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Integrating generative artificial intelligence in secondary mathematics education: An inclusive pedagogy framework for visually impaired learners

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Abstract

Widespread access to digital technologies including artificial intelligence has expanded opportunities for developing nations to enhance special education. However, existing research reveal limited pedagogical frameworks to guide integration of Generative artificial intelligence (Gen-AI) in teaching and learning for the visually impaired. Additionally, while mathematics education has continued to receive increased attention, limited studies exist on strategies for improving achievement in mathematics for learners with visual impairment (VI). Towards filling this gap, this paper focuses on development of a pedagogical framework that can inform integration of Gen-AI in teaching secondary mathematics to enhance inclusivity of learners with VI. The paper adopts a review-based methodology, particularly a systematic qualitative review approach, to examine and synthesize existing research from peer-reviewed sources. The scope of the review was mainly tool-specific with a focus on inclusive education for learners with VI. The findings show that Gen-AI can potentially enhance mathematics education for learners with VI. The findings underscore the fundamental pedagogical design elements that are instrumental in stimulating inquiry-based learning and interactive collaboration. Additionally, teachers' input in course design and addressing potential ethical limitations of Gen-AI content is crucial. The theories of problem-based learning, flow and TPACK are considered important foundations for guiding Gen-AI integration. The proposed framework is useful in guiding mathematics teachers, policy makers and future research focusing on integration of Gen-AI in teaching mathematics for learners with VI. The framework offers a design-based research approach guided by congruent theories towards informing Gen-AI based interventions that can enhance mathematics education.

Keywords: *inclusive education, interactive learning, multi-modal pedagogy, mathematics education*

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1. Introduction

Global statistics show that approximately 2.2 billion people have visual impairment (VI), with the majority of this population living in Sub-Saharan Africa (World Health Organization, 2023). About 1.5 million of these are children, representing approximately 3.6% of the global blind population. The number of persons with VI in Africa continues to increase due to population growth and poor living conditions. Although about 85% of VI cases are attributable to preventable causes, visual impairment remains a major global health and socioeconomic challenge, that contributes to inequality and annual productivity losses estimated at US$411 billion worldwide (World Health Organization, 2023). Undeveloped and developing nations experience approximately four times higher rates of distance VI than developed countries. Similarly, inadequately addressed near-vision impairment exceeds 80% in western, eastern, and central Sub-Saharan Africa, compared to less than 10% in developed nations (World Health Organization, 2023).

The consequences of visual impairment extend beyond health concerns and significantly affect educational and social outcomes. As the literature indicates, children with early-onset irreversible severe visual impairment are at risk of delayed motor, language, emotional, social, and cognitive development. Learners with VI are also exposed to limited educational opportunities (World Health Organization, 2023). The effects persist into adulthood, where individuals with VI face higher risks of unemployment, depression, and anxiety. In Kenya, the prevalence of VI among children is estimated at approximately 2.4% (Fricke et al., 2018; Muma & Obonyo, 2020). Persons with VI account for about 36% of the total population of persons living with disabilities (PLWD) in the country. However, the exact number of school-aged children with visual impairment has not been fully established.

Recognizing the importance of equitable access to education, the Government of Kenya and various educational stakeholders have demonstrated progressive efforts toward promoting inclusive education for all learners, including those with VI (UNESCO, 2023; Wodon et al., 2018). The Sustainable Development Goals (SDGs), particularly SDG 4, emphasize the elimination of barriers to education and the creation of inclusive and equitable learning environments. However, inadequate attention to the needs of learners with VI can hinder the realization of quality education for all (Abdillah & Agung, 2025). Despite policy commitments, the lack of appropriate tools, resources, and instructional strategies continues to undermine inclusive education, particularly in developing countries. Consequently, learners with disabilities in many African countries are more likely to enroll late, progress slowly, drop out of school, and derive fewer educational benefits than their peers (UNESCO, 2023; Wodon et al., 2018). Evidence from 11 African countries further reveals substantial disparities in secondary school enrolment and completion among students with disabilities. Even when learners with VI remain in school, they generally perform poorly in academic areas such as mathematics and reading (UNESCO, 2023; Wodon et al., 2018).

Among school subjects, mathematics presents unique challenges for learners with VI. Mathematics education has received increasing attention in Kenya and globally, with innovative instructional approaches being introduced to improve learning outcomes (Li et al., 2024). Nevertheless, limited attention has been devoted to special needs contexts, particularly to strategies for improving mathematics achievement among learners with VI (Okumu et al., 2021). In Kenya, mathematics performance in the Kenya Certificate of Secondary Education (KCSE) has remained a concern across many secondary schools. Learners with VI have been disproportionately affected, consistently recording poor performance, a situation that has been largely attributed to inadequate pedagogical approaches (Musango et al., 2024; Okumu et al., 2021). As a core STEM (Science, Technology, Engineering, and Mathematics) subject, mathematics occupies a central place in educational systems worldwide. In Kenya, its importance has become even more pronounced because it is compulsory at the secondary school level. Recent university admission reforms for the 2023/2024 academic year have further elevated its significance by making mathematics grades a key determinant of university entry eligibility. Unlike several other subjects, mathematics has no equivalent alternative and is now a compulsory component in calculating university admission scores (KUCCPS, 2024). The importance of mathematics for academic progression, coupled with its predominantly visual and inquiry-based nature, creates significant learning barriers for learners with VI. These challenges necessitate multimodal pedagogical interventions that can support more meaningful and accessible learning experiences. In this regard, Generative Artificial Intelligence (Gen-AI) offers considerable potential through voice-based and audio-enhanced functionalities that provide alternative ways for learners with VI to engage with mathematical concepts and problem-solving processes. However, despite the growing adoption of AI technologies in education, there remains a limited body of pedagogical frameworks and evidence-based strategies to guide the effective integration of Gen-AI in mathematics education for visually impaired learners. This gap highlights the need for the current study. Specifically, this study aims to assess the key pedagogical design principles and considerations for integrating Gen-AI into mathematics education for learners with visual impairment (VI) and to develop a tailored pedagogical framework and intervention implementation plan to guide its effective adoption and use.

