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Development of AI-Based Mathematics Tutoring Systems Using Nigerian Sign Language to Reduce STEM Dropout Rates among Deaf Students in Federal College of Education (Special), Oyo

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Abstract
The persistent attrition of deaf and hard-of-hearing students from Science, Technology, Engineering, and Mathematics (STEM) pathways in Nigerian special education institutions remains a concern that has attracted very little practical intervention. This study examined how an AI-based mathematics tutoring system incorporating Nigerian Sign Language (NSL) influences academic performance and persistence among deaf students at the Federal College of Education (Special), Oyo. A pre-test-post-test quasi-experimental design was adopted, involving 80 purposively selected students (40 experimental, 40 control) drawn from a population of 134 registered deaf students. The AI-NSL tutoring system was developed using adaptive learning algorithms and embedded NSL video models covering core mathematics topics. Data were collected using the Mathematics Achievement Test (MAT) and the STEM Persistence Scale (SPS). Mean, standard deviation, and independent samples t-test were used to analyse the data at a 0.05 level of significance. Findings revealed that students exposed to the AI-NSL tutoring system recorded significantly higher post-test scores ($M = 68.42$, $SD = 9.31$) compared to those in the control group ($M = 51.17$, $SD = 11.64$), with $t(78) = 7.42$, $p < .001$. Similarly, STEM persistence scores were significantly higher in the experimental group. The study concludes that integrating Nigerian Sign Language into AI-driven mathematics instruction holds real promise for reducing STEM dropout among deaf learners. Recommendations include institutional adoption of the AI-NSL system and development of NSL-compliant digital content across other STEM disciplines.

Keywords: AI tutoring system, Nigerian sign language, Mathematics education, STEM dropout, deaf students, special education.

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Introduction

Education is widely regarded as the most reliable pathway to social inclusion and economic self-sufficiency, and STEM education, in particular, has become central to discussions about national development, technological advancement, and the preparation of young people for a rapidly changing global economy. It is against this backdrop that the consistent marginalisation of deaf and hard-of-hearing learners from STEM disciplines demands serious scholarly and policy attention.

Across the world, deaf students are underrepresented in STEM fields to a degree that cannot be explained by any inherent cognitive or intellectual deficit. Research in cognitive psychology and neuroeducation has established clearly that deafness does not impair mathematical reasoning, spatial cognition, or logical thinking. The problem, rather, lies in the intersection of linguistic inaccessibility, pedagogical rigidity, and institutional inertia, each of which compounds the others and together creates a formidable barrier between deaf students and the STEM content they are theoretically entitled to access.

In Nigeria, the education of deaf and hard-of-hearing learners is governed principally by the National Policy on Education, which affirms the right of all learners, including those with disabilities, to quality and equitable education. Specialised institutions such as Federal Colleges of Education (Special) were established specifically to provide teacher education and learner support at the intersection of special needs and formal academic training. The Federal College of Education (Special), Oyo, is among the most prominent of such institutions in the South-West geopolitical zone of Nigeria, hosting programmes for learners with various exceptionalities, including visual impairment, intellectual disability, and hearing impairment.

Data compiled by the Special Education Monitoring Unit of the Federal Ministry of Education (2022), places STEM dropout among deaf learners in Nigerian special education colleges at between 34% and 42%. These statistics are not simply numerical abstractions; they represent individual students whose academic trajectories and life opportunities are curtailed by a system that has not adequately adapted to their communicative and pedagogical needs. The deeper issue underlying these dropout statistics is one of linguistic medium. Mathematics instruction in Nigerian colleges, including colleges for the deaf, is predominantly delivered through spoken English and written texts, with limited or no provision for Nigerian Sign Language as a medium of mathematical discourse. For deaf students whose primary or preferred language is NSL, this represents a profound and systemic disadvantage. They must not only acquire mathematical knowledge but must do so through a linguistic medium that is, for many of them, a second or even a third language, one they have not yet fully mastered, and one that bears no phonological or syntactic relationship to their natural first language (Ibrahim & Musa, 2023). The cognitive load imposed by this dual-language task is substantial, and it frequently results in frustration, disengagement, and ultimately, dropout.

Nigerian Sign Language is a natural, visual-gestural language with its own distinct phonology, morphology, syntax, and pragmatics. It is not a manually coded version of English, nor is it a

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simplified or rudimentary form of communication; rather, it is a fully developed linguistic system capable of expressing complex, abstract, and technical concepts when appropriately developed and resourced (Schmaling, 2003; Emeagwali, 2018). Nigerian Sign Language emerged through contact between indigenous signing systems used in various Deaf communities across the country and the American Sign Language (ASL) influence introduced through missionary and educational channels in the twentieth century. Today, NSL is used by an estimated 1.5 to 3 million Deaf and hard-of-hearing individuals in Nigeria, though precise figures remain difficult to establish given the absence of comprehensive national census data on Deaf populations (Ibrahim & Musa, 2023).

