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Research Article

Examining the effect of AI-based tutoring systems on students' mathematical problem-solving skills: The moderating role of mathematics anxiety

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This study used mathematics anxiety as a moderating variable to investigate how AI-based tutoring systems affected university students' ability to solve mathematical problems. A cross-sectional survey design was used, and a standardized questionnaire was used to collect data from 338 students. Amos was used for Structural Equation Modeling analysis of the general data. Students' ability to solve mathematical problems was directly and significantly impacted by AI-based tutoring systems, according to the findings. Additionally, students' ability to solve mathematical problems was adversely affected by mathematics anxiety. Lastly, the relationship between students' ability to solve mathematical problems and AI-based tutoring systems was negatively moderated by mathematics anxiety. We advised teachers to implement strategies to reduce mathematics anxiety in the classroom. These include creating a loving technique for a loving environment, offering techniques for lowering anxiety, and encouraging a growth mentality.

Keywords: AI-based tutoring systems, mathematical problem-solving skills, mathematics anxiety

1. Introduction

Traditional teaching and learning approaches have changed as a result of the increasing use of artificial intelligence (AI) in educational settings. The potential of AI-driven tutoring systems to enhance students' learning outcomes, especially in mathematics, has garnered a lot of attention (Suvendu & Deb, 2024). By fostering critical thinking and analytic reasoning, mathematics problem-solving abilities are essential to students' academic success (Nilimaa, 2023). Therefore, using AI-based tools to improve these abilities has emerged as a key area of study in education. Even with the advancement in digital learning resources, students' performance in mathematics is frequently hindered by math-related anxiety (Ng et al., 2022). Students who suffer from math anxiety may become less confident and find it more difficult to use effective problem-solving techniques. Thus, it is essential to comprehend how AI-based tutoring systems, mathematics problem-solving abilities, and mathematics anxiety interact. Examining this relationship can provide insightful information for creating strategies that improve educational outcomes.

Through the use of machine learning algorithms, natural language processing, and adaptive learning models, artificial intelligence tutoring systems offer customized educational materials that are suited to the individual needs of each learner (Lin et al., 2023). By using these cutting-edge technologies, these systems can track students' progress, analyze their learning habits, and adjust the way that content is delivered. This adaptive approach improves students' overall engagement and comprehension by providing them with tailored learning experiences that cater to their strengths and weaknesses. According to studies by Leddo and Garg (2021), students who utilized AI-powered tutoring systems outperformed those who received traditional classroom teaching in mathematics. Additionally, by utilizing scaffolding strategies, interactive feedback, and step-by-step problem-solving assistance, AI tutoring systems effectively adapt to students' cognitive needs (Son, 2024).

According to Zuo et al. (2024), mathematics anxiety is a psychological issue that adversely affects students' performance in mathematics by affecting their self-efficacy, problem-solving skills, and cognitive processing abilities. According to research by Daker et al. (2021), students who struggle with mathematics frequently engage in avoidance behaviors, perform worse academically, and have low engagement levels. Conversely, studies have shown that learning outcomes are enhanced by interventions that use personalized learning environments to address anxiety (Zhou et al., 2022).

By providing an individualized and encouraging learning environment, AI-based tutoring systems have demonstrated a great deal of promise in lowering math anxiety. These systems are made to adjust to each learner's unique requirements, offering customized instruction that corresponds with their comprehension and speed. Students can interact with mathematical ideas in a relaxed environment by using interactive features and adaptive strategies, which reduces the stress and intimidation that are frequently connected to math learning (Trung et al., 2025). It is essential to comprehend how mathematics anxiety affects learning outcomes and to determine how effective AI-based tutoring is. Although AI systems have the potential to encourage more in-depth mathematical learning, there are differences in how anxiety affects students' openness to these systems (Guo et al., 2023). High-anxiety students, for example, might need extra support features like calming prompts, motivational interventions, or anxiety-reduction activities built into the AI tutoring systems (Liu et al., 2017). AI-based systems that integrate anxiety-reduction strategies increased students' perseverance and improved their performance in mathematics, according to research by Su et al. (2024). Therefore, removing anxiety-related obstacles with AI systems can give students of different anxiety levels more inclusive and productive learning opportunities.

2. Statement of Problem

Students' academic performance and future professional development, especially in STEM fields, depend heavily on students' ability to solve mathematical problems. However, according to several studies, students frequently have trouble learning and using efficient problem-solving techniques (Simanjuntak et al., 2021). Artificial Intelligence-based tutoring system techniques have become a vital alternative for improving students' mathematical problem-solving abilities, even though traditional teaching approaches have tried to address this issue (Liu et al., 2025; Trung et al., 2025). To improve students' comprehension and cognitive engagement in mathematics, AI-based tutoring systems make use of intelligence recommendation systems, adaptive learning algorithms, and personalized feedback mechanisms (Rizvi, 2023). According to research, by tailoring the delivery of content to reach learners' unique needs, these systems can greatly enhance learning outcomes (Asio & Gadia, 2024).