The findings of this review are expected to provide valuable insights for teachers and educators regarding the design of inclusive mathematics learning experiences for learners with VI, particularly at the secondary school level. By addressing the current shortage of AI-supported pedagogical models, the study contributes to efforts aimed at leveraging digital technologies to strengthen inclusive education. The findings will enhance educators' understanding of how Gen-AI can facilitate active, interactive, and accessible mathematics learning for visually impaired students. Furthermore, the study integrates relevant theoretical perspectives to advance understanding of learning processes and formative assessment practices within inclusive mathematics classrooms. The insights generated will also support school leaders and policymakers in identifying the competencies and institutional capacities required to enable mathematics teachers to create more supportive and effective learning environments for learners with VI.

2. Literature Review

2.1. Accessible and Inclusive Education for Learners with VI

As nations strive to achieve equitable and quality education for all, educators are increasingly required to adopt appropriate pedagogical approaches that facilitate inclusive learning environments (Commonwealth of Australia, 2023; U.S. Department of Education, 2023). This necessitates a re-examination of how teachers' capacities and available resources influence the selection and effective use of emerging digital technologies to enhance educational opportunities for learners with diverse experiences, interests, and needs (Antoninis et al., 2023). For learners with VI, improving access to inclusive education requires intentional efforts to adapt learning environments to address their unique needs, particularly in relation to the inquiry-based and highly visual nature of STEM subjects. Accelerating progress toward Sustainable Development Goals (SDGs) 4 and 8 therefore demands innovative approaches that promote lifelong learning opportunities for learners with VI and other special educational needs (Abdillah & Agung, 2025; Gikandi et al., 2025). Such efforts not only support educational inclusion but also contribute to social justice, equitable employment, and broader socioeconomic participation.

The need for inclusive educational innovations is further reinforced by emerging labour market realities. Although labour markets have demonstrated considerable resilience in the digital era, limited alignment between labour rights and emerging vulnerabilities continues to undermine social justice, particularly for marginalized populations. United Nations projections suggest a worsening labour market outlook characterized by higher unemployment rates and sluggish economic growth across many countries (Arslantas & Gul, 2022; United Nations, 2024). These trends are likely to widen income disparities and threaten equitable access to decent work for marginalized groups, including women, young people, and persons with disabilities. Consequently, strengthening educational opportunities and skill development for learners with VI becomes increasingly important in preparing them for meaningful participation in future labour markets.

While digital Braille assistive technologies have significantly improved access to education for learners with VI, their effectiveness in supporting mathematics and science learning at the secondary school level remains limited (Gikandi et al., 2025). Existing technologies, including Orbit Reader 20, Dot Mini, and Focus devices, provide valuable accessibility functions but often lack advanced multimedia capabilities such as voice-based interaction, text-to-speech integration, and video input and output features. Furthermore, these technologies generally offer limited opportunities for personalized learning experiences tailored to the individual needs, preferences, and learning pace of learners with VI. These limitations are particularly problematic in mathematics education, where conceptual understanding often depends on interactive, inquiry-based, and multimodal learning experiences.

In this context, Gen-AI offers promising opportunities to address many of the limitations associated with existing assistive technologies. The voice-enabled, multilingual, and adaptive capabilities of Gen-AI can provide learners with VI more personalized and accessible learning experiences (Frick, 2024; Richardson et al., 2024). More importantly, AI-supported teaching and learning environments facilitate diverse and repetitive scenario-based learning experiences that can be adapted to individual learner needs. Such features are particularly valuable for promoting inquiry-based learning, problem-solving, critical thinking, and interactive collaboration, all of which are fundamental components of effective mathematics education (Bolick & Silva, 2024; Frick, 2024; Lucien & Park, 2023; Moore et al., 2024; Richardson et al., 2024). Consequently, Gen-AI has the potential to transform mathematics learning for learners with VI by providing more inclusive, engaging, and learner-centered educational experiences.

2.2. Research Gaps on Use of AI in Education for Learners with VI

The aforementioned gaps inspired the current study, which seeks to develop an inclusive pedagogical framework to guide the use of AI-based assistive technologies in mathematics education for learners with VI. Despite the growing interest in educational technologies, the potential of AI to support learning among visually impaired learners remains underexplored. This challenge is particularly evident in developing and underdeveloped nations, where the needs of learners with disabilities are often overlooked or inadequately addressed due to poverty, resource constraints, and prevailing social norms (Antoninis et al., 2023; Bulathwela et al., 2024; Kasiram & Subrayen, 2013). Furthermore, traditional educational settings in many developing countries continue to face challenges such as overcrowded classrooms and limited opportunities for personalized learning, conditions that further disadvantage learners with VI (Labadze et al., 2024).

As digital technologies become increasingly integrated into education, AI-based tools offer promising opportunities to address many of these longstanding challenges. Compared to traditional classroom environments, AI-supported learning systems can facilitate more inclusive, interactive, and personalized learning experiences (Mboya et al., 2025; Mina et al., 2023; Ribes-Lafoz et al., 2026). By leveraging expanding access to digital devices, internet connectivity, and improving ICT literacy levels, developing nations can utilize Gen-AI to broaden educational opportunities for learners with VI. The multimodal capabilities of AI-supported learning environments, including voice-based interaction, adaptive feedback, and personalized content delivery, can significantly enhance access to quality secondary education for visually impaired learners (Mina et al., 2023). In the long term, improved educational access can contribute to greater independence, enhanced employability, and stronger social inclusion during adulthood (Arslantas & Gul, 2022; United Nations, 2024).

Despite the promising benefits, the integration of AI into education is not without challenges. Recent empirical studies have identified concerns regarding the accuracy, reliability, and ethical implications of AI-generated content (Mboya et al., 2025; Ribes-Lafoz et al., 2026). Such limitations have direct implications for educational quality and learner outcomes. Furthermore, previous studies suggest that excessive reliance on AI-generated content may compromise learners' originality and expose them to algorithmic biases and misinformation (Kim, 2023; Tao et al., 2026). These concerns highlight the need for carefully designed pedagogical approaches that maximize the benefits of AI while mitigating its potential risks.

Against this backdrop, the primary objective of the current review-based study is to develop an inclusive pedagogical framework to guide the integration of Gen-AI for learners with VI at the secondary school level, which serves as a critical pathway to higher education in Kenya. Specifically, the study seeks to inform a holistic multimodal approach to mathematics education that leverages Gen-AI to create adaptive, interactive, and accessible learning environments. By providing guidance on the effective pedagogical integration of AI technologies, the proposed framework aims to enhance mathematics learning experiences and educational outcomes for learners with visual impairment while supporting broader goals of inclusive and equitable education.

