Teachers' Use of Assistive Technology in STEM Instruction for Students with Visual Impairment in Inclusive Basic Schools in Ghana

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Abstract

Assistive technology is important for improving access to Science, Technology, Engineering, and Mathematics (STEM) instruction for learners with visual impairment in inclusive classrooms. However, in Ghana, its use in inclusive basic schools remains limited and inconsistent. This qualitative multiple-case study explored how teachers use assistive technology in STEM instruction for learners with visual impairment in three historically inclusive basic schools in Ghana. All twenty-one (21) teachers teaching STEM-related subjects in the selected schools participated in the study. Data were collected through semi-structured interviews, classroom observations, and review of assistive technology resources, and were analysed thematically. The findings showed that teachers relied mainly on basic braille-related resources, while access to low-vision devices, digital tools, and specialised STEM assistive technologies was limited and uneven across schools. Assistive technology was used primarily to improve access to visual and text-based STEM content, support mathematical tasks, and promote participation in classroom activities. However, such use was not consistent and was often dependent on the availability of resources and teachers' confidence in using them. Factors that supported integration included teacher training, collaboration with specialists, supportive school leadership, and resource availability. Key barriers included inadequate training, limited and costly assistive technology, weak infrastructure, curriculum and assessment pressures, and insufficient institutional support. The study concludes that although teachers show commitment to inclusive STEM instruction, sustained use of assistive technology is constrained by inadequate resources and weak support systems. It recommends increased provision of STEM-related assistive technology, continuous teacher professional development, and stronger school-level support to improve inclusive STEM instruction for learners with visual impairment in Ghana.

Keywords: Assistive Technology; Inclusive STEM; Visual Impairment; Teacher Practices; Ghana.

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Introduction

Inclusive education has gained global momentum as countries strive to secure equitable access to quality learning for all children, including those with disabilities (UNESCO, 2020). In Ghana, this commitment is articulated in the Inclusive Education Policy introduced by the Ministry of Education and the Special Education Division of the Ghana Education Service (GES) in 2015. The policy seeks to ensure that learners with special educational needs are taught in regular schools alongside their peers and receive appropriate supports to participate meaningfully in learning (Ministry of Education, 2015). Despite this policy direction, evidence suggests that the inclusion of learners with visual impairment in Ghanaian basic schools remains uneven, with persistent barriers in curriculum access and classroom participation. These challenges are particularly pronounced in STEM instruction (Awini, 2025; Kelly & Smith, 2011; Le Fanu et al., 2022; Nyavor, 2020).

STEM instruction is often anchored in visual representations, spatial reasoning, diagrams, symbols, and hands-on practical activities. When these instructional demands are not adapted, they inadvertently marginalise learners with visual impairment and restrict their access to foundational STEM concepts (Rule & Stefanich, 2012; Sahin & Yorek, 2009). In inclusive classrooms, learners with visual impairment may struggle to access board work, laboratory demonstrations, graphical data, and spatial models, thereby limiting their active engagement in STEM instruction.

Assistive Technologies (AT), including screen readers, low-vision devices, tactile diagrams, braille displays, talking scientific tools, and accessible digital resources, are widely recognised as critical supports that can enable learners with visual impairment to access STEM content and participate more independently in classroom activities (Abner & Lahm, 2002; Kelly & Smith, 2011). However, in many Ghanaian inclusive basic schools, AT integration in STEM instruction remains limited and inconsistent. Teachers' use of AT is often shaped by individual effort rather than a coherent, school-wide instructional approach. Constraints commonly reported in the Ghanaian context include inadequate pre-service and in-service preparation, limited availability of AT resources, weak infrastructure, and insufficient institutional and leadership support for technology-enabled inclusion (Agamboka & Dogbe, 2020; Awini, 2025).

These gaps are particularly visible in Ghana's three historically inclusive basic schools, Ghana National Basic Inclusive School (Cape Coast), St. Joseph Integrated Basic School (Bechem), and Avakpedome Basic School (Volta Region). These schools have long served as flagship sites for educating learners with visual impairment within inclusive settings (Anthony, 2011; Avoke, 2002). Although teachers in these contexts often demonstrate strong commitment to inclusive values, STEM instruction frequently depends on improvised strategies such as extended verbal explanations, peer-assisted learning, and teacher-made adaptations, with limited systematic use of AT-mediated instructional supports (Awini, 2025). Consequently, learners with visual impairment may experience restricted participation, uneven learning opportunities, and continued achievement gaps in STEM instruction (Kelly & Smith, 2011; Le Fanu et al., 2022; Nyavor, 2020).

This situation raises concerns for Ghana's progress toward Sustainable Development Goal (SDG) 4, which emphasises inclusive and equitable quality education for all learners (United Nations, 2015). More importantly, it highlights the need for research that foregrounds teachers' classroom realities, specifically, the assistive technologies they use, how they are used within STEM lessons, and the contextual factors that shape or constrain such practices. Understanding teachers' experiences and perceptions of AT integration is essential for informing teacher preparation,

strengthening school-level resourcing and leadership support, and building partnerships that can sustain technology-enabled inclusive STEM learning in Ghanaian basic schools. Ghana's Inclusive Education Policy (Ministry of Education, 2015) affirms a national commitment to equitable access and participation for all learners, including those with visual impairment.

However, in STEM instruction, this commitment remains difficult to realise because these subjects depend heavily on diagrams, symbols, graphical representations, demonstrations, and practical activities that are often inaccessible without appropriate assistive technologies (AT) and instructional adaptations (Kelly & Smith, 2011; Rule & Stefanich, 2012). As a result, learners with visual impairment remain at risk of exclusion from meaningful participation in STEM instruction within inclusive basic schools.

Although existing studies in Ghana have identified broad challenges such as limited teacher preparation, inadequate AT resources, and weak institutional support for inclusive practice (Agamboka & Dogbe, 2020; Awini, 2025), there is still limited empirical evidence on how teachers actually use assistive technologies in STEM instruction for learners with visual impairment. In particular, little is known about the specific AT tools teachers employ, how these tools are integrated into day-to-day STEM instruction, and the contextual conditions that facilitate or hinder such integration in inclusive school settings. This leaves an important gap in understanding how inclusive STEM instruction is enacted in practice for learners with visual impairment. This gap is especially important in Ghana's three historically inclusive basic schools, Ghana National Basic Inclusive School, St. Joseph Integrated Basic School, and Avakpedome Basic School, which are often regarded as model sites for inclusive education (Anthony, 2011; Avoke, 2002).