Even with these developments, there is still little empirical data on how well AI-based tutoring programs improve students' ability to solve mathematical problems, especially when taking into account personal psychological issues like math anxiety. A well-established psychological barrier that hinders students' ability to participate in mathematical tasks successfully is mathematics anxiety (Ramo & Carmen, 2025). Research has demonstrated that high levels of mathematics anxiety impair cognitive processing, decrease working memory capacity, and impair performance in problem-solving situations (Scheibe et al., 2023). Research on how AI-based tutoring systems may lessen or worsen the effects of anxiety on problem-solving abilities is still lacking, despite earlier studies showing a link between mathematics anxiety and learning outcomes (Caviola et al., 2022). Few studies have looked at how AI-based tutoring systems affect math achievement (Khazanchi et al., 2024) or how math anxiety affects performance (Demedts et al., 2022). Notably, little is known about how mathematics anxiety influences the relationship between students' ability to solve mathematical problems and AI-based tutoring systems. Investigating this interaction is essential to creating focused interventions that can improve AI tutoring platforms in various educational settings.

This study aims to explore the relationship between AI-based tutoring systems, mathematics anxiety, and students' mathematical problem-solving skills. Specifically, it pursues three key research objectives: to assess the effect of AI-based tutoring systems on students' mathematical problem-solving skills; to evaluate the impact of mathematics anxiety on students' ability to solve mathematical problems; and to determine whether mathematics anxiety moderates the influence of AI-based tutoring systems on students' problem-solving performance. In line with these objectives, the study proposes the following hypotheses:

H1: AI-based tutoring systems positively influence students' mathematical problem-solving skills

H2: Mathematics anxiety negatively affects students' mathematical problem-solving skills.

H3: Mathematics anxiety moderates the nexus between AI-based tutoring systems and students' mathematical problem-solving skills.

3. Literature Review

3.1. Effect of AI-based Tutoring Systems on Students' Mathematical Problem-solving Skills

Artificial intelligence-based tutoring systems have gained significant interest in mathematics education due to their ability to enhance students' problem-solving abilities. These systems use AI techniques to provide immediate feedback, adjust to individual needs, and provide personalized instruction. Research shows that AI-powered tutoring programs significantly improve math proficiency by offering individualized learning opportunities (Alvarez et al., 2024). Adaptive learning algorithms are used to customize instruction to meet each student's needs (Wang et al., 2023). These systems analyze student data to develop individualized learning paths, resulting in more effective and efficient learning. AI-driven algorithms can evaluate student performance, offer tailored comments and suggestions, and enhance participation and problem-solving abilities (Tsiani et al., 2025). The use of AI in mathematics education has been linked to the development of critical thinking and problem-solving skills. By using AI-based tools, students are prompted to approach mathematical problems more critically and responsibly, which improves their comprehension of basic ideas. AI applications in mathematics education foster critical thinking and a deeper understanding of mathematical concepts, according to a systematic review. Based on these discussions, we therefore hypothesized that;

H1: AI-based tutoring systems significantly influence students' mathematical problem-solving skills.

3.2. Effect of mathematics Anxiety on Students' Mathematical Problem-solving Skills

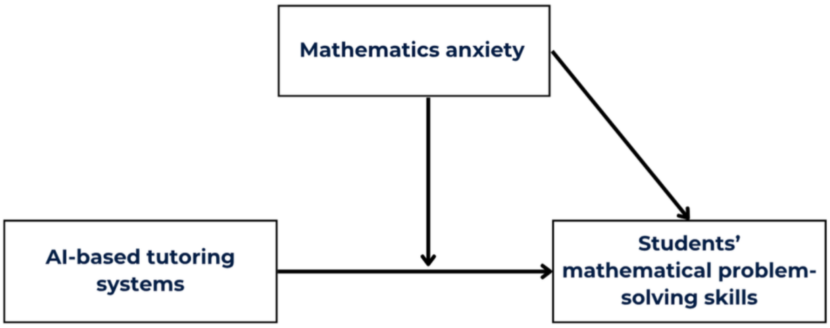
An established psychological concept, mathematics anxiety has a major impact on students' cognitive abilities, especially when it comes to problem-solving situations. Math anxiety has been the subject of much research in recent years and is defined as a feeling of tension, apprehension, or fear that interferes with mathematics performance (Khasawneh et al., 2021). Math anxiety has been shown to affect cognitive abilities, especially working memory, which is crucial for solving complicated problems (Živković et al., 2023). Math anxiety dramatically impairs working memory efficiency, which limits students' ability to remember and manipulate information when tackling multi-step mathematical problems, according to research by Florentine (2023). Furthermore, it was shown by Zhang et al. (2024) that elevated anxiety impairs students' capacity to apply efficient problem-solving techniques by interfering with the prefrontal cortex's normal function. Based on these discussions, we therefore hypothesized that;

H2: Mathematics anxiety negatively affects students' mathematical problem-solving skills.

Based on H1 and H2, we further proposed that;

H3: Mathematics anxiety moderates the nexus between AI-based tutoring systems and students' mathematical problem-solving skills.

Figure 1
Conceptual Framework



The proposed framework outlines the relationship between AI-based tutoring systems, students' mathematical problem-solving skills, and mathematics anxiety. The framework suggests that while AI tutoring systems may improve problem-solving skills, this effect may vary based on students' levels of mathematics anxiety.