2.2. Theoretical Framework

In the proposed framework, teachers are expected to adopt Problem-Based Learning (PBL) as the primary pedagogical approach for integrating Gen-AI into mathematics education. PBL provides a congruent theoretical foundation that emphasizes collaboration, materiality, and flexibility in the learning process (Scholkmann et al., 2025). From this perspective, mathematics learning should accommodate diverse learner needs and support the progressive construction of knowledge through active, contextualized engagement in a supportive learning environment. In practice, this requires teachers to guide learners through ill-structured or complex mathematical problem spaces to explore alternative solution pathways and develop deeper conceptual understanding. Through PBL, learners are encouraged to make decisions, test different approaches, evaluate outcomes, and connect their experiences to authentic real-world situations. Such active participation is particularly valuable in mathematics education, where conceptual understanding is strengthened through inquiry, exploration, and problem-solving.

The PBL approach is further strengthened by its alignment with Flow Theory, which emphasizes the relationship between challenge, skill development, and intrinsic motivation.

According to Barrett (2010), learners are most engaged when there is an appropriate balance between their current capabilities and the complexity of the academic task. Learners with limited problem-solving skills should initially encounter tasks with manageable levels of challenge, while more advanced learners should be provided with increasingly complex learning experiences. As learners successfully solve progressively challenging tasks, their skills and confidence develop over time. Maintaining this balance is critical because tasks that are too easy may result in boredom, whereas excessively difficult tasks may lead to frustration and disengagement. Barrett (2010) refers to this optimal balance as the "flow channel," a state in which learners are intrinsically motivated and fully engaged in learning activities. Within the proposed framework, Gen-AI serves as an important enabler of this process by supporting the personalization of learning experiences. Through its capacity to adapt content, provide differentiated feedback, and adjust task complexity according to individual learner needs and interests, Gen-AI can help teachers sustain learner engagement while promoting continuous academic growth (Mboya et al., 2025).

While PBL and Flow Theory provide the pedagogical and motivational foundations of the framework, successful implementation also depends on teacher competence in integrating digital technologies. In this regard, the Technological Pedagogical Content Knowledge (TPACK) model developed by Mishra and Koehler (2006) offers a valuable conceptual foundation for understanding how teachers can effectively integrate Gen-AI into mathematics instruction. The TPACK framework emphasizes the interplay among content knowledge, pedagogical knowledge, and technological knowledge in facilitating meaningful learning experiences. Building on this foundation, subsequent developments such as the Mathematics Teacher TPACK Standards and the TPACK Development Model recognize the progressive nature of technology integration and the need for teachers to remain responsive to emerging digital innovations. The model describes a technology-specific progression through five stages, recognizing, accepting, adapting, exploring, and advancing, across key pedagogical dimensions, including curriculum, learning, teaching, and assessment. Importantly, the framework acknowledges that teachers may demonstrate varying levels of competence with different technologies and may employ different digital tools to support distinct pedagogical purposes.

The growing integration of Gen-AI into education further extends the relevance of TPACK by highlighting the need for teachers to develop AI literacy and AI-TPACK competencies. Teachers must be capable of guiding learners in the effective use of AI tools, including how to formulate prompts, critically evaluate AI-generated responses, and align AI-supported activities with intended learning outcomes (Karataş & Ataç, 2025). Equally important, teachers must exercise sound pedagogical judgment, monitor learning progress, and continuously assess the extent to which desired educational outcomes are being achieved. Consequently, PBL, Flow Theory, and TPACK collectively provide complementary theoretical foundations for the proposed framework, offering pedagogical, motivational, and technological perspectives that support the effective integration of Gen-AI in inclusive mathematics education for learners with visual impairment.

3. Methodology

3.1. Research Design

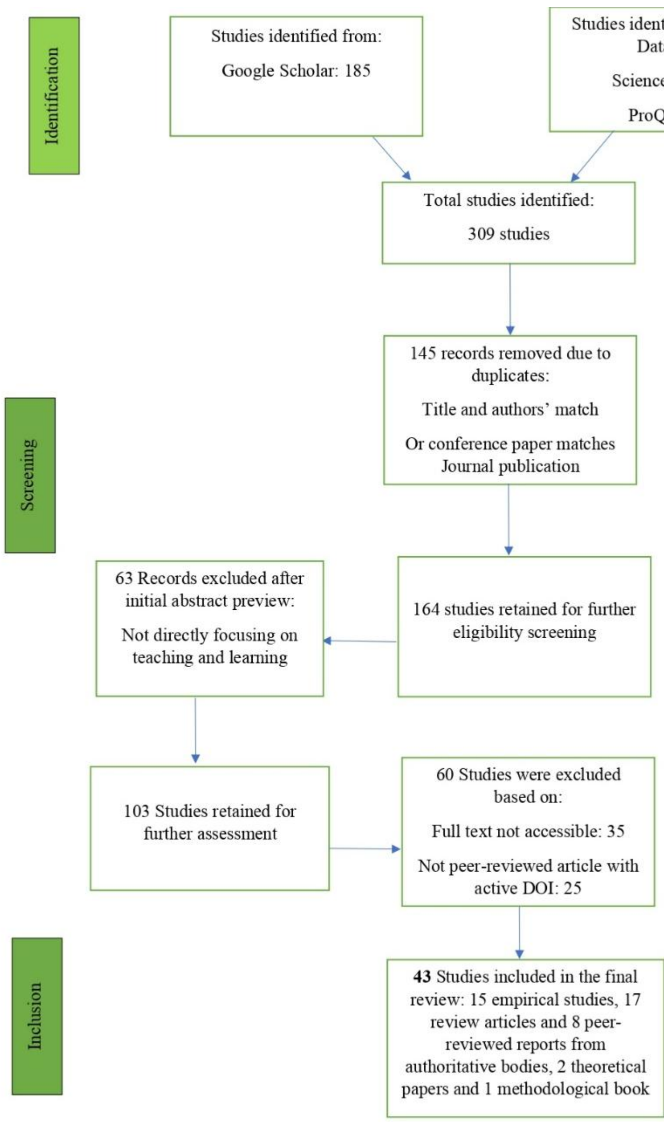
This study adopts a systematic qualitative review approach to explore how Gen-AI is being applied in mathematics education, particularly for learners with VI. The primary aim is to generate insights that can inform the development of an effective pedagogical framework for mathematics teaching and learning among learners with VI, while also providing practical guidance for teachers implementing inclusive instructional practices. A systematic qualitative review was considered appropriate because it enables the critical analysis, synthesis, and interpretation of existing research in a structured and transparent manner.