Despite their longstanding role in educating learners with visual impairment, there is limited qualitative evidence on whether STEM instruction in these schools is supported by systematic AT integration or continues to depend largely on non-technological and improvised strategies. Without such evidence, it is difficult to determine the extent to which assistive technology is enabling meaningful participation in STEM instruction for learners with visual impairment or to identify the school- and classroom-level factors shaping teachers' practices. There is therefore a critical need to examine teachers' use of assistive technologies in STEM instruction for learners with visual impairment in Ghana's historically inclusive basic schools, with particular attention to the types of technologies employed, how they are integrated into classroom practice, and the contextual factors that support or constrain their use. It is against this backdrop that the study sought to explore how teachers in inclusive basic schools in Ghana integrate assistive technologies into STEM instruction for learners with visual impairment. Specifically, the study sought to generate an in-depth understanding of the assistive technologies that teachers use, how these technologies are applied during STEM instructions, and the contextual conditions that shape their integration. The following research questions guided the study:

1. What types of assistive technologies are available and used in STEM instruction for learners with visual impairment in inclusive basic schools in Ghana?
2. How do teachers integrate assistive technologies into STEM instruction for learners with visual impairment, and how consistent is this integration across different classroom activities?
3. What do teachers perceive as the key school- and classroom-level factors that facilitate or hinder their integration of assistive technologies in inclusive STEM instruction?

Literature review and theoretical framework

This section reviews literature on assistive technology, inclusive STEM instruction, and the education of learners with visual impairment. It also outlines the theoretical framework and examines empirical studies on teachers' use of assistive technologies in inclusive classrooms. The review situates the study within existing scholarship and identifies the gap it addresses. This study is guided primarily by the Universal Design for Learning (UDL) framework. UDL provides a strong instructional lens for analysing teachers' integration of assistive technologies in inclusive STEM classrooms because it is explicitly concerned with how teaching is designed to accommodate learner diversity from the outset (Meyer et al., 2014). The framework emphasises three core principles: multiple means of representation, engagement, and action/expression**.**

Within STEM instruction for learners with visual impairment, these principles align directly with the pedagogical purposes of Assistive Technologies (AT). Multiple means of representation speak to how teachers use AT (e.g., braille, tactile, audio, digital magnification tools) to present STEM concepts that are often visually encoded. Multiple means of engagement support the use of AT to sustain participation in STEM learning activities, including practical tasks and collaborative work. Multiple means of action/expression address how learners with visual impairment can demonstrate understanding through accessible tools and alternative response formats. By applying UDL, this study interprets assistive technology use as part of inclusive instructional design rather than as an add-on or specialised support. Although not adopted as a separate guiding theory, the study recognises a related sociocultural idea that assistive technologies function as mediating tools in classroom interaction. This view helps explain why teachers' AT practices are influenced by access to tools, collaboration, scaffolding, and the broader classroom environment. These supporting concepts are drawn on in interpreting teachers' experiences but remain secondary to the UDL lens.

Inclusive STEM education and visual impairment

Research indicates that learners with visual impairment face barriers in accessing STEM curricula and participating fully in STEM subjects (Dabi & Negassa Golga, 2024; Rule & Stefanich, 2012; Sahin & Yorek, 2009). In this review, STEM curricula refer to the planned content, skills, learning activities, and assessment expectations embedded in school STEM areas, whereas STEM subjects refer to the specific subjects through which this curriculum is delivered. In Ghana's basic school curriculum, the National Council for Curriculum and Assessment identifies Science, Mathematics, and Computing as distinct curriculum areas, making them the most relevant STEM subjects for this study (Ministry of Education, 2020). This distinction matters because enrolment in STEM subjects does not necessarily ensure equitable access to the curriculum that those subjects are intended to deliver. Ghana's curriculum documents themselves emphasise inclusion and equal access to a broad and balanced curriculum for all learners, which strengthens the relevance of accessibility within STEM learning.

The literature shows that STEM learning often depends on diagrams, graphs, symbols, demonstrations, measurements, and spatial reasoning. Earlier work by Rule and Stefanich (2012) and Sahin and Yorek (2009) remains useful in showing how these visual and spatial demands can disadvantage learners with visual impairment when adaptations are absent. However, the point is

not merely that STEM is visual; it is that much of its meaning is carried through formats that are inaccessible unless deliberately adapted. In inclusive classrooms, this may limit access to board work, diagrams, experiments, models, and graphical representations, thereby constraining active participation and concept development. Thus, access to STEM subjects does not automatically guarantee access to STEM curricula. Meaningful participation depends on whether curriculum materials and classroom activities are made accessible through appropriate instructional adaptations and assistive supports.

Assistive technologies for STEM instruction

Assistive technologies are widely recognised as important supports for enabling access to STEM content among learners with visual impairment. Earlier studies identified tools such as screen readers, braille devices, tactile diagrams, digital magnifiers, and talking scientific equipment as important for translating visually presented STEM content into accessible formats (Kelly & Smith, 2011; Abner & Lahm, 2002). Recent literature indicates that assistive technologies remain important for improving access to mathematics, science, and other visually demanding learning experiences for learners with visual impairment, especially where tactile, auditory, or enlarged alternatives to standard print and graphics are needed (Dabi & Negassa Golga, 2024; Shoaib et al., 2023). Similarly, accessible graphics, braille-based materials, and adapted digital tools are increasingly recognised as important for supporting participation and engagement in visually intensive subjects (Tennison et al., 2023; Traitruengsakul & Silamut, 2026).

For the present study, the importance of assistive technology lies not only in the devices themselves, but in their instructional function. Assistive technologies help teachers represent complex STEM concepts through tactile, auditory, enlarged, or otherwise accessible alternatives. In UDL terms, they broaden representation and action/expression pathways, allowing learners with visual impairment to work toward the same curricular goals as their peers. This is particularly important in STEM because access barriers often arise at the point where abstract content is communicated through diagrams, equations, charts, symbols, and practical demonstrations.