4. Methodology

4.1. Research Design

Data for this study were gathered quantitatively through a cross-sectional survey design. A cross-sectional survey is especially well-suited for evaluating a population that presents traits, viewpoints, or actions over a specified period. By taking a momentary picture of the variables of interest, the researcher can examine the patterns and relationships between them without changing the study environment.

4.2. Population and Sample

University students enrolled in courses related to mathematics education at AAMUSTED, situated in Kumasi, Ghana, made up the study's target population. In particular, first- and second-year students enrolled in the Bachelor of Science in Information Technology Education and the Bachelor of Science in Mathematics Education made up the population. Calculus, statistics, and computing mathematics are among the advanced and foundational mathematics topics covered in these students' coursework, which is why they were chosen. These subjects are essential for fostering both mathematical competency and instructional proficiency (Adler & Davis, 2006).

Using the Krejcie and Morgan (1970) table, which estimated the sample size for a population of 2,800 university students, the proper sample size for the study was determined. To ensure accessibility for all respondents, the researchers distributed a structured questionnaire on paper for data collection. All 338 university students who were chosen completed the survey. The respondents' program of study and gender are shown in Table 1.

Table 1
Demographics of the participants

Demographics	*Frequency (N)*	*Percentage (%)*
Gender		
Male	220	65.1
Female	118	34.9
Program of Study		
BSc. Information Technology Eud.	169	50.0
BSc. Mathematics Education	169	50.0

Additionally, we employed basic random sampling methods and stratified sampling. First, we used stratified sampling techniques to group the respondents according to their study program. The population is separated into discrete strata (e.g., gender and program of study) through stratified sampling. To represent the entire population, we also employed simple random sampling, which minimizes bias and guarantees that each unit in the population has an equal chance of being chosen, to choose representatives from each stratum.

4.3. Data Collection

Initially, the researcher requested permission from the heads of the various departments where the data would be collected. Following approval, we attended lectures from the appropriate department to discuss the questionnaire distribution and hear verbal instructions. After distributing hard copies of the questionnaires to various department heads, researchers began gathering data from the 19th of 20th of February, 2025, to the 25th of April, 2025. At the end of the process, 338 completed questionnaires were collected.

4.4. Instruments

The structured questionnaire used in this study was created based on the main variables of interest, which were students' ability to solve mathematical problems, AI-based tutoring systems, and mathematics anxiety. Three sections, designated A, B, and C, comprised the questionnaire. The four items in Section A, which were taken from the work of Mounkoro et al. (2024), evaluated AI-based tutoring systems. The three items in Section B, which measured students' mathematics problem-solving skills, were taken from Ukobizaba et al. (2021). To address mathematics anxiety, section C used four items that were modified from Szczygieł (2022). A five-point Likert scale was used to rate each item on the survey: 1 indicated strongly agree, 2 indicated agree, 3 indicated neutral, 4 indicated disagree, and 5 indicated strongly disagree.

4.5. Common Method Bias

To address potential common bias [CMB], this study implemented several procedural and statistical techniques, following the guidance of Podsakoff and Organ (1986). Before the main data collection, a pilot test of the questionnaire was conducted to identify and revise any ambiguous items or wording. For a more rigorous statistical assessment of CMB, Harman's single-factor test was performed, in line with the procedure outlined by Asare & Boateng (2025). The analysis revealed that the first factor accounted for 39.802% of the total variance when the number of factors was limited to one, well below the 50% threshold. This indicates that on single factor dominated the variance, thus confirming the absence of significant common method bias in the dataset (Podsakoff & Orang, 1986).

4.6. Validity and Reliability

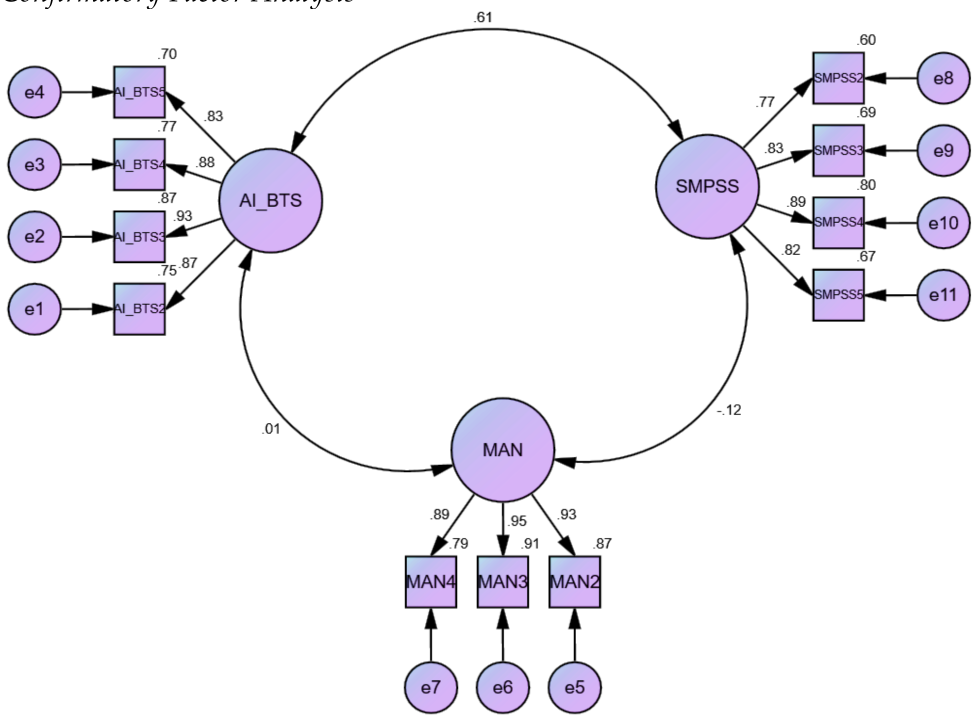
Confirmatory Factor Analysis [CFA] was performed using Amos to evaluate the extent to which the collected data aligned with the proposed measurement model. The analysis utilized the maximum likelihood estimation methods, which are commonly applied to assess model fit. As proposed by Lotey et al. (2025), model fit indices, the measurement items presented in Table 2, strongly fit the model. All the necessary fit indices met their corresponding levels, as indicated by Table 2 and Figure 2. To put it another way, these findings showed that the CFA model fits the data for the study's constructs in an acceptable manner, validating its validity and dependability.