To identify relevant literature, the study involved searching major academic databases, including ProQuest, ScienceDirect, and Google Scholar, for peer-reviewed articles published between 2018 and 2025. A set of inclusion criteria was applied to ensure the selection of studies focusing on the use of Gen-AI in educational contexts. The search process was guided by specific keywords and phrases, including “Gen-AI educational tools”, “mathematics education”, “inclusive education”, “learners with visual impairment”, and “teaching mathematics to learners with visual impairment.” Relevant Boolean operators such as “AND” and “OR” were used to refine and optimize the search results.

The selection process followed the three main stages of literature review proposed by Galvan (2006). As illustrated in Figure 1, the first stage involved searching and screening articles based on their relevance to the study and their publication dates. The second stage consisted of skimming the identified articles by examining their titles, abstracts, objectives, and keywords to determine their suitability for inclusion. The third stage involved a detailed review of the selected full-text articles, focusing on their content, methodological approaches, and findings to assess the extent to which they addressed the research objectives and questions.

Figure 1

Prisma flow diagram



Through this systematic process, the review sought to analyze and synthesize existing evidence on the application of AI in mathematics education for learners with VI. The resulting synthesis provides valuable insights into current practices, opportunities, and challenges associated with Gen-AI integration, thereby informing the development of pedagogical designs for inclusive mathematics education and identifying directions for future research.

3.2. Inclusion and Exclusion Criteria

The review process involved a systematic search of relevant literature from major academic databases, targeting studies that examined the use of Gen-AI in teaching secondary school mathematics to learners with visual impairment (VI). Due to the limited availability of studies specifically addressing Gen-AI use in mathematics education for learners with VI, the review also considered closely related research on the application of Gen-AI in broader educational contexts, both locally and internationally. Consequently, the review adopted a tool-specific focus while maintaining a strong emphasis on inclusive education for learners with VI. Studies examining the application of Gen-AI in both special education and mainstream formal education settings were considered. In addition, only studies that focused on the direct use of Gen-AI tools to support teaching and learning processes were included.

The literature search and review were guided by several key themes and search phrases, including application of AI in education for the visually impaired, AI in mathematics education, AI interventions in mathematics classrooms, inclusive pedagogy for learners with visual impairment, usability considerations for Gen-AI integration in mathematics education, self-paced learning and personalization using Gen-AI, using AI to promote interaction and collaborative learning, and AI bias, limitations, and ethical issues. These themes were selected to capture both the pedagogical opportunities and the implementation challenges associated with Gen-AI in inclusive mathematics education.

A set of inclusion and exclusion criteria was applied to ensure the relevance and quality of the selected literature. Only peer-reviewed studies published between 2018 and 2025 were considered, with the exception of three foundational sources that were retained because of their theoretical and methodological significance. Eligible studies included empirical research, review articles, theoretical papers, and authoritative reports that addressed the use of Gen-AI or related AI technologies in formal educational settings. Studies were required to have full-text accessibility, identifiable authorship, and active DOI links where applicable. Articles focusing primarily on administrative applications of AI rather than teaching and learning processes were excluded. Similarly, studies conducted outside formal education contexts and sources with incomplete publication information were not considered. To minimize redundancy, review studies covering substantially similar themes were screened, and only the most relevant sources were retained.

As shown in Figure 1, the initial search yielded 185 papers from Google Scholar, 64 from ScienceDirect, and 60 from ProQuest. Following preliminary screening, many of the identified sources were excluded because they were not directly related to teaching and learning or did not meet the established inclusion criteria. After title, abstract, and full-text screening, a total of 43 sources were found eligible for inclusion in the review. These comprised 15 empirical studies, 17 review articles, 2 theoretical papers, 1 methodological book, and 8 peer-reviewed reports from authoritative organizations that addressed relevant themes. The final set of selected studies provided the evidence base for the thematic analysis and synthesis presented in this review. Guided by the identified themes, these sources were analyzed to generate insights into the opportunities, challenges, and pedagogical considerations associated with the integration of Gen-AI in mathematics education for learners with visual impairment.

4. Findings and Discussion

4.1. Adaptive Learning Technologies for Learners with Visual Impairment

Learners with VI continue to face significant educational challenges, particularly in relation to accessing personalized, interactive, creative, and effective learning experiences (Mina et al., 2023). In mathematics education, these challenges are further amplified by the need to accommodate diverse learning styles while providing sufficient opportunities for practice, individualized support, and timely feedback. Studies conducted in Kenya have highlighted persistent barriers to inclusive learning environments for learners with VI, including inadequate pedagogical approaches, limited personalized feedback, scalability challenges, and insufficient access to diverse learning resources (Musango et al., 2024; Okumu et al., 2021). As a result, many learners with VI experience difficulties in achieving optimal learning outcomes, particularly in STEM subjects such as mathematics (Mina et al., 2023). Addressing these challenges requires pedagogical approaches that promote adaptive learning, individualized support, and meaningful learner engagement.

In response to these challenges, the current study developed a framework to guide the integration of Gen-AI in mathematics education for learners with VI. The framework focuses particularly on the use of Generative Pre-trained Transformer (GPT-3.5 Turbo), an advanced large language model (LLM) developed by OpenAI, as well as other comparable Gen-AI tools such as Ernie Bot. These technologies have demonstrated substantial potential in generating instructional materials, mathematics exercises, worked solutions, and formative feedback tailored to learners' needs (Kim, 2023; Mboya et al., 2025; Rahman et al., 2023). Effective mathematics instruction for learners with VI requires careful planning of lesson flow, clearly defined learning outcomes, personalized learning opportunities, and ongoing assessment. However, such opportunities are often difficult to provide consistently within conventional classroom settings, especially where teachers face resource and workload constraints (Musango et al., 2024; Okumu et al., 2021). Gen-AI offers a promising means of addressing these limitations by supporting the automated generation of diverse learning resources and adaptive feedback mechanisms.