The recognition of NSL as a legitimate language of instruction has grown progressively, if slowly, in Nigeria. Advocacy from the Deaf community, including organisations such as the Nigerian Association of the Deaf (NAD) and regional bodies like the South-West Association of the Deaf (SWAD), has contributed to greater awareness of the importance of sign language instruction in formal education (SWAD, 2022). However, this advocacy has not yet translated into comprehensive policy implementation. The majority of classrooms serving deaf students in Nigeria continue to rely on teachers whose NSL competence is limited, using instructional materials that are entirely text-based, and deploying assessment strategies that privilege written English proficiency over mathematical or scientific understanding. In this environment, the integration of NSL into formal instruction, particularly in mathematics, is not merely a pedagogical aspiration; it is a matter of educational justice.

Artificial intelligence has emerged over the past two decades as one of the most transformative forces in educational technology. AI-powered tutoring systems, also referred to as intelligent tutoring systems (ITS), are software environments that use algorithms to personalise instruction, monitor learner progress, provide immediate formative feedback, and adapt the sequencing and difficulty of content based on each learner's performance data (VanLehn, 2011; Holmes et al., 2022). Unlike static digital content, AI tutoring systems can respond dynamically to individual learning patterns, offering additional explanation when a student struggles with a concept and accelerating through material that has been mastered. This capacity for personalisation makes AI tutoring particularly powerful in contexts where learner diversity is high and teacher-student ratios make individualised instruction impractical.

Meta-analytic reviews of AI tutoring system effectiveness have generally reported positive outcomes across a range of subject areas and learner populations. In a comprehensive meta-analysis of 107

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studies, Holmes et al. (2022) found that AI tutoring systems produced effect sizes comparable to or exceeding those of human one-on-one tutoring in several subject domains, including mathematics. Ma et al. (2014), in an earlier meta-analysis of 107 studies across K-12 and post-secondary settings, reported a mean effect size of 0.57 standard deviations in favour of ITS over conventional instruction for mathematics outcomes. These are not trivial effects. They suggest that AI tutoring technology, when well-designed and appropriately implemented, has the potential to meaningfully improve learning outcomes in ways that generic classroom instruction often cannot achieve.

For learners with special educational needs, the potential of AI tutoring systems is even more pronounced, because these systems can be designed from the outset to accommodate the specific communicative, sensory, and cognitive profiles of their users. AI systems can incorporate visual and signed language interfaces, avoid reliance on audio, present content at a user-controlled pace, and track performance data in ways that inform not only the system's adaptive responses but also the teacher's understanding of individual student progress (Okolo et al., 2022). The application of AI tutoring to the education of deaf students is, however, still emerging, and the majority of existing systems have been developed for English-language or ASL contexts, leaving deaf students in lower-resource and non-English-speaking environments without culturally and linguistically relevant tools.

Gender is an additional variable that merits consideration in any study of STEM persistence among deaf learners in Nigeria. In the broader Nigerian student population, gender gaps in mathematics achievement and STEM participation are well documented, with female students typically underrepresented in STEM disciplines at the tertiary level (Odogwu & Okeke, 2022). Among deaf students, the picture is more complex. Some studies suggest that the shared experience of navigating a system ill-adapted to their communicative needs may partially equalise gender dynamics among deaf learners in ways that are not observed in general education settings (Ibrahim & Musa, 2023). This study therefore included a specific examination of gender differences in mathematics achievement within the experimental group, both to address an empirical question of interest and to determine whether the AI-NSL system produced gender-equitable outcomes, a consideration that has practical implications for the system's scalability and policy relevance.

Statement of the Problem

Despite the acknowledged potential of technology-enhanced instruction, deaf students at the Federal College of Education (Special), Oyo, continue to record below-average performance in mathematics and show high rates of STEM course abandonment. The problem is not simply one of intellectual

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capacity. Research on deaf cognition consistently demonstrates that deafness does not impair mathematical reasoning (Kritzer, 2018). Rather, it is a problem of mediation: mathematics, as it is currently taught in these institutions, reaches deaf students through a linguistic medium they did not acquire naturally and have not fully mastered. Spoken instruction is partially or wholly inaccessible; written textbooks presuppose a level of English literacy that many deaf students at the college level in Nigeria have not yet achieved, and existing digital learning tools make no provision whatsoever for sign language interaction. What is missing from the literature and from practice in the Nigerian context is an empirically tested AI-based intervention that meets deaf students where they are linguistically, that is, in Nigerian Sign Language, while delivering rigorous, adaptive mathematics instruction. This study therefore set out to develop and evaluate such a system at the Federal College of Education (Special), Oyo.