Teachers' integration of AT in inclusive STEM classrooms

Despite the potential of assistive technology, evidence consistently shows that classroom integration remains uneven. Across inclusive settings, teachers' use of assistive technology is shaped not only by attitudes toward inclusion but also by confidence, practical knowledge, access to devices, and the level of instructional support available. In Ghana and related contexts, studies continue to show that teachers often have limited practical exposure to inclusive strategies and remain unevenly prepared to translate inclusive intentions into classroom action. Recent Ghana evidence on teacher preparedness suggests that inclusive education is reflected in teacher education, but readiness for implementation remains inconsistent, especially where practice-based preparation is weak (Naami & Mort, 2023). This has implications for assistive technology integration in STEM instruction. Even when teachers hold positive beliefs about inclusion, the use of assistive technology may remain irregular if teachers cannot access functional devices, lack hands-on preparation, or are uncertain about how to embed these tools meaningfully into lesson delivery. Thus, the issue is not simply whether teachers value assistive technology, but whether they are positioned to use it routinely and effectively in the context of classroom instruction.

Ghanaian context and factors shaping teachers' AT use

In Ghana, although the Inclusive Education Policy was introduced in 2015, implementation has frequently been described as uneven, particularly with respect to resourcing, teacher support, and the everyday realities of inclusive classroom practice. More recent Ghana literature continues to point to gaps between policy commitment and school-level implementation, especially in relation to disability support, resource provision, and teacher preparedness (Naami & Mort, 2023; Opoku et al., 2021).

Within this broader context, teachers in inclusive schools often rely on verbal explanations, peer support, and improvised strategies when specialised resources are unavailable. Existing Ghana-based studies have examined inclusive education policy implementation, general classroom accommodations, support services, and broader inclusive practices for learners with visual impairment. For example, Agamboka and Dogbe (2020) address instructional accommodations, while other Ghana studies focus more broadly on access, participation, or support systems for learners with visual impairment. There is also evidence from Ghanaian school contexts that access to assistive technology remains limited, uneven, and associated with gaps in teacher knowledge and skill. A UEW-hosted study at Adidome Senior High School, for instance, reported low awareness, outdated tools, and indications that teachers lacked sufficient knowledge and skills to support effective assistive technology use.

Recent literature on teacher preparation in Ghana also suggests that, although inclusive education is increasingly reflected in pre-service programmes, practical exposure to inclusive pedagogies and technology-supported strategies remains uneven (Naami & Mort, 2023). Beyond training, teachers' assistive technology practices are shaped by contextual factors such as class size, workload, device availability, school leadership, collaboration with specialists, and external support. These conditions influence not only whether teachers use assistive technology, but also how consistently and creatively they integrate it into STEM lessons.

Although prior studies establish that assistive technologies and related instructional accommodations can support accessibility for learners with visual impairment, there is still limited qualitative evidence in Ghana that foregrounds teachers' everyday realities of assistive technology integration in inclusive STEM classrooms, particularly within historically inclusive basic schools. Most existing work has focused on policy implementation, general inclusive practices, learner access, or support services rather than on the specific technologies teachers actually use, how those technologies are applied during STEM lessons, and the school- and classroom-level conditions shaping such practices. This study addresses that gap by exploring teachers' use of assistive technologies in STEM instruction for learners with visual impairment in inclusive basic schools in Ghana, focusing on the types of AT employed, the ways they are integrated into classroom practice, and the contextual factors that facilitate or constrain their use.

Methodology

This section describes the methodological procedures used to conduct the study. It outlines the research design, study sites, sample and sampling, data collection instruments and procedures, data analysis, and trustworthiness.

Research design

This study adopted a qualitative multiple-case study design. The design was appropriate because it enabled an in-depth exploration of how teachers integrate assistive technologies (AT) into STEM instruction for learners with visual impairment across different inclusive school contexts. By focusing on teachers' lived classroom practices and perceptions, the qualitative case approach supported rich description and interpretation of the types of AT used, how these tools are applied during STEM lessons, and the contextual factors shaping their integration (Creswell, 2013; Yin, 2018). The three historically inclusive basic schools constituted bounded cases, allowing for both within-case and cross-case understanding of teachers' AT practices.

Study areas

The study was conducted in three historically inclusive basic schools in Ghana: Ghana National Basic Inclusive School in Cape Coast in the Central Region, St. Joseph Integrated Basic School in Bechem in the Ahafo Region, and Avakpedome Basic School in the Akatsi South District of the Volta Region. These schools were purposively selected because they have a long history of educating learners with visual impairment alongside sighted peers and are recognised within Ghana's inclusive education system as established inclusive basic schools. These schools are important to the present study because they represent longstanding attempts to implement inclusion in ordinary basic school settings rather than in separate special schools. They therefore provide valuable contexts for examining teachers' classroom practices in relation to assistive technology and inclusive STEM instruction. In addition, their location in different regions of Ghana allows the study to capture experiences across varied educational and resource contexts while focusing on schools that share a common inclusive orientation. This makes them especially suitable for exploring how teachers use assistive technologies in STEM instruction for learners with visual impairment and what contextual factors shape such use.

Population and sampling

The overall teacher population across the three schools is approximately 75 teachers, with 21 STEM teachers (teaching Science, Mathematics, ICT/Computing, and related STEM areas). The target population for this study comprised all STEM teachers in the three schools. Using total purposive sampling (census), all 21 STEM teachers were included. This sampling strategy was adopted because STEM teachers are directly responsible for delivering visually intensive content and are therefore best positioned to provide information-rich accounts of AT integration for learners with visual impairment (Palinkas et al., 2015). Including all STEM teachers also strengthened cross-case comparability and ensured that diverse STEM teaching realities within and across schools were captured.

Data collection instruments

Three qualitative instruments were employed to enable triangulation and provide a richer, more credible understanding of teachers' use of assistive technologies in inclusive STEM classrooms. First, a semi-structured interview guide was used to obtain in-depth accounts from teachers. The interviews focused on teachers' lived experiences and perspectives regarding the assistive technologies they use in STEM lessons. Specifically, teachers were asked to describe the types of AT available to them and the ones they actively use, how they integrate these tools into different

STEM activities such as teaching, demonstrations, experiments, assignments, and assessment, and the factors that support or constrain their efforts. The semi-structured interview format allowed the researcher to maintain consistency across participants while also using follow-up probes to clarify context-specific experiences and classroom realities (Creswell, 2013; Kallio et al., 2016).