The pedagogical value of Gen-AI is particularly evident in mathematics education, where learners benefit from repeated exposure to varied problem-solving scenarios. Creating diverse mathematical problem spaces, developing sufficient practice exercises, and providing individualized feedback are often time-intensive tasks for teachers (Okumu et al., 2021). Gen-AI can support these processes by automatically generating multiple practice activities, offering step-by-step explanations, and delivering personalized formative feedback based on learners' responses (Roest et al., 2023). Recent advancements in large language models, including GPT-3.5 Turbo, Ernie Bot, and Bidirectional Encoder Representations from Transformers (BERT), have demonstrated considerable potential for generating educational content and supporting personalized learning experiences (Kim, 2023). Furthermore, research suggests that these emerging technologies can produce educational content that is both relevant and responsive to specific learning needs (Kim, 2023; Rahman et al., 2023). Through its ability to interpret natural language prompts and generate human-readable responses, GPT-3.5 Turbo can facilitate multimodal and multilingual learning experiences, including the generation of voice-based explanations and responses to mathematics-related queries (Mboya et al., 2025).

Building on these capabilities, the framework seeks to guide the use of Gen-AI tools such as GPT-3.5 Turbo and Ernie Bot in developing mathematics instructional materials, exercises, solutions, and feedback aligned with the Kenyan secondary school mathematics curriculum. For the purposes of this study, the framework also incorporates a tailored user-interface layer integrated with the Gen-AI platform. This interface serves as the primary access point through which teachers and learners can interact with AI-generated content and monitor learning progress. In addition to facilitating chat-based interaction and collaboration, the platform supports the generation and evaluation of mathematics exercises, delivery of personalized feedback, and creation of adaptive learning pathways. Such features contribute to an adaptive learning environment capable of addressing the diverse learning needs of learners with VI while supporting meaningful engagement in mathematics learning (Okumu et al., 2021). Consequently, the framework aims to support teachers in creating personalized, interactive, and inclusive learning environments that enhance mathematics achievement among learners with visual impairment, particularly within developing-country contexts where such opportunities remain limited (Okumu et al., 2021).

For an inclusive pedagogical framework to be effective, however, technological innovation must be accompanied by careful consideration of teacher capacity, ethical issues, and contextual implementation factors. Teachers require the knowledge and skills necessary to use Gen-AI effectively, evaluate AI-generated outputs, and make appropriate pedagogical decisions based on learners' needs (Okumu et al., 2021; Ribes-Lafoz et al., 2026). At the same time, it is important to recognize that Gen-AI technologies present several limitations and ethical concerns. Existing studies have identified challenges related to algorithmic bias, dependence on outdated training data, inaccuracies in generated content, and concerns regarding reliability and trustworthiness (Kim, 2023; Mboya et al., 2025; Tao et al., 2026). These issues have important implications for educational quality and learner outcomes. Consequently, teacher oversight remains essential in reviewing, validating, and contextualizing AI-generated content before it is used for instructional purposes (Ribes-Lafoz et al., 2026). The framework therefore incorporates mitigation strategies aimed at reducing the risks associated with content bias, inaccuracies, and reliability concerns while maximizing the educational benefits of Gen-AI. Through this balanced approach, Gen-AI can serve as a transformative pedagogical tool for promoting inclusive mathematics education and improving learning opportunities for learners with visual impairment.

4.2. The Use of AI in Mathematics Education

The developed framework adopts a Design-Based Research (DBR) approach as the overarching model for guiding the integration of Gen-AI in mathematics education for learners with VI. DBR is particularly suitable because it aligns with the principles of active, adaptive, and inclusive learning environments that are essential for improving learner engagement and educational outcomes among visually impaired learners. As a research and instructional design approach, DBR bridges theory and practice by enabling the systematic development, implementation, evaluation, and refinement of educational interventions within authentic learning contexts. Consequently, it provides a suitable foundation for designing and improving inclusive mathematics learning environments that leverage Gen-AI technologies.

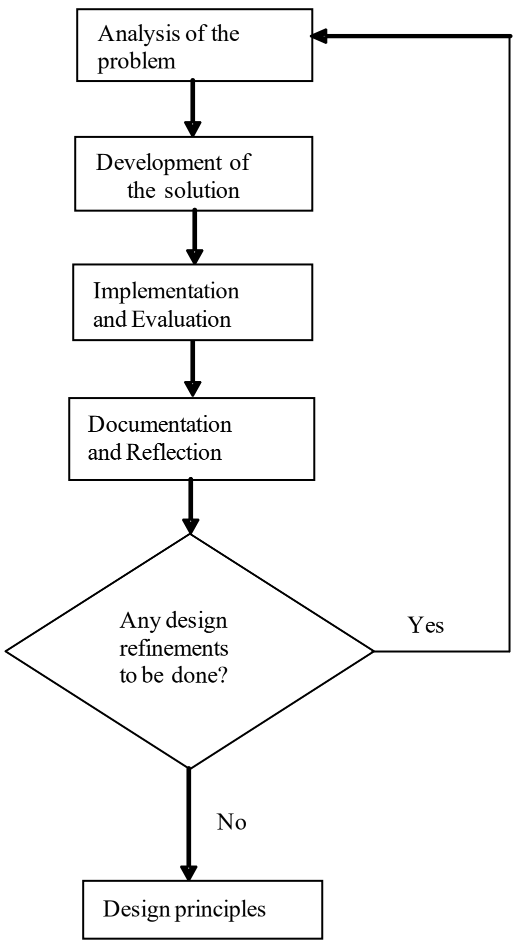
The implementation of the dveloped intervention should therefore be guided by the DBR process. DBR offers an appropriate framework for addressing educational challenges that involve both classroom-based inquiry and course design. According to Wilson et al. (2025), the DBR process comprises four major stages: (a) analysis of practical problems by researchers and practitioners, (b) development of solutions grounded in relevant theoretical frameworks, (c) testing and evaluation of the solutions in authentic educational settings, and (d) documentation and reflection to generate refined design principles. Within the framework, mathematics teachers are expected to operationalize these stages through their course design and instructional practices. Specifically, teachers should begin by identifying learning challenges and learner needs, develop Gen-AI-supported instructional solutions, implement and evaluate the interventions in classroom settings, and subsequently document and reflect on the outcomes to inform continuous improvement.

A key strength of DBR is its iterative nature, which supports continuous refinement of educational interventions over time. Mathematics teachers working with learners with VI should therefore employ iterative cycles of design, implementation, evaluation, and redesign throughout the duration of the course (Hakkarainen, 2009). As illustrated in Figure 2, the classroom environment should be organized into two or more iterative cycles, with each cycle progressing through the core stages of the DBR process. This cyclical approach enables teachers to respond to emerging learner needs, assess the effectiveness of instructional strategies, and progressively improve the intervention based on evidence gathered during implementation.