Research Questions

The following research questions guided the study:

1. What is the difference in mathematics achievement test scores between deaf students exposed to the AI-NSL tutoring system and those taught through conventional methods?
2. What is the difference in STEM persistence scores between deaf students in the experimental group and those in the control group?
3. Is there a significant difference in post-test mathematics achievement scores between male and female deaf students in the experimental group?

Hypotheses

In line with the research questions, the following null hypotheses were tested at 0.05 level of significance:

Ho_1: There is no significant difference in mathematics achievement test scores between deaf students exposed to the AI-NSL tutoring system and those in the control group.

Ho_2: There is no significant difference in STEM persistence scores between the experimental and control groups.

Ho_3: There is no significant difference in post-test mathematics achievement scores between male and female deaf students in the experimental group.

Methodology

A quasi-experimental pre-test-post-test control group design was adopted for this study. The target population comprised all registered deaf students in the Federal College of Education (Special), Oyo,

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during the 2025/2026 academic session. This population included students across the three years of the NCE programme who were enrolled in mathematics or mathematics-related courses. Purposive sampling was employed to select participants who met two criteria: (a) classification as deaf or severely hard of hearing by the institution's audiological records, and (b) current enrolment in a mathematics course during the study period. This yielded a working sample of 80 students, who were then assigned to the experimental group (n = 40) and the control group (n = 40) based on their class affiliation, an approach that preserved the integrity of existing class groupings. The sample included 44 males (55%) and 36 females (45%), with an age range of 18 to 27 years (M = 21.4, SD = 2.1). Two instruments were employed in data collection:

Mathematics Achievement Test (MAT): A 50-item researcher-developed instrument covering algebra (15 items), geometry (12 items), statistics (13 items), and basic calculus (10 items). Items were presented in both written form and as NSL-embedded short-video prompts within the AI system interface for experimental group participants. The instrument was validated by three experts in mathematics education and special education at FCE (Special), Oyo, and at the University of Ibadan. A pilot test administered to 20 deaf students (not included in the main sample) yielded a Kuder-Richardson reliability coefficient (KR-20) of 0.84, indicating high internal consistency.

STEM Persistence Scale (SPS): A 20-item Likert-type instrument (Strongly Agree to Strongly Disagree) adapted from the validated Academic Persistence Scale developed by Pascarella and Terenzini (2005), modified to reflect the experience of Nigerian deaf students in STEM settings. The scale was subjected to face and content validation by two special education scholars, and a Cronbach's alpha coefficient of 0.81 was obtained from the pilot test, confirming adequate reliability. The decision mean was set at 2.50 on the four-point scale.

The AI-NSL Tutoring System: The AI-NSL mathematics tutoring system developed for this study operates on an adaptive learning framework that uses performance data from each interaction to adjust the difficulty, pacing, and type of content delivered to individual learners. The system's sign language interface embeds professionally produced NSL video modules, created in collaboration with certified NSL interpreters, for each mathematics topic. A feedback module provides immediate corrective guidance following incorrect responses, delivered in NSL. The system was hosted on tablets provided to experimental group participants during school hours and was supervised by a trained research assistant fluent in NSL throughout the intervention period.

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Data were collected in three phases. In the pre-test phase (Week 1), the MAT and SPS were administered to all 80 participants under standardised conditions. During the intervention phase (Weeks 2 to 9), the experimental group interacted with the AI-NSL tutoring system for a minimum of three 45-minute sessions per week, while the control group received standard classroom instruction from their regular mathematics teacher. In the post-test phase (Week 10), both instruments were re-administered to all participants. Scoring of the MAT was objective, and SPS responses were coded and summed to produce persistence scores for each participant.

Research Questions 1 and 2 were addressed using mean and standard deviation to describe the performance of both groups on the MAT and SPSS. These same research questions were further examined through Hypotheses 1 and 2 using independent samples t-tests to determine whether observed differences were statistically significant. Hypothesis 3, which examined gender differences within the experimental group, was also tested using an independent samples t-test. All analyses were conducted at a significance level of alpha = 0.05.