Furthermore, the average variance extracted [AVE] values for each construct were higher than the 0.05 threshold recommended by Fornell and Larcker (1981). This implies that the items in each construct effectively measured the underlying concepts they were intended to evaluate, indicating that each construct had a sufficient degree of convergent validity. An AVE above 0.5, which shows that the shared variance among the indicators is larger than the variance due to measurement error, strengthens the constructs' reliability. Along with AVE, the reliability criteria outlined by Asare and Boateng (2025) were met by Cronbach's alpha [CA] and composite reliability [CR] values, both of which were higher than 0.7. The remarkable internal consistency of the constructs is demonstrated by the fact that each construct's items measured the same underlying notion and displayed a high degree of correlation. The fact that each construct's items measured the same underlying concept and showed a high degree of correlation highlights the constructs' strong internal consistency. Lastly, these results boost confidence in the caliber of the measurement model by confirming the validity and reliability of the study's constructs.

Table 2
Confirmatory Factor Analysis

Model Fit Indices: CMIN = 72.517; DF = 41; CMIN/DF = 1.769; TLI = .984; CFI = .988; GFI = .956; RMR = .029; RMSEA = .052; PClose = .403;	*Std. Estimate*
AI-BTS: CA = .930; CR = .931; AVE = .771	
AI_BTS2: I find the AI-based tutoring system engaging and interactive.	.869
AI_BTS3: The AI-based tutoring system significantly improved my understanding of the subject matter.	.930
AI_BTS4: The AI-based tutoring system motivates me to continue learning and improves my study habits.	.877
AI_BTS5: I feel confident in the accuracy of the information provided by the AI tutoring system.	.834
MAN: CA = .947; CR = .948; AVE = .858	
MAN2: I feel nervous when I have to solve mathematical problems in front of others.	.934
MAN3: I get anxious when I have to use mathematics in my daily life.	.955
MAN4: I feel tense and uneasy during mathematics classes.	.889
SMPSS: CA = .897; CR = .899; AVE = .691	
SMPSS2: I am confident in understanding the problem before attempting to solve it.	.773
SMPSS3: I check my solutions to ensure they are correct.	.833
SMPSS4: I can explain the steps I used to solve mathematical problems.	.893
SMPSS5: I can break down complex problems into smaller, manageable parts	.820

Figure 2
Confirmatory Factor Analysis



The analysis showed that 0.6 was the lowest standardized factor loading among the measurement variables. This suggests that each measurement item made a substantial contribution to the explanation of its corresponding latent constructs. Good reliability is indicated by a factor loading of 0.6 or greater, which strengthens the measurement model. Strong loadings like this show how well the observed variables capture the theoretical ideas they were intended to assess.

Discriminant validity was assessed by comparing the square root of the Average Variance Extracted for each construct with intercorrelated values. Amoako et al. (2022) confirmed discriminant validity when the lowest AVE exceeds the highest interconstruct correlation. The smallest AVE value (0.733) exceeded the highest observed intercorrelation (.602), indicating constructs' distinctness and acceptable discriminant validity in the measurement model.

Table 3
Discriminant Validity

Variables	*CR*	*AVE*	*AI_BTS*	*MAN*	*SMPSS*
AI_BTS	.931	.771	**.878**		
MAN	.948	.858	.013***	**.926**	
SMPSS	.899	.691	.615***	−.116***	**.831**

5. Results

Covariance-based structural equation modeling [SEM] with Amos (v. 23) was used to perform the path analysis. Using 5,000 bootstrapping samples and a 95% confidence interval, a Bias-Corrected [BC] percentile bootstrapping technique was used to improve statistical reliability. Table 4 provides a summary of the findings, and Figure 3's structural model provides additional illustrations.