Within these iterative cycles, teachers assume the dual role of educator and action researcher. As shown in Figure 2, action research is embedded within the solution-development and implementation phases to allow teachers to systematically investigate and improve their own practice. Teachers actively participate in designing, implementing, and evaluating the intervention while simultaneously encouraging learners' active engagement, collaboration, and peer-feedback processes. Through continuous observation and evidence gathering, teachers assess both the learning processes and the educational outcomes associated with the intervention. This process enables informed pedagogical decision-making and supports the development of increasingly effective instructional strategies.

Figure 2

Key phases in the DBR process



Furthermore, continuous documentation and reflection constitute critical components of the DBR process. Throughout each cycle, teachers are expected to document implementation experiences, learner responses, challenges encountered, and emerging insights. Reflection on these experiences provides the basis for refining instructional designs, improving Gen-AI integration strategies, and enhancing learner support mechanisms. Consequently, documentation and reflection function as essential mechanisms for ensuring that the intervention evolves in response to contextual realities and learner needs. Through these iterative cycles of analysis, design, implementation, evaluation, documentation, and reflection, the proposed framework seeks to establish sustainable design principles for inclusive mathematics education that effectively support learners with visual impairment.

4.3. Inclusive Pedagogy for learners with Visual Impairment

Usability considerations for Gen-AI integration in mathematics education. The seamless integration of Gen-AI tools, such as GPT-3.5 Turbo, has the potential to transform mathematics education by providing more adaptive, personalized, and inclusive learning experiences. However, realizing this potential requires the customization of GPT-3.5 Turbo to meet the specific instructional and accessibility needs of mathematics education for learners with VI. As summarized in Table 1, the proposed framework incorporates mechanisms for interpreting natural-language queries and commands, and enables the generation of contextually relevant mathematics exercises, solutions, and explanations. Such customization is consistent with recommendations from previous studies that emphasize the importance of tailoring AI-generated content to address the diverse learning needs of students and improve the educational usefulness of Gen-AI tools (Mboya et al., 2025; Sivarajkumar et al., 2024; Wang, 2024).

To support effective implementation of the framework, the customized Gen-AI system should be integrated with a Learning Management System (LMS) that serves as the central platform for managing educational content, user access, and learning progress. Integrating AI-generated exercises within the LMS creates a unified and user-friendly learning environment in which learners can seamlessly access instructional materials, practice activities, and feedback. In addition, the LMS facilitates essential administrative functions, including user authentication, access control, and progress monitoring. By combining the adaptive capabilities of Gen-AI with the organizational functions of an LMS, the framework provides a structured and scalable environment for inclusive mathematics learning among learners with visual impairment.

Self-paced learning and analytical capability. Individual student data resulting from model performance, including completion times, correctness, and code quality, will be analyzed by the Adaptive Learning Engine. The engine will dynamically adjust the difficulty level of exercises, thereby providing a personalized learning experience that is aligned with individual learners' pace, needs, and interests. The literature underscores the need for AI-based tools with self-paced learning and automated learning analytics capabilities, which are central to promoting accessible, adaptive, and sustainable learning platforms in the digital society (Mao, 2025). The framework also incorporates collaborative tools such as GitHub to serve as a collaborative platform. These features would enable learners with VI to collaborate simultaneously with other users while working on practice exercises.

Interaction between individual and collaborative learning. The integration of a database system to support the OpenAI platform is also a core component of the proposed system. The database will store user profiles, progress data, content, and AI-generated exercises. In addition to supporting data privacy and adherence to ethical guidelines, the database is critical for tracking users' interactions, monitoring performance metrics, and maintaining a complete record of exercises. Furthermore, features such as discussion forums, chat functions, and notification systems will be incorporated into the communication module to facilitate interaction and discussion among students and teachers, thereby enabling the provision of timely feedback. Essentially, the aim of such a collaborative environment is to provide diverse opportunities for feedback and learning support.

4.4. Key Components of the Developed Implementation Framework

4.4.1. The workflow structure

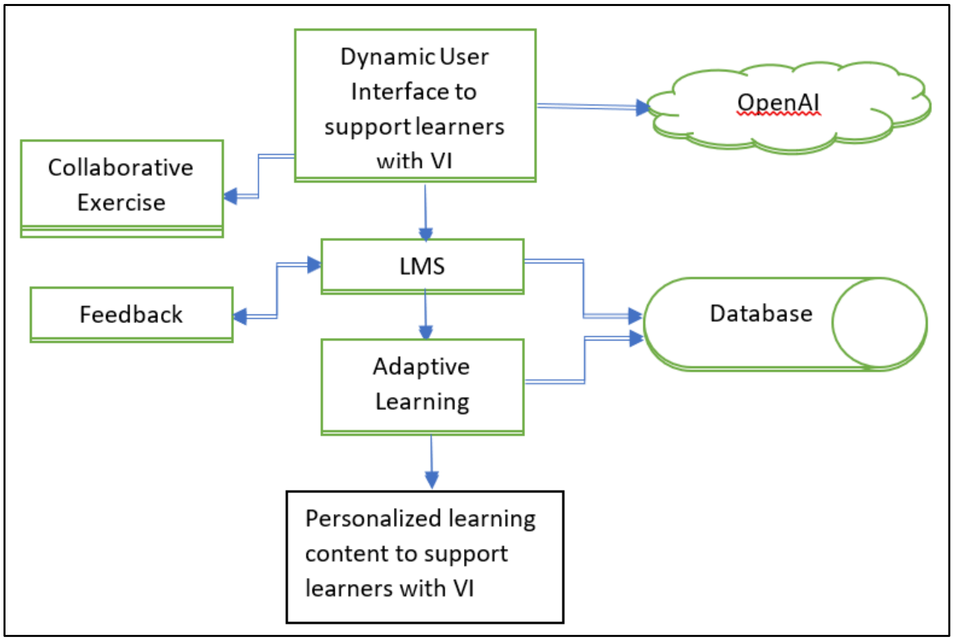
The workflow involves a seamless progression. Learners and instructors initially log in through a User Interface (UI) or Learning Management System (LMS). The AI tool then generates mathematics exercises, sample solutions, and relevant explanations based on natural-language commands or queries from the user. The Adaptive Learning Engine dynamically collects student performance data and customizes exercise difficulty levels according to user inputs.