Second, a classroom observation guide was developed to capture teachers' actual practices as they occurred naturally in the classroom. Non-participant observations documented the specific AT tools teachers employed during STEM lessons, the ways these tools were used to represent concepts and facilitate participation for learners with visual impairment, and how classroom conditions shaped AT integration. Attention was paid to contextual features such as availability of resources, class size, peer support, lesson structure, and teacher-learner interaction patterns. These observations helped to corroborate or contrast teachers' verbal reports from interviews with what was practically enacted during lessons.

Third, an AT availability and use checklist supported by document review was used to build a contextual profile of AT resourcing in each school. The checklist recorded the presence, type, and functionality of AT resources relevant to STEM instruction, including braille and tactile materials, low-vision aids, talking STEM devices, and accessible digital tools. In addition, relevant school records and documents, such as resource logs, inclusive education reports, or instructional support notes, were reviewed to establish how AT provision and inclusive STEM practices were organised at the school level. All instruments were developed based on existing literature on inclusive STEM and assistive technology for learners with visual impairment and were reviewed by experts in special and inclusive education to ensure clarity, relevance, and alignment with the study objectives.

Data collection procedures

Data collection was carried out over ten weeks during the 2024/2025 academic year. Ethical clearance was obtained from the University of Education, Winneba Institute of Research Board, followed by permission from the Ghana Education Service and school heads. Written informed consent was secured from all participating teachers.
Each of the 21 STEM related subjected teachers participated in an individual semi-structured interview lasting approximately 25–35 minutes. Interviews were audio-recorded with permission and later transcribed verbatim. Each teacher was observed during at least two STEM instructions. Field notes were taken to capture AT-related instructional practices, teacher–learner interactions, and contextual classroom features. An inventory of AT tools available in each school was completed with the support of school leaders and resource persons. Relevant documents (e.g., resource logs, inclusive education reports, lesson support records) were reviewed to complement interview and observation data.

Data analysis

Interview transcripts and observation notes were analysed thematically following Braun and Clarke's (2006) six-step procedure. First, the researcher familiarised himself with the data through repeated reading of the transcripts and observation notes. Second, initial codes were generated by systematically identifying meaningful segments of data related to teachers' use of assistive technologies in STEM instruction. Third, related codes were grouped into candidate themes. Fourth, these themes were reviewed and refined in relation to both the coded extracts and the full

dataset. Fifth, the final themes were defined and named in line with the study objectives: the types of assistive technologies used, how they were integrated into STEM instruction, and the factors shaping their integration. Finally, the report was produced by presenting the themes with supporting evidence from interviews and observations. Coding was inductive, allowing patterns to emerge from the data. A cross-case analysis was then conducted to compare patterns across the three schools.

Trustworthiness

Trustworthiness was ensured through multiple strategies. Credibility was strengthened through triangulation of interviews, classroom observations, and assistive technology inventory and document data, as well as through member checking of key interpretations with participants. Peer debriefing was also used to refine the analysis and reduce potential researcher bias. Transferability was supported through a rich contextual description of the study setting and participants. Dependability and confirmability were enhanced by maintaining an audit trail documenting data collection, coding, theme development, and analytic decisions.

Results

This section presents the findings of the study. It begins with the demographic information of the participants to provide context for the interpretation of the findings, followed by the thematic results on teachers' use of assistive technologies in inclusive STEM instruction.

Demographic information of participants

The study involved 21 STEM teachers from the three selected historically inclusive basic schools. The participants comprised 12 females and 9 males. Their qualifications varied, with 7 holding diplomas, 11 holding bachelor's degrees, and 3 holding postgraduate qualifications. Their general teaching experience also differed: 9 had taught for 1-5 years, 5 for 6-10 years, and 7 for 11 years or more. In terms of inclusive teaching experience, 4 had 1-5 years, 8 had 6-10 years, and 9 had 11 years or more. By subject area, 8 taught Mathematics, 7 taught Science, and 6 taught ICT/Computing. These characteristics show that the participants represented varied professional backgrounds and levels of experience relevant to inclusive STEM instruction.

Data from teacher interviews, classroom observations, and the AT inventory revealed clear patterns in (1) the types of assistive technologies teachers used, (2) how they integrated assistive technologies into STEM lessons, and (3) the factors shaping such integration. Descriptive inventory counts and observation tallies are presented only to support the qualitative themes.

Types of assistive technologies are available and used in STEM instruction for learners with visual impairment in inclusive basic schools in Ghana

Across the three historically inclusive schools, teachers' accounts consistently pointed to a narrow assistive-technology (AT) base for STEM instruction, dominated by braille resources and supplemented by a few scarce STEM-specific tools.

Braille tools as the foundational AT for STEM

Teachers unanimously identified Braille textbooks, slates, and styluses as the most stable AT resources supporting STEM instruction. They described braille as the core medium through which learners who are braille readers access mathematics notation, science texts, and class exercises. One teacher stressed that Braille resources are "basic but indispensable," explaining:

> "These resources may seem basic to some, but to us, they are absolutely indispensable. Without Braille, the child cannot follow the mathematics or write the science work independently." *(Teacher, Mathematics, GNBS)*

Another teacher emphasised the functional value of Braille for conceptual work in STEM:

> "It's not just about reading. It's about thinking through problems, labelling diagrams, solving equations, and recording observations. Braille gives them the autonomy to engage with the subject matter like any other student." *(Teacher, Science, St. Joseph).*

A third teacher echoed this, highlighting Braille as a prerequisite for participation:

> "When they have the braille text, they can work along with the class. Without it, they must wait for someone to interpret everything, and that slows learning." *(Teacher, ICT/Computing, Avakpedome).*

Observations aligned with these accounts, showing braille materials used in nearly every STEM lesson involving learners with visual impairment.