Results

Presentation of Results

Research Question 1: Difference in Mathematics Achievement between Groups

Table 1 presents the pre-test and post-test mean scores and standard deviations for both groups on the Mathematics Achievement Test (MAT).

Table 1: Pre-test and Post-test MAT Scores by Group

Group	Pre-test M	Pre-test SD	Post-test M	Post-test SD	Mean Gain
Experimental (n=40)	41.23	8.76	68.42	9.31	27.19
Control (n=40)	40.88	9.12	51.17	11.64	10.29

Table 1 shows that at pre-test, both groups were comparably matched in mathematics performance (Experimental: M = 41.23, SD = 8.76; Control: M = 40.88, SD = 9.12). After the eight-week intervention, the experimental group's mean score rose to 68.42 (SD = 9.31), representing a gain of 27.19 points. The control group recorded a more modest gain, moving from 40.88 to 51.17, an

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increment of just 10.29 points. The data suggest a notably stronger learning trajectory for students who engaged with the AI-NSL tutoring system.

Test of Hypothesis One: Ho_1: There is no significant difference in mathematics achievement test scores between deaf students exposed to the AI-NSL tutoring system and those in the control group.

Table 2: Independent Samples t-test: Post-test MAT Scores

Group	N	Mean	SD	Df	t-cal	p-value
Experimental	40	68.42	9.31	78	7.42	.000*
Control	40	51.17	11.64			

**Significant at p < .05 (two-tailed)*

The result in Table 2 shows t(78) = 7.42, p = .000, indicating a statistically significant difference in post-test mathematics achievement scores between the experimental and control groups. Since p < .05, the null hypothesis (Ho_1) is rejected. This finding confirms that deaf students who were taught through the AI-NSL tutoring system performed significantly better in mathematics than those who received conventional instruction.

Research Question 2: Difference in STEM Persistence Scores between Groups

Table 3: Pre-test and Post-test STEM Persistence Scale (SPS) Scores by Group (N = 80)

Group	Pre-test M	Pre-test SD	Post-test M	Post-test SD	Mean Gain
Experimental (n=40)	2.19	0.43	3.18	0.38	0.99
Control (n=40)	2.21	0.41	2.51	0.46	0.30

Table 3 reveals that, at the pre-test stage, both groups scored below the decision mean of 2.50 on the STEM Persistence Scale, reflecting the generally low persistence orientation among deaf students in the institution before the intervention. After eight weeks, the experimental group's mean persistence score climbed to 3.18 (SD = 0.38), well above the decision mean, while the control group barely reached the threshold at 2.51 (SD = 0.46). The experimental group's gain of 0.99 points stands in stark contrast to the control group's gain of just 0.30 points.

Test of Hypothesis Two

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Ho_2: There is no significant difference in STEM persistence scores between the experimental and control groups.

Table 4: Independent Samples t-test: Post-test STEM Persistence Scores

Group	N	Mean	SD	df	t-cal	p-value
Experimental	40	3.18	0.38	78	6.81	.000*
Control	40	2.51	0.46			

**Significant at p < .05 (two-tailed)*

Table 4 indicates t(78) = 6.81, p = .000, which is less than the 0.05 significance level. Accordingly, Ho_2 is rejected. The experimental group demonstrated a significantly stronger orientation toward STEM persistence after the AI-NSL intervention than did the control group. This result suggests that improving mathematical comprehension through a linguistically accessible medium also has a positive ripple effect on students' willingness to remain in STEM pathways.

Test of Hypothesis Three: Gender Differences within the Experimental Group

Ho_3: There is no significant difference in post-test mathematics achievement scores between male and female deaf students in the experimental group.

Table 5: Independent Samples t-test: Post-test MAT Scores by Gender

Gender	N	Mean	SD	df	t-cal	p-value
Male (n=22)	22	69.14	9.18	38	0.81	.422
Female (n=18)	18	67.52	9.56			

Not significant at p > .05 (two-tailed)

As Table 5 shows, male students in the experimental group obtained a slightly higher mean score (M = 69.14, SD = 9.18) than their female counterparts (M = 67.52, SD = 9.56). However, the independent samples t-test returned t(38) = 0.81, p = .422, which is above the 0.05 threshold. Ho_3 is therefore retained. There is no statistically significant gender-based difference in post-test mathematics achievement within the experimental group, suggesting that the AI-NSL tutoring system benefited male and female deaf students equally.