As shown in Figure 3, students engage with the content and mathematics exercises through the Collaborative Platform, which encourages teamwork, the sharing of exercises, real-time feedback, and collaboration. Figure 3 presents a basic representation of the main components of the proposed framework. The key components include a dynamic interface designed to accommodate the varying needs of learners with VI, collaborative learning activities, adaptive content delivery, and personalized feedback opportunities.

The LMS, together with the interface, enables the monitoring of learners' progress and the provision of feedback from the instructor through the UI or Communication Module. This provides a centralized view of each learner's progress where the instructor can monitor the performance and achievement of individual students as well as groups.

Figure 3

Components of the proposed framework for personalized learning for learners with VI



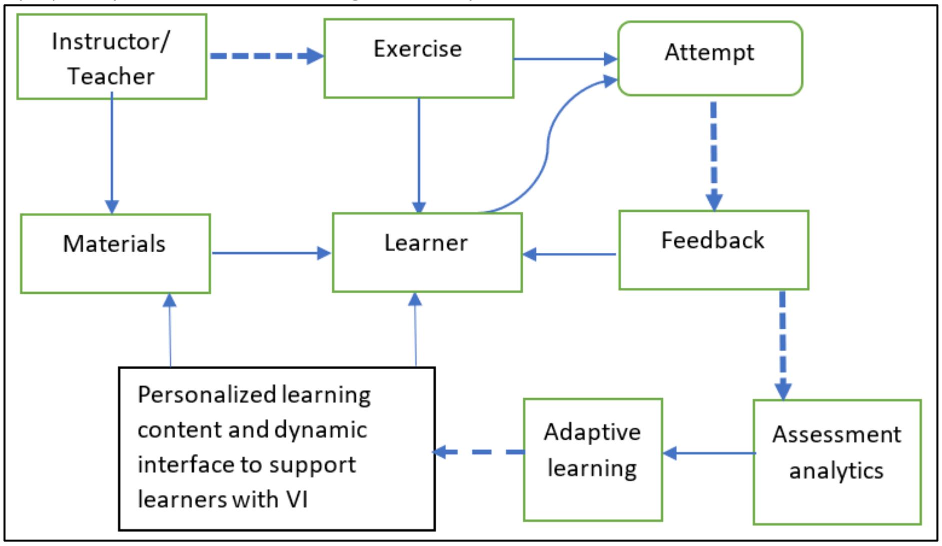
4.4.2. Lifecycle of mathematics exercises

Within the framework, the primary responsibility for content creation rests with the teacher or instructor, who utilizes the capabilities of the OpenAI model to generate learning materials and mathematics exercises. Subsequently, students become both users and co-creators of content by engaging with teacher-generated materials and contributing to learning activities. This process supports the development of relevant knowledge and problem-solving skills.

As students submit their completed exercises and receive feedback, the feedback loop progressively evolves into a collaborative learning process. Within this framework, learners have opportunities to engage with diverse mathematics exercises generated by the OpenAI model and receive immediate automated feedback based on the available code snippets and responses. The OpenAI model facilitates real-time interaction among learners, teachers, and peers, thereby fostering iterative and interactive learning processes in which content creation and feedback are integrated into the educational workflow. This pedagogical design is illustrated in Figure 4.

Figure 4

Lifecycle of mathematics learning activities for learners with VI



The dashed arrows in Figure 4 illustrate the use of Gen-AI in creating mathematics learning activities, providing feedback on students' mathematics exercise attempts, and supporting the development of an adaptive learning environment for learners with VI. Figure 4 also shows the need to adapt content to meet the diverse needs of learners with VI, while providing personalized learning content and opportunities for continuous formative feedback.

4.4.3. Reusability and scalability of the Gen-AI framework

The developed framework also assumes that teachers will be motivated to use open-source technologies and engage in teamwork, thereby providing opportunities for others to adopt, adapt, or further develop the framework. Reusability and scalability are key considerations in assessing the value of modern digital educational technologies, including Gen-AI-based solutions (Vandeputte, 2025). The platform will be designed to be flexible and adaptable to allow integration with different learning management systems and educational settings. The modular design and cloud-based deployment will facilitate the scalability of the solution, allowing it to accommodate larger student cohorts and diverse educational contexts.

4.4.4. Implementation of AI intervention in a mathematics classroom

The framework is based on the assumption that teachers will have opportunities for capacity building in the use of digital tools, including Gen-AI platforms. This implies that teachers will be able to identify relevant content and create mathematics exercises for learning and assessment based on the identified characteristics of high-quality AI-generated content. For instance, GPT-3.5 Turbo is considered a suitable platform because it can be adapted to generate content that is authentic, unique, diverse, and readily usable. Furthermore, the developed platform should be accessible to individual learners with VI.

It is important to note that although newer GPT models are available, GPT-3.5 Turbo remains relevant in educational settings, particularly in developing nations where balancing cost, speed, and reliability is crucial. In addition, GPT-3.5 Turbo provides natural-language explanations of mathematics solutions and practice exercises that are comprehensive and accurate. Accordingly, the framework is based on the teaching of mathematics using GPT-3.5 Turbo.

The framework is expected to be refined by teachers during actual classroom implementation based on the intended learning outcomes. However, despite the benefits of applying such a framework, educators should remain cognizant of the limitations of Gen-AI. This implies that teachers should deliberately address the ethical issues associated with AI-generated content.

4.5. The Intervention Implementation Framework

The intervention implementation framework should entail the identification, development, and vetting of instructional materials, as well as the identification of potential flaws and corresponding mitigation strategies. This should be followed by the use of GPT-3.5 Turbo to support the pilot testing and evaluation of mathematics teaching before proceeding to the main implementation phase in a conventional classroom setting.

As presented in Table 1, it is a consolidated output of this review. It synthesizes the conceptual findings presented in Section 4.4, summarized in Figures 3 and 4, and translated the key insights into practical guidelines for classroom-based activities. The teacher plays a central role as both course designer and facilitator. Consistent with the findings of this review, the framework captures key course design activities and highlights the teacher's responsibility for designing the learning environment, developing instructional materials, and evaluating learning resources in alignment with the intended learning goals.