Scarce and uneven low-vision and digital supports

Beyond braille, teachers reported that low-vision tools and digital AT were rare, unevenly distributed, and often limited to a small number of learners. A teacher described how access differed from class to class:

> "Access depends on which child is in your class and what tool the school happens to have." *(Teacher, Science, Avakpedome).*

Teachers acknowledged that magnifiers and large-print texts helped some learners but were limited for complex STEM tasks:

> "Magnifiers help, but they're not enough when the diagrams are complex, or the print is too dense. The child ends up straining, and sometimes they just give up." *(Teacher, Science, GNBS).*

> "Large-print textbooks are useful, but they don't always include the graphs or formulas clearly. In math and science, missing one symbol can change everything." *(Teacher, Mathematics, St. Joseph).*

Teachers who had some digital tools also described their limitations for STEM-specific notation:

> "Screen readers are great for reading text, but they struggle with equations, tables, and scientific notation. The student hears a jumble of numbers and symbols that don't make sense." *(Teacher, Mathematics, GNBS).*

> "We try to use screen readers for coding lessons, but when the syntax gets technical, the feedback becomes confusing. The student needs constant clarification." *(Teacher, ICT/Computing, Avakpedome).*

One teacher summed up the partial nature of these tools for STEM access:

> "These tools are helpful, but they're not a substitute for tactile or Braille-based resources. STEM is visual and spatial without those supports, access is partial at best." *(Teacher, Science, St. Joseph).*

Teachers added that even where digital or low-vision supports existed, they were not consistently present in mainstream STEM lessons, reducing their everyday instructional value.

STEM-specific AT is valued but limited in supply and scope

Teachers described tactile diagrams, embossed charts, and talking calculators as highly relevant for STEM, yet stressed that low supply and rotational use prevented routine integration**.** A mathematics teacher noted:

> "We only have two talking calculators for the whole school… most of the time we just describe what they cannot see." *(Teacher, Mathematics, St. Joseph).*

Other teachers expanded on how scarcity disrupts instruction:

> "We have only one talking calculator in the whole department. The students have to take turns, and sometimes they miss parts of the lesson while waiting." *(Teacher, Mathematics, GNBS).*

> "The talking calculator is shared among five students. They end up copying answers instead of exploring the steps themselves." *(Teacher, Mathematics, Avakpedome).*

Tactile diagrams were similarly described as useful but insufficient:

> "It's frustrating. You want to teach a concept in real time, but you have to pause because the tactile diagram is being used in another class." *(Teacher, Science, St. Joseph).*

> "We rotate the tactile materials across subjects, math, science, even geography. The learners need consistent access, not occasional exposure." *(Teacher, Science, Avakpedome).*

Where tactile resources were absent, teachers reported improvising:

> "Sometimes I improvise with cardboard and string to make tactile diagrams because the official ones are either worn out or unavailable." *(Teacher, Science, GNBS).*

Teachers clearly perceived benefits when tactile/braille diagrams were available:

> "When they use the braille diagrams, they become more active… they even ask questions like the sighted students." *(Teacher, Science, GNBS).*

Yet they noted these opportunities were not frequent:

> "We don't have enough for every science lesson, so we use the tactile diagrams only when the topic really demands it." *(Teacher, Science, Avakpedome).*

Absence of advanced STEM AT

Teachers across all three schools reported that advanced AT, such as digital braille notetakers, refreshable braille displays, accessible simulations, and 3D/tactile STEM models, were not available. They viewed this absence as limiting higher-order STEM learning:

> "We don't have any of the advanced tools like Braille displays or audio graphing software. It limits how far we can go with topics like data analysis or coding." *(Teacher, ICT/Computing, GNBS).*

> "Without the right technology, we're forced to simplify the content too much. The students miss out on the depth of the subject." *(Teacher, Science, St. Joseph).*

> "I want to teach programming, but we don't have accessible platforms. The screen readers can't keep up with the syntax, and there's no tactile feedback." *(Teacher, ICT/Computing, Avakpedome).*

> "It's like trying to teach chemistry without a lab. You can explain the concepts, but the students can't experiment or explore independently." *(Teacher, Science, GNBS).*

Teachers connected this directly to learners' STEM growth:

> "We're stuck with basic tools. The learners are capable, but the lack of advanced AT keeps them from reaching their full potential in STEM." *(Teacher, Mathematics, St. Joseph).*

Observed pattern of minimal AT variety in lessons

Teachers' accounts were reinforced by observations showing that AT use occurred in only a minority of lessons. Teachers linked this pattern to scarcity rather than unwillingness:

> "We don't use much AT because we simply don't have it. It's not a matter of choice, it's a matter of availability." *(Teacher, Science, Avakpedome).*

Overall, teachers' voices show that AT use in inclusive STEM classrooms is dominated by traditional braille tools, with limited access to low-vision supports, digital AT, and specialised STEM devices. The narrow AT base strongly shapes what teachers can integrate into everyday STEM instruction and explains the frequent reliance on improvisation when specialised tools are unavailable.

Teachers' integration and consistency with assistive technologies into STEM instruction for learners with visual impairment

Teachers described assistive technology integration as largely practical, selective, and dependent on the demands of particular lessons rather than as a routine feature of all STEM instruction. Their accounts showed that AT was used mainly to adapt visual content, support access to text and calculations, and facilitate learner participation in classroom activities. However, this integration was not consistent across lessons or activity types, as it often depended on the availability of tools, the nature of the STEM task, and teachers' confidence in using them.

In some classrooms, teachers also used generic devices as "makeshift" assistive technologies, including smartphones or tablets with TalkBack or VoiceOver, WhatsApp voice notes, and simple audio recorders, to distribute materials, clarify tasks, and provide feedback in accessible formats. However, the limited availability of more advanced assistive technologies, such as refreshable braille displays, structured tactile-graphics production tools, and other specialised devices, meant that digital integration in some classrooms remained minimal and was often limited to verbal explanation and the sharing of accessible files.

1 AT for accessing diagrams, charts, and other visual STEM content

Across the schools, teachers explained that their most common use of AT was to make visual materials reachable to learners with visual impairment. They spoke repeatedly about using tactile or braille-based resources, and then "walking" learners through diagrams during science or mathematics lessons.

- One teacher shared that AT becomes essential "whenever we move to diagrams or charts," because without it, "the child is only listening and guessing"
- Another teacher noted that even when tactile diagrams are limited, they still try to adapt by "raising the diagram in braille or using embossed charts so they can feel what others are seeing."

  Classroom observations supported this pattern: AT use was most visible when lessons required interpretation of graphs, labelled figures, maps, or science illustrations.