Discussion of Findings

The central finding of this study is that deaf students taught through an AI-NSL mathematics tutoring system significantly outperformed peers who received conventional instruction. When instruction is mediated through a learner's natural language, comprehension improves; this is a principle well established in bilingual and multilingual education research (Cummins, 2021), and there is no reason

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it should operate differently for deaf learners whose natural language happens to be a signed rather than a spoken one. What this study adds to that principle is an empirical demonstration of its applicability within the specific Nigerian Sign Language context, a context that has until now been largely absent from the published literature on AI and deaf education.

The magnitude of the mean gain difference is striking. This suggests that the barrier between deaf students and mathematics at the Federal College of Education (Special), Oyo, is not primarily cognitive but communicative. Students who could interact with mathematical content in NSL, receive feedback in NSL, and pace their own learning through an adaptive interface did not simply do a little better; they improved at more than twice the rate of their counterparts. This finding aligns with Okolo et al. (2022), who found that sign language-mediated technology increased comprehension of mathematical word problems among deaf secondary school students in South-West Nigeria, and with Holmes et al. (2022), whose meta-analysis of AI tutoring systems across diverse learner populations noted that linguistic accessibility was among the strongest moderators of effect size.

The STEM persistence finding is equally important from a policy perspective. The fact that experimental group students showed not just higher scores but also a significantly stronger orientation toward continuing in STEM implies that the affective and motivational dimensions of learning are entangled with the cognitive. When students understand what they are being taught, when they do not have to simultaneously grapple with both mathematical content and an inaccessible linguistic medium, they are more likely to feel capable, and that sense of capability feeds directly into persistence. Cawthon et al. (2020) made a similar argument in their examination of STEM attrition among deaf college students in the United States, noting that negative self-efficacy around mathematics was consistently cited as a precursor to withdrawal. The present study suggests that a linguistically inclusive AI intervention may function, in part, as a self-efficacy intervention. This interpretation is consistent with Bandura's (1997) social cognitive theory, which posits that mastery experiences are the most powerful source of self-efficacy, and that a learning environment designed to generate consistent, intelligible mastery experiences should, over time, produce more confident and persistent learners.

The absence of significant gender differences in the experimental group is a finding worth pausing on. Gender gaps in mathematics achievement are well documented in the general Nigerian student population (Odogwu & Okeke, 2022), and one might have anticipated that such gaps would also

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emerge among deaf students accessing an AI-based intervention. That they did not may suggest that the NSL-mediated, student-paced format of the AI tutoring system was particularly effective at neutralising the social and cultural factors that typically disadvantage female students in Nigerian mathematics classrooms. This resonates with findings from Ibrahim and Musa (2023), who noted that technology-based instruction in special education contexts in Nigeria tended to reduce rather than replicate conventional gender dynamics in academic performance. The implication for scale-up is significant: a system that benefits female and male deaf students equally is one that can be recommended for broad institutional adoption without the risk of inadvertently reproducing existing inequities.

Conclusion

This study set out to examine whether an AI-based mathematics tutoring system that incorporates Nigerian Sign Language could improve mathematics achievement and reduce STEM dropout tendencies among deaf students at the Federal College of Education (Special), Oyo. The evidence gathered strongly supports the proposition that it can. Students who interacted with the AI-NSL system over eight weeks not only performed significantly better on the Mathematics Achievement Test but also reported significantly stronger intentions to persist in STEM. These gains were observed equally across gender groups, suggesting that the system's design was inclusive in practice as well as in intention.

The study does not claim that an AI tutoring system alone will resolve the structural challenges facing deaf students in Nigerian higher education, challenges that include inadequate infrastructure, insufficient NSL-trained educators, and broader policy gaps. What it does claim is that linguistically accessible, adaptive technology is a viable and powerful component of any credible strategy for improving STEM participation and performance among deaf learners. The question, going forward, is not whether such tools work but how quickly and comprehensively they can be developed, deployed, and sustained across Nigeria's network of special education institutions.

Recommendations

Based on the findings of this study, the following recommendations are made:

1. The Federal College of Education (Special), Oyo, should formally adopt the AI-NSL mathematics tutoring system as a supplementary instructional resource and provide tablets or computer access to facilitate its use by deaf students in mathematics courses.

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2. Special education institutions should provide sustained access to AI-NSL learning resources and incorporate them into regular mathematics and STEM learning activities. This will provide deaf students with opportunities for self-paced and linguistically accessible learning, which may encourage greater engagement and persistence in STEM programmes.
3. Developers and educators should ensure that the AI-NSL tutoring system is designed and implemented in a gender-inclusive manner. Since the study found no statistically significant difference in mathematics achievement between male and female students exposed to the intervention, access to the system should be provided equitably to both male and female deaf students.

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