Table 1 also shows that students are actively guided and involved in the generation and use of AI-generated content. Personalized support is provided to help them navigate the designed mathematics activities both individually and collaboratively. Furthermore, the framework highlights the need for teachers to continuously monitor and adapt the learning environment and the evolving learning discourse, while assessing learning progress and providing opportunities for individualized feedback. However, it is important to acknowledge that the framework is informed primarily by the analysis of existing literature and conceptual perspectives. Therefore, it offers conceptual insights and guidance, with limited empirical evidence drawn directly from the reviewed studies.

Table 1

Proposed intervention implementation framework

S/No.	Activity	Evaluation strategy	Performance metrics
1	Teacher to develop and evaluate instructional materials.	Peer review	Evaluation tool to assess accuracy, relevance and understandability of developed materials.
2	Conduct trials with students to generate pilot materials using GPT 3.5 Turbo & prepare content evaluation report.	Review of generated materials	Evaluation tool to assess practicality, uniqueness, and if generated materials are readily usable.
3	Teacher to evaluate pilot content and student feedback	Vetting of pilot report	Evaluation tool to assess practicality, uniqueness, and if generated materials are readily usable.
4	Discussion on mathematics topics using collaborative tools	Discussion	Level of Engagement/ Rate of Participation
5	Access platform and learn to design and teach mathematics lesson using from GPT-3.5 Turbo	Design content and assessment activities/Quizzes	Ability to design mathematics content and quizzes and solve given exercises based on diverse problem space
6	Generate, learn and run mathematics activities from GPT-3.5 Turbo.	Exercises	Ability to explain mathematical solutions and identify alternative solution path
7	Generate and attempt mathematics exercises from GPT-3.5 Turbo.	Exercises	Ability to write generate and solve new mathematics problems
8	Induction for learners	Conduct induction sessions for students on using AI-driven tools. Provide technical support and guidance during the induction period	Learners' ability to interact with the platform
10	Integration of AI- based learning activities	Integrate AI-driven exercises across mathematics topics	Diverse learning and assessment activities

S/No.	Activity	Evaluation strategy	Performance metrics
11	Planning for Evaluation phase	Embed exercises into the curriculum as part of learning and formative assessment activities Students' and teachers' Engagement Monitoring and evaluation: The teacher plans how to conduct evaluation/ data collection on learning processes and products Implement tools to track student engagement with AI exercises Monitoring and evaluation to gather real-time data on student usage and interaction Evaluate the effectiveness of AI-driven exercises on student performance Assess engagement and learning experiences	Diverse opportunities for teacher feedback and peer-peer feedback

5. Conclusion

This study suggests that AI-supported teaching and learning environments can provide opportunities for diverse and problem-based learning experiences that enhance inclusive education for learners with visual impairment (VI). The key pedagogical design principles conceptually elaborated in this paper highlight the fundamental course design elements that are instrumental in stimulating inquiry-based learning, problem-solving, critical thinking, and interactive collaboration, which are central to mathematics education. The findings also underscore the crucial role of teachers in course design and in facilitating interactive learning environments. In this regard, the theories of Problem-Based Learning (PBL), Flow, and TPACK are identified as important foundations for guiding the integration of Gen-AI in mathematics education.

The review further identifies several pedagogical considerations that should inform the integration of Gen-AI. These include a purposeful focus on personalized learning and assessment, the provision of diverse problem-solving opportunities, and tailored learning support to address varying learner needs across different contexts. In addition, the findings highlight the importance of ethical considerations and the need for teacher efficacy in addressing potential challenges associated with teaching mathematics to learners with VI. In particular, teachers play a critical role in mitigating ethical concerns related to the accuracy, reliability, and originality of AI-generated content.

Other important considerations identified in the review include usability factors related to Gen-AI integration in mathematics education, self-paced learning and learning analytics capabilities, the balance between individual and collaborative learning, and contextual considerations associated with workflow design and implementation. While Gen-AI is viewed as a potentially transformative pedagogical solution for inclusive education, the review also emphasizes the importance of teachers' AI-TPACK competencies in ensuring its effective and responsible use. These pedagogical considerations form the conceptual foundation of the framework. The framework conceptually exemplifies strategies for integrating Gen-AI to support a dynamic multimodal approach to inclusive mathematics education for learners with VI. Through its emphasis on personalization, adaptability, collaboration, and continuous feedback, the framework provides guidance for designing learning environments that are responsive to diverse learner needs.

A key limitation acknowledged in this paper is that the framework may require further contextualization and validation during actual implementation to ensure its suitability for specific classroom settings. As a review-based study, the insights presented are derived primarily from the analysis of existing literature and conceptual perspectives. Consequently, the findings are limited to conceptual understanding and are supported by relatively limited empirical evidence, which reflects the emerging nature of this field and the current paucity of relevant literature. Nevertheless, the paper achieves its intended purpose by providing valuable conceptual insights to guide current practice and inform future empirical research aimed at improving mathematics education for learners with visual impairment.

The implementation framework articulated in this paper has several implications for practice and future research.

First, there is a need to identify appropriate capacity-building strategies to enable teachers to effectively use Gen-AI as a tool for teaching mathematics to learners with VI. Particular attention should be given to enhancing teachers' AI-TPACK competencies. Future research should therefore focus on the development and application of AI-TPACK within the context of inclusive education.

Second, the framework should be considered a conceptual guide for informing effective strategies for integrating Gen-AI in mathematics education. Further empirical studies are needed to validate and refine the framework and to determine its effectiveness in facilitating a dynamic multimodal approach to inclusive learning.

Third, future empirical research should investigate the effects of Gen-AI integration on learners' experiences, engagement, and performance in mathematics, particularly among learners with visual impairment. Such studies would provide evidence regarding the educational value and practical applicability of Gen-AI-supported learning environments.

Fourth, future research should examine the strengths and limitations of the Gen-AI approach in comparison with existing digital Braille assistive technologies, particularly in relation to efficiency, effectiveness, and productivity in mathematics teaching and learning. Additional studies should also explore the usability of Gen-AI tools and their capacity to support dynamic personalization for visually impaired learners with diverse needs and learning styles.

Finally, the framework can encourage system developers to adopt more user-centered design approaches when advancing or customizing existing Gen-AI tools for mathematics education among learners with VI. In particular, future development efforts should focus on enhancing content adaptation capabilities and incorporating dynamic personalization features that better support inclusive learning experiences.

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