2. AT for mathematical calculations and symbol-heavy work

Mathematics lessons were another clear area where teachers incorporated AT, especially for computation and number concepts. Teachers in schools with talking calculators described using them to support learners with visual impairment during class exercises.

- A teacher in one of the schools with talking calculators explained that these devices help learners "check their own answers instead of depending on someone to read every step"
- Another teacher said that talking calculators are used particularly "for the four basic operations and word problems," because they "give the child confidence, eliminate fear of getting lost in the numbers."

However, teachers also stressed that this form of integration depended on whether the school had functional devices, and in many cases, they had to rotate a few tools among several learners.

3. AT for text-oriented STEM lessons and reading tasks

Teachers also described using AT for text-heavy aspects of STEM**,** such as reading comprehension in science, ICT-related notes, or interpreting written instructions for experiments. Large-print texts, braille versions of materials, or audio supports were mentioned as practical ways to keep learners with visual impairment on the same page as their peers.

- One teacher explained that in lessons with more reading than calculation, "large print is what helps them follow the same notes"
- Another teacher noted that AT is not only for "science practicals*,"* but also *"*when we are doing theory, definitions, descriptions, procedures, so they don't lag."

4. AT within collaborative and multisensory teaching approaches

Teachers also reported integrating assistive technologies into collaborative and multisensory STEM activities. Braille materials, tactile resources, and audio supports were used during group work and practical tasks to enable learners with visual impairment to access shared content and contribute to lesson activities. One teacher explained that "the child gives ideas using braille or tactile materials," while another noted that they combine "auditory, tactile, and movement activities" during instruction. These accounts show that AT integration in this area involved embedding accessible tools within group-based and multisensory classroom tasks.

Teachers further linked their integration practices to UDL thinking, saying they intentionally combine auditory, tactile, and kinaesthetic methods to keep STEM materials perceivable and usable for everyone. A few teachers gave examples of rare but innovative AT integration, such as tactile graphing boards or audio-supported graphing in mathematics, talking thermometers or tactile periodic tables during chemistry, and braille-labelled robotics kits with audio programming supports in technology lessons. Teachers stressed that these were not routine practices but depended on access and external support.

Overall, teachers integrate AT mainly to translate visual STEM content into tactile, braille, or auditory form, to support calculations in mathematics, to enable access to text-based STEM tasks, and to promote participation in group and multisensory activities. Integration is present but

inconsistent, with more sustained use in lessons where tools are available, and teachers feel confident using them.

Teachers' perception of the key school- and classroom-level factors that facilitate or hinder their integration of assistive technologies in inclusive STEM instruction

Teachers' accounts showed that AT integration is shaped by a mix of teacher-level, school-level, and system-level conditions. They described both enabling and constraining factors, often in paired ways (e.g., "we are willing, but we need support").

1.Teacher competence and confidence

Teachers consistently explained that their ability to integrate AT improves when they have training or prior exposure.

- One teacher said professional development "opens your eyes to what is possible," because "after training, you stop fearing the tools."
- Another teacher described confidence as key: "Once you know how to use it, you will always find a way to bring it into the lesson."

Teachers also highlighted the value of collaboration with specialists (e.g., Teachers of the Visually Impaired). Across the three cases, specialist involvement (AT/resource staff and, where available, O&M instructors) was intermittent and primarily on-request rather than through scheduled co-planning or co-teaching; no routine team-teaching cycles were documented during the study period. They felt that working with specialists improves instructional design and helps them adapt STEM resources more effectively.

2. Availability of functional AT resources

Teachers consistently indicated that the availability of functional assistive technology resources supported more routine integration of AT in STEM instruction. Rather than suggesting that access itself was always the direct problem, their accounts showed that when relevant materials were available, teachers were better able to include learners with visual impairment in ongoing classroom activities. Teachers referred to tactile graphics, braille materials, talking calculators, and accessible digital tools as resources that made inclusive STEM instruction more feasible in practice.

- One teacher explained that "when the materials are there, the lesson becomes easier for everyone, including the sighted."
- Another noted that "having even a few tactile resources changes the whole class," because learners with visual impairment **"**can work alongside others, not behind them."

These accounts suggest that the availability of functional AT resources acted as an enabling condition for inclusive STEM instruction by making it easier for teachers to organise accessible lesson activities and support learner participation.

3. Perceived leadership and collegial support

Teachers perceived supportive leadership and collegial encouragement as important conditions that enabled their use of assistive technology in STEM instruction. Their accounts suggested that where school leaders were seen as supportive of inclusion, teachers felt more confident to experiment with AT and adapt lessons for learners with visual impairment. They also viewed collegial and pedagogical encouragement within the school as helpful in promoting more flexible and creative approaches to inclusive STEM teaching.

- One teacher noted that "when the head supports inclusion, you feel encouraged to try and even fail and try again."
- Another explained that in contexts where UDL-oriented thinking is encouraged, "teachers become more creative with adapting STEM lessons."

These accounts indicate that teachers viewed leadership support and collegial encouragement as factors that could strengthen their willingness to integrate AT into classroom practice.

4. Curriculum flexibility and positive teacher attitudes

Teachers indicated that flexible curricula and differentiated assessment make AT integration smoother. They also stressed that their own commitment to equity pushes them to seek solutions.

- As one teacher put it, "my attitude is that the child must learn, so I keep looking for ways."
- Another explained, "if you believe they can do STEM, you won't stop adapting until they get it."

Hindering factors

Teachers' accounts also pointed to several barriers that constrained the effective integration of assistive technology in STEM instruction. These hindering factors operated at the teacher, school, and system levels and were perceived to limit the regular and confident use of AT in inclusive classroom practice.

1. Limited training and awareness

Many teachers reported that they had not received formal training in AT or inclusive STEM methods. They felt that this leads to underuse or surface-level use.

- One teacher said plainly, "we want to use the tools, but nobody trained us on them."
- Another added that some colleagues still hold low expectations about learners with visual impairment, which reduces effort toward AT-based adaptations.

2. Resource constraints and infrastructure gaps

Teachers repeatedly described the cost and scarcity of devices as a major barrier. They mentioned that more advanced tools (refreshable braille displays, digital braille notetakers, 3D models) are either unavailable or unaffordable. Poor internet access and outdated devices were also reported as limiting digital AT use.