Table 4
Paths results

Direct Effect	*Std. Estimate*	*S.E.*	*C.R.*	*p-value*
AI_BTS → SMPSS	.616	.065	9.675	***
MAN → SMPSS	−.124	.054	−2.357	.018
Moderating Effect	*Std. Estimate*	*S.E.*	*C.R.*	*p-value*
AI_BTSxMAN→ SMPS	−0.027	.065	−.415	.156

5.1. H1: AI-based tutoring systems significantly influence students' mathematical problem-solving skills

Research hypothesis 1 aimed to ascertain whether AI-based tutoring systems significantly influence students' mathematical problem-solving skills. As presented in Table 4, AI-based tutoring systems have a positive, direct, and significant effect on students' mathematical problem-solving skills (B = 0.616). as a result, students' ability to solve mathematical problems is directly enhance by 61.6% when they used AL-based tutoring systems Based on the study findings, hypothesis one (H1), which states that "AI-based tutoring systems significantly influence students' mathematical problem-solving skills", failed to be rejected.

5.2. H2: Mathematics anxiety negatively affects students' mathematical problem-solving skills.

The second research hypothesis (H2) also aims to determine whether students' ability to solve mathematics problems is adversely affected by mathematics anxiety. Math anxiety harms students' ability to solve mathematical problems (B = −.124), as Table 4 demonstrates. The second research hypothesis (H2), according to the findings, that "mathematics anxiety negatively affects student mathematical problem-solving skills," was not disproved.

5.3. H3: Mathematics anxiety moderates the nexus between AI-based tutoring systems and students' mathematical problem-solving skills

Lastly, the study looked at how students' mathematical problem-solving skills and AI-based tutoring systems relate to mathematics anxiety. The z-score method, which involved multiplying the standardized (z-score) values of AI-based tutoring systems and mathematics anxiety, was used to calculate the interaction term (AI-BTSxMAN). The accuracy of the interaction analysis is improved by this standardization. Students' problem-solving skills were insignificantly impacted negatively by the interaction term (B = −0.027, $p > .01$), as shown in Table 4. This suggests that as math anxiety rises, the beneficial effects of AI-based tutoring programs on problem-solving skills diminish. Based on this, research hypothesis three (H3), which states that "Mathematics anxiety negatively moderates the relationship between AI-based tutoring systems and students' mathematical problem-solving skills," failed to be rejected. Figure 3 shows the path summaries.

Figure 3
Path Summary Illustration

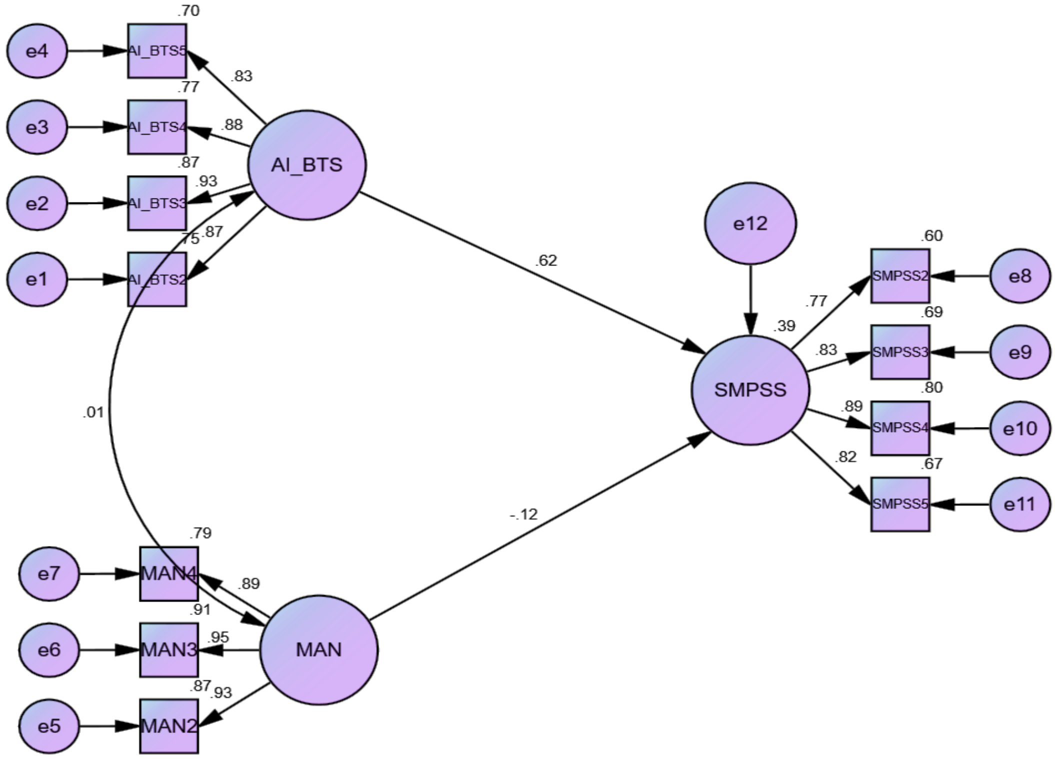
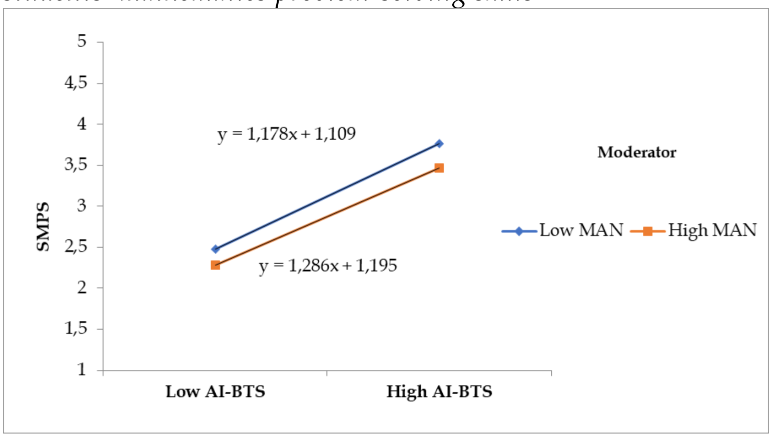


