general guidelines are presented in Table 11 with a description.

To enhance the effectiveness of assistive technologies (ATs), focus should be placed on improving accessibility, availability, and affordability. Promoting local innovation and manufacturing can significantly reduce costs and foster self-reliance. Solutions such as 3D printing and open-source software development provide cost-effective, customizable approaches tailored to local needs.

Therefore, it is important to encourage educators' professional development through ongoing support and training to use both low-tech and high-tech ATs in the classroom effectively. Emphasis should be placed on adaptability, fostering the development of ATs tailored to individual student needs and diverse educational settings. Another critical component is ensuring accessible infrastructure to support AT integration. Developing standards and guidelines for integrating ATs with existing educational technologies will also ensure ease of use and interoperability.

Finally, fostering stakeholder collaboration is essential for evaluating ATs' impact, improving equity, and driving inclusion. These efforts should be supported by practical training, awareness, and usability guidelines. By integrating these, the educational community can address existing challenges and ensure that ATs are practical tools for achieving educational goals for all students.

Table 11. General guidelines.

Guideline	Description
Improve accessibility, availability, and affordability	Develop affordable ATs for low-resource settings using local innovation like 3D printing. Build infrastructure to support AT integration.
Enhance training, awareness, and usability	Provide ongoing training for educators to use ATs effectively. Ensure ATs are user-friendly, adaptable, and interoperable with existing systems.
Strengthening technological integration	Develop standards for AT compatibility and adaptability. Build infrastructure to ensure seamless AT use in educational settings.
Promote equity and inclusion	Design adaptable ATs that benefit all students, regardless of type of impairment or socio-economic status. Support local, affordable solutions to reduce disparities.
Facilitate stakeholder collaboration and evaluation	Foster partnerships to improve AT availability and equity. Evaluate ATs regularly to enhance their effectiveness and impact.

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APPENDIX 1. Categories

Main category	Subcategory	Examples
Complexity	Low-tech AT	Braille machines, communication boards, adaptive scissors
	Mid-tech AT	Speech-generating devices, screen readers, hearing aids
	High-tech AT	Virtual Reality (VR), socially assistive robots (SARs), AAC devices
Functionality	Communication AT	AAC devices, Speechify, GoTalk 9+
	Mobility AT	Wheelchairs, prosthetics, assistive canes
	Learning and general educational support AT	3D printed learning aids, tactile graphics, digital math tools
	Hearing AT	Assistive listening devices, cochlear implants, personal amplifiers
	Vision AT	Braille displays, magnifier, smart canes, tactile technology
	Cognitive AT	AI-based learning tools, memory aids, brain-computer interface
Target group	Students with visual impairments	Braille displays, screen readers, tactile technology
	Students with hearing impairments	Hearing aids, assistive listening devices
	Students with mobility impairments	Wheelchairs, prosthetics
	Students with learning disabilities (difficulty)	AI-based tools, digital learning tools, tactile technology
	Students with multiple impairments or disabilities	Integrated AT systems, custom learning aids
Implementation context	Classroom-based AT	Interactive whiteboards, AAC devices
	Home-based AT	Smartphones with accessibility features, home-adapted communication boards
	Hybrid learning environments	VR platforms, AI-assisted tutoring systems
Socio-economic accessibility	Affordable and widely available AT	Smartphones, open-source screen readers
	Mid-range AT	Digital hearing aids, mid-tech communication devices
	Premium and advanced AT	High-tech AAC Devices, SARs, tactile technology
Stakeholder involvement	Government and public sector	Government subsidies, national AT programs
	Private sector	Innovation and manufacturing, market-driven products
	Non-governmental organizations (NGOs), and civil society	Support in low-resource settings, awareness campaigns
	Educational institutions	Implementation and training, supportive infrastructure