- One teacher explained that "even where we know the tool exists, we don't have it here, so we improvise."
- Another said, "sometimes the device is there but not working, so you go back to talking only."

3. Rigid curriculum and assessment demands

Teachers noted that use standardised tests and inflexible lesson pacing often discouraged AT integration because "there is no time to adapt everything."

- A teacher described this as a conflict: "we are pushed to finish the syllabus, so adapting materials becomes difficult."

4. Time pressure, workload, and weak institutional support

Teachers felt overwhelmed by the extra time needed to prepare tactile materials or learn new technologies, especially with large classes. They also pointed to the lack of clear school or district policies, funding, and technical support as reasons AT integration is not sustained.

- One teacher said, "if there were technical support and clear policy, we would not be struggling alone."

Teachers' integration of AT is facilitated by training, confidence, specialist collaboration, availability of inclusive resources, supportive leadership, curriculum flexibility, and positive inclusive attitudes**.** It is hindered by limited training, shortages, and high cost of AT, weak infrastructure, rigid curricula and assessment pressures, workload/time constraints, and inadequate institutional policy and technical support**.**

Discussions

This discussion re-examines the findings against the study objectives and the Universal Design for Learning (UDL) lens, while situating teachers' experiences within contemporary literature on assistive technology (AT) and inclusive STEM for learners with visual impairment in low-resource contexts.

A narrow assistive technology profile anchored in Braille reflects broader low-resource realities

Teachers' accounts indicate that the assistive technology profile supporting inclusive STEM instruction in the three historically inclusive schools remains narrow and is strongly centred on traditional braille tools, such as braille textbooks, slates, and styluses, with only limited and inconsistent access to STEM-specific devices, including tactile diagrams, embossed charts, and

talking calculators. This predominance of braille as the most dependable means of access aligns with evidence that, in many inclusive systems, braille continues to serve as the foundational medium for literacy, mathematical notation, and science text access for blind learners, particularly where digital assistive technologies are limited. Rosenblum et al. (2015), for example, found that students with visual impairment continue to depend heavily on braille materials and tactile graphics for access to mathematics and science content, underscoring the continuing centrality of braille in STEM learning.

At the same time, teachers' repeated emphasis on the absence of advanced STEM-related assistive technologies, such as refreshable braille displays, braille notetakers, accessible simulations, and three-dimensional or tactile STEM models, points to a structural constraint on what inclusive STEM instruction can achieve when assistive technology provision does not extend beyond basic braille resources. This reflects broader evidence that meaningful participation in contemporary STEM increasingly depends on a more diverse range of tools that combine braille and tactile supports with accessible digital and interactive technologies. Fernández-Batanero et al. (2022) similarly show that while traditional supports remain important, effective inclusion in contemporary learning contexts requires access to more specialised and digitally responsive forms of assistive technology.

Teachers' descriptions of low-vision and digital tools as helpful but limited for complex STEM tasks further reinforce this point. Their accounts suggest that generic digital supports are often insufficient when STEM learning involves equations, graphs, scientific notation, and other highly structured visual-symbolic representations. This is consistent with evidence from sub-Saharan Africa showing that digital access tools alone do not guarantee curriculum access when learning materials remain visually encoded and insufficiently adapted. Le Fanu et al. (2022), for instance, argue that limited accessible materials and assistive resources continue to constrain meaningful curriculum participation even in contexts where inclusion policies are in place.

Taken together, these findings suggest that Ghana's historically inclusive schools, despite their status as established sites of inclusive education, still reflect a pattern common in many low-resource settings: Braille remains available as a basic access support, but STEM-specific and digital assistive technologies are scarce and unevenly available. This interpretation is consistent with Ghana-based evidence indicating that inclusive schools often operate with a limited range of assistive technologies and constrained access to devices beyond basic braille-related tools. Nyavor (2020), for example, similarly reports limited assistive technology variety and uneven access in Ghanaian inclusive basic schools.

Teachers' integration of AT reflects UDL-aligned intentions but remains episodic

Teachers integrated assistive technology mainly to make diagrams and other visual materials accessible through braille or tactile alternatives, support mathematical calculations through tools such as talking calculators, enable access to text-heavy STEM lessons through braille, large print, or audio formats, and facilitate participation in collaborative and multisensory activities. These practices are consistent with the Universal Design for Learning (UDL) principle of providing multiple means of representation and action/expression, particularly in subjects where key meanings are conveyed through visual and symbolic formats. As Al-Rawi and Al-Thani (2021) argue, UDL-aligned instruction often relies on assistive technology and alternative sensory channels to reduce access barriers and increase participation among diverse learners.

More specifically, the observed practices reflected the three core UDL principles. The use of tactile graphics, audio description, and screen-reader-ready materials provided multiple means of representation. Allowing oral, braille, and typed responses reflected multiple means of action and expression. Similarly, the use of varied task pathways, peer support, and frequent instructional check-ins supported multiple means of engagement. In this sense, assistive technology used to access diagrams, charts, and other visual STEM content functioned as a representation scaffold, helping teachers translate visually encoded content into more accessible forms for learners with visual impairment.

However, teachers' repeated description of assistive technology use as occurring on a "lesson-by-lesson" basis rather than as a regular feature of instruction suggests that integration was reactive and episodic rather than embedded in routine classroom practice. This pattern is widely reported in low-resource inclusive STEM contexts, where assistive technology tends to be used during highly visual moments, such as work involving graphs, experiments, or diagrams, but is less evident in the ordinary flow of lessons because of scarcity, time pressure, or limited teacher confidence. The Global Education Monitoring background report for sub-Saharan Africa similarly indicates that inconsistent access to adapted materials and assistive technology often forces inclusion to depend on teacher improvisation, resulting in uneven participation for learners with visual impairment (ICEVI & UNESCO GEM Report Team, 2020).

Teachers' occasional use of more innovative assistive technology practices, such as tactile graphing, talking thermometers, and braille-labelled robotics, further suggests that pedagogical creativity was present, but depended heavily on the availability of resources and support. This aligns with evidence that innovation in inclusive STEM teaching expands when teachers have access to appropriate tools and receive practical training in STEM-specific assistive technology use. Ali (2021), for example, found that hands-on exposure to assistive technology strengthened teachers' ability to integrate such tools into mathematics instruction. Overall, the findings suggest that although teachers demonstrated UDL-consistent intentions in their use of assistive technology, the conditions required for sustained and routine integration were not yet stable across the school contexts studied.