Figure 4 presents the two-way interaction effect of mathematics anxiety in the relationship between AI-based tutoring systems and students' mathematics problem-solving skills. The figure illustrates how varying levels of mathematics anxiety moderate the impact of AI-based tutoring tools on students' performance in solving mathematical problems.

Figure 4
Two-way Interaction Effect of Mathematics Anxiety in the nexus between AI-based tutoring Systems and students' mathematics problem-solving skills



According to Figure 4, Mathematics Anxiety dampens the positive relationship between AI-based tutoring systems and students' mathematics problem-solving skills.

6. Discussion

The result shows that students' mathematics problem-solving skills were positively, directly, and significantly impacted by AI-based tutoring systems, demonstrating the potential of technology-enhanced learning resources to raise students' mathematical achievement and cognitive engagement. This outcome is consistent with other research showing how AI-powered platforms offer personalized instruction, real-time scaffolding, and adaptive feedback, all of which are essential for fostering problem-solving skills (Halkiopoulos & Gkintoni, 2024). These systems frequently adapt to the speed and ability level of their users, encouraging independent thought and deeper conceptual understanding, two crucial components of solving mathematical problems (Rane, 2023). Furthermore, the constructivist viewpoint, which maintains that learning is most successful when students actively construct knowledge through interactions with supportive environments and tools, is supported by these results. By mimicking one-to-one instruction, AI-based tutoring systems enable these kinds of settings and replicate the efficacy of human tutoring (Banjade et al., 2024). The study's significant positive coefficient (see Table 4) demonstrates that students' ability to solve mathematical problems significantly improves as they use AI-based platforms more frequently. This effort might be explained by the AI's capacity to deconstruct difficult issues into digestible steps, providing guidance and support that boost students' self-esteem and capacity for strategic thought (Soesanto et al., 2022). Lastly, the results have important ramifications for AI-based tutoring in regular classroom instruction, particularly in large or under-resourced classrooms where individualized support may be scarce. The investment in AI technologies to close learning gaps and advance equity in mathematics education is also supported by this data. When carefully applied, AI systems can be effective instruments to improve student outcomes, especially in difficult subjects like mathematics, as highlighted by Opesemowo and Ndlovu (2024). The study findings validate the use of AI in contemporary teaching methods by demonstrating its transformative power in improving students' problem-solving skills.

Moreover, the result that students' mathematics problem-solving skills are adversely affected by mathematics anxiety is consistent with a substantial body of research. Students' capacity to comprehend, plan, and resolve complex problems is diminished by this cognitive interference. The negative coefficient supports the notion that emotional and psychological barriers can seriously impair mathematical competence by showing that higher anxiety levels are linked to poorer problem-solving performance (Barroso et al., 2021). This conclusion is supported by a number of empirical studies. For example, Živković et al. (2022) discovered that students with high levels of math anxiety had poorer performance on math tasks because they had impaired executive functioning, especially when time was of the essence. Similarly, it has been pointed out that nervous students frequently avoid math practice, which gradually erodes their abilities and self-esteem and produces a cycle that impairs problem-solving (Insorio, 2025; Zakariya, 2018). The results highlight how crucial it is to address mathematics anxiety in curriculum design and instructional interventions. The detrimental effects of anxiety on students' mathematics reasoning may be lessened with the use of strategies like growth mindset training, anxiety-reduction techniques, and the creation of supportive classroom environments (Stohlmann & Yang, 2024). Teachers and policymakers should understand that developing mathematical problem-solving abilities calls for emotional and psychological scaffolding in addition to cognitive support. Thus, combining affective and cognitive teaching methods can help create a more inclusive and successful mathematics education.

6. Practical Implications

Based on the findings that AI-based tutoring systems significantly enhance students' mathematical problem-solving skills and that mathematics anxiety negatively affects their performance, several practical implications emerge. First, educators and developers should consider implementing personalized learning pathways to reduce anxiety. This involves integrating adaptive features into AI-based tutoring systems that adjust content difficulty and pacing according to each student's anxiety levels and skill progression. By embedding real-time emotional recognition or anxiety-detection mechanisms—such as self-report check-ins or behavioral cues—the systems can offer timely encouragement, hints, or simplified problem steps to prevent frustration and support a more confident and resilient approach to problem-solving.