Facilitators and barriers show that AT integration is shaped by interacting teacher-school- and system-level conditions

Teachers identified several factors that supported their integration of assistive technology in STEM instruction, including competence and confidence developed through training, collaboration with Teachers of the Visually Impaired (TVIs) or other resource personnel, availability of functional resources, supportive leadership, and positive attitudes toward inclusion. These findings are consistent with broader literature showing that AT integration is more likely to occur when teachers have practical preparation, access to specialist support, and school environments that encourage inclusive resource use. Fernández-Batanero et al. (2022), for example, emphasise that teacher preparation and institutional commitment are among the strongest influences on sustained classroom use of assistive technology.

At the same time, teachers reported a set of barriers that limited consistent and effective AT integration. These included inadequate training, the high cost and low supply of assistive technologies, weak infrastructure, curriculum and assessment pressures, workload and time demands, and limited institutional support. Such constraints reflect challenges documented more

broadly across sub-Saharan Africa, where inclusive education policies often exceed the level of practical resourcing available in schools. Le Fanu et al. (2022) similarly note that policy commitments to inclusion frequently outpace the provision of accessible materials, resources, and support structures, leaving teachers to rely on improvisation in under-resourced classrooms.

The findings further suggest that these barriers do not operate in isolation; rather, they interact in ways that weaken sustained AT use. Limited training may reduce teachers' confidence, low confidence may discourage experimentation with available tools, and irregular access to devices may prevent assistive technology from becoming part of routine instruction. The ICEVI and UNESCO GEM Report Team (2020) likewise stress that without coordinated financing, procurement, and technical support, inclusive schools are unlikely to sustain technology-enabled participation for learners with visual impairment. In this sense, the findings indicate that AT integration in inclusive STEM instruction is shaped not simply by teacher willingness, but by a broader set of interconnected teacher-, school-, and system-level conditions. Viewed through the UDL lens, these facilitators and barriers suggest that the challenge of AT integration is not merely one of individual teacher choice, but of whether schools and education systems provide the supports necessary for multiple means of representation, engagement, and action/expression to become routine in classroom practice. Although teachers were making efforts to widen access to STEM learning, the conditions required to sustain those efforts were not consistently in place.

Conclusions

This study examined teachers' use of assistive technologies in STEM instruction for learners with visual impairment in three historically inclusive basic schools in Ghana. Three main conclusions may be drawn. First, the assistive technology available for inclusive STEM instruction remains limited and heavily concentrated around basic braille-related resources, which restricts the extent to which learners with visual impairment can access the full visual and practical demands of STEM learning. Second, assistive technology integration in STEM instruction is present but not yet routine; it tends to occur selectively in response to immediate instructional demands rather than as a fully embedded feature of classroom practice. Third, teachers' integration of assistive technology is shaped by interrelated enabling and constraining conditions at the teacher, school, and system levels, indicating that meaningful progress in inclusive STEM instruction depends on structural support as much as on teacher commitment.

Taken together, these conclusions suggest that inclusive STEM education in historically inclusive schools in Ghana is still operating below its full potential. Although teachers value assistive technology and attempt to adapt instruction, their efforts are constrained by limited resources, inconsistent training, and weak institutional support. The broader implication is that technology-enabled inclusion in STEM cannot depend on teacher goodwill alone; it requires sustained investment in resources, professional learning, and school-level systems that normalise assistive technology as part of everyday teaching and learning.

Recommendations

Based on the findings, the study recommends the following priority actions:

1. The Ministry of Education, Ghana Education Service, and district directorates of education should minimise overreliance on braille-only supports by implementing a coordinated system for procuring, distributing, maintaining, and monitoring STEM-specific assistive technologies. Such provision should include tactile and embossed diagrams, talking scientific tools, sufficient talking calculators, accessible ICT and coding resources, and low-vision aids. Schools should also be supported to make these resources available in mainstream classrooms, rather than limiting them to resource rooms, so that assistive technology can be integrated into everyday STEM instruction.

2. The district directors of education and headteachers of the school should institutionalise STEM-AT professional development for teachers**.** Teachers need continuous, hands-on training focused on how to embed AT into STEM lesson cycles (diagrams/graphs, practicals, problem-solving, and assessment), not just general inclusion workshops. Follow-up coaching and peer learning should be built into convert episodic use into routine practice

3. Schools should strengthen and formalise collaboration between STEM teachers and teachers of the visually impaired or resource personnel through more regular joint planning, shared preparation of accessible materials, and classroom support where feasible. This recommendation is based on the finding that teachers viewed specialist collaboration as helpful for lesson adaptation and confidence building, but reported that such support was often intermittent and ad hoc.

4. Headteachers and school authorities should develop and enforce school-level AT plans that cover access procedures, maintenance, lesson-planning expectations, and budgeting. Supportive leadership and clear policy guidance are necessary to sustain AT use beyond individual teacher effort.

5. District education authorities should allow flexible pacing and alternative assessment formats where AT-mediated learning requires adaptation time, while schools actively pursue partnerships with NGOs, disability organisations, universities, and tech providers for AT resourcing and technical support.

Limitations of the Study

This study focused on three historically inclusive basic schools, which, while information-rich, may not fully represent AT realities in newer or non-flagship inclusive schools across Ghana. In addition, the findings relied on teachers' self-reports and classroom observations within a limited timeframe, so AT use patterns may vary across terms or curriculum topics. Nonetheless, triangulation across interviews, observations, and AT inventories strengthened credibility.

Declarations

Ethical approval and consent

Permission was secured from the Ghana Education Service and heads of the participating schools. All participants received information sheets detailing the study purpose, procedures, risks, and benefits. Informed consent was obtained from all teachers before data collection. Participation was voluntary, and confidentiality and anonymity were assured through the use of pseudonyms and school codes.

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Authors' contributions

Single-author manuscript. The author conceptualised the study, designed the methodology, collected the data, conducted the analysis, and drafted and revised the manuscript.

Competing interest

The author declares no competing interests**.**

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