Furthermore, it is essential for schools and teacher preparation programs to incorporate AI-based tutoring systems into the regular mathematics curriculum, not as substitutes for instruction, but as complementary tools that enrich guided teaching. Teachers should receive professional development on how to interpret data generated by these systems, recognize signs of mathematics anxiety, and implement targeted interventions. Leveraging the proven benefits of this technology can help educators differentiate instruction and increase classroom efficiency, especially in settings with limited resources.

Lastly, designers of AI tutoring systems should focus on creating emotionally intelligent interfaces that promote motivation, alleviate pressure, and foster positive attitudes toward mathematics. This could be achieved by incorporating gamified elements, supportive feedback, and engaging visuals that make mathematical problem-solving more approachable and less intimidating for students.

7. Conclusions

This study utilized a cross-sectional survey design, collecting data from 338 university students using a structured questionnaire. The data were analyzed through Structural Equation Modeling (SEM) with Amos (v. 23). The findings revealed that the AI-based tutoring system positively and directly influenced students' mathematics problem-solving skills. In constructs, mathematics anxiety hurts these skills. Finally, mathematics anxiety was found to negatively moderate the nexus between AI-based tutoring systems and students' problem-solving skills.

8. Limitations

Notwithstanding the study's advantages, several drawbacks must be noted. First, the cross-sectional survey design restricts the capacity to infer causality, even though it helps obtain a snapshot view of the variables. It is impossible to say whether AI-based tutoring systems directly improved students' problem-solving abilities or whether other underlying factors had an impact because the data was gathered all at once. An additional constraint of the extent and applicability of the results. The study only looked at first- and second-year students enrolled in mathematics-related programs at one university, AAMUSTED, in Kumasi, Ghana. The larger population of college students utilizing AI-based tutoring programs or studying mathematics at various academic levels, disciplines, or institutions may not be represented by this sample. Therefore, care should be taken when extrapolating the results to other contexts, such as senior high schools, other geographical locations, or international educational environments with disparate academic, cultural, or technological infrastructure. Finally, despite using stratified and basic random sampling to reduce bias, the study's reliance on quantitative methods prevented it from delving deeply into the subtleties of how mathematics anxiety presents itself in different learning contexts or into students' individual experiences with AI-based tutoring systems. The use of single survey instruments across constructs also raised the possibility of shared method variance, which could have inflated or deflated the relationships among variables, even though efforts were made to mitigate common method bias through procedural and statistical approaches (e.g., Harman's one-factor test).

9. Suggestions for Further Studies

To evaluate how students' abilities to solve mathematical problems have changed over time or to determine the causal links between AI-based tutoring and performance outcomes, future studies should think about using an experimental or longitudinal design. Including more universities and a wider range of programs in the study can improve generalizability and offer a more comprehensive viewpoint on the application of AI in mathematics education. Despite understanding students' attitudes, engagement levels, and real-time interactions with AI tools may also be possible through mixed-methods approaches that incorporate focus groups, interviews, and classroom observations. Finally, to better understand how AL-based tutoring systems affect mathematics learning outcomes, future research should examine additional moderating or mediating factors like students’ digital literacy, teacher support, or intrinsic motivation.

10. Recommendations

Firstly, to promote equity in mathematics education, we recommend that teachers use AI to augment traditional instruction by offering focused support and closing learning gaps, particularly in settings with limited resources. Moreover, teachers should use techniques to lessen math anxiety in the classroom because it has a detrimental effect on students’ ability to solve problems. These include fostering a growth mindset, providing strategies for reducing anxiety, and establishing a nurturing atmosphere. Furthermore, teachers should also use positive reinforcement and low-stakes problem-solving to normalize math difficulties. In the end, this method improves students’ mathematical competency by lowering anxiety, boosting confidence, and fostering an atmosphere where they feel at ease with difficult assignments. Finally, AI-based tutoring systems and anxiety-reduction techniques should be integrated into teacher training programs. They should receive training on how to identify and treat math anxiety, improve problem-solving abilities, and use AI platforms efficiently.

Author contributions: All authors have sufficiently contributed to the study, and agreed with the conclusions.

Data availability: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declaration of interest: No conflict of interest is declared by author.

Ethics statement: All participants provided informed consent prior to their involvement in the study. They were informed about the study's purpose, procedures, and their right to withdraw at any time without consequence.

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References

Adler, J., & Davis, Z. (2006). Opening another black box: Researching mathematics for teaching in mathematics teacher education. *Journal for Research in Mathematics Education*, *37*(4), 270–296.

Alvarez, J. I., Cortez, A. O., & Alberto, M. Z. (2024). Personalized learning in action: Utilizing AI-powered tutors to bridge the gap in mathematics. *International Journal of Research Studies in Education*, *13*(8), 15–25. https://doi.org/10.5861/ijrse.2024.24074

Amoako, T., Sheng, Z. H., Dogbe, C. S. K., & Pomegbe, W. W. K. (2022). Assessing the moderation role of ICT in the relationship between supply chain integration and SME performance. *Journal of Industrial Integration and Management*, *7*(2), 203–233. https://doi.org/10.1142/S2424862221500160

Asare, B., & Boateng, F. O. (2025). Self-awareness and self-regulatory learning as mediators between ChatGPT usage and pre-service mathematics teacher's self-efficacy. *Journal of Pedagogical Research, 9*(2), 38-54. https://doi.org/10.33902/JPR.202530637

Asio, J. M. R., & Gadia, E. D. (2024). Predictors of student attitudes towards artificial intelligence: Implications and relevance to the higher education institutions. *International Journal of Didactical Studies, 5*(2), 27763. https://doi.org/10.33902/ijods.202427763

Banjade, S., Patel, H., & Pokhrel, S. (2024). Empowering education by developing and evaluating generative ai-powered tutoring system for enhanced student learning. *Journal of Artificial Intelligence and Capsule Networks*, *6*(3), 278–298. https://doi.org/10.36548/jaicn.2024.3.003

Barroso, C., Ganley, C. M., McGraw, A. L., Geer, E. A., Hart, S. A., & Daucourt, M. C. (2021). A meta-analysis of the relation between math anxiety and math achievement. *Psychological Bulletin*, *147*(2), 134–168. https://doi.org/10.1037/bul0000307

Caviola, S., Toffalini, E., Giofrè, D., Ruiz, J. M., Szűcs, D., & Mammarella, I. C. (2022). Math performance and academic anxiety forms, from sociodemographic to cognitive aspects: a meta-analysis on 906,311 participants. *Educational Psychology Review*, *34*(1), 363-399. https://doi.org/10.1007/s10648-021-09618-5

Daker, R. J., Gattas, S. U., Sokolowski, H. M., Green, A. E., & Lyons, I. M. (2021). First-year students' math anxiety predicts STEM avoidance and underperformance throughout university, independently of math ability. *Npj Science of Learning*, *6*(1). https://doi.org/10.1038/s41539-021-00095-7

Demedts, F., Reynvoet, B., Sasanguie, D., & Depaepe, F. (2022). Unraveling the role of math anxiety in students' math performance. *Frontiers in Psychology*, *13*, 1–9. https://doi.org/10.3389/fpsyg.2022.979113

Florentine, R. (2023). *The relationship between academic anxiety, metacognition, and academic achievement* [Unpublished master's thesis]. University of Calgary.

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research*, *18*(1), 39. https://doi.org/10.2307/3151312

Guo, Y., Li, X., & Song, S. (2023). A study of college students' openness personality and English learning anxiety. *SHS Web of Conferences*, *171*, 01015. https://doi.org/10.1051/shsconf/202317101015

Halkiopoulos, C., & Gkintoni, E. (2024). Leveraging AI in e-learning: personalized learning and adaptive assessment through cognitive neuropsychology—a systematic analysis. *Electronics*, *13*(18), 3762 https://doi.org/10.3390/electronics13183762

Insorio, J. E. (2025). *Math dance and song: Means to reduce student mathematical anxiety and promote engagement. International Journal of Didactical Studies, 6*(3), Article 32161. https://doi.org/10.33902/ijods.202532161

Khasawneh, E., Gosling, C., & Williams, B. (2021). What impact does maths anxiety have on university students? A scoping review. *BMC Psychology*, *9*, 37. https://doi.org/10.1186/s40359-021-00537-2

Khazanchi, R., Di Mitri, D., & Drachsler, H. (2024). The effect of ai-based systems on mathematics achievement in rural context: a quantitative study. *Journal of Computer Assisted Learning, 41*(1), e13098. https://doi.org/10.1111/jcal.13098

Krejcie, R. V., & Morgan, D. W. (1970). Determining sample size for research activities. *Educational and Psychological Measurement*, *30*(3), 607–610. https://doi.org/10.1177/001316447003000308

Leddo, J., & Garg, K. (2021). Comparing the effectiveness of ai-powered educational software to human teachers . *International Journal of Social Science and Economic Research*, *6*(3), 953–963. https://doi.org/10.46609/ijsser.2021.v06i03.015

Lin, C. C., Huang, A. Y. Q., & Lu, O. H. T. (2023). Artificial intelligence in intelligent tutoring systems toward sustainable education: a systematic review. *Smart Learning Environments*, *10*, 41. https://doi.org/10.1186/s40561-023-00260-y

Liu, J., Sun, D., Sun, J., Wang, J., & Yu, P. L. H. (2025). Designing a generative AI enabled learning environment for mathematics word problem solving in primary schools: Learning performance, attitudes and interaction. *Computers and Education: Artificial Intelligence, 9,* 100438. https://doi.org/10.1016/j.caeai.2025.100438

Lotey, E. K., Boateng, F. O., Arthur, Y. D., Adu-Obeng, B., & Gordon, J. F. (2025). Exploring GeoGebra acceptance: an implication for pre-service mathematics teachers' professional development. *Cogent Education*, *12*(1), 2514980. https://doi.org/10.1080/2331186X.2025.2514980

Mounkoro, I., Rafique, T., Tapia, E. D. L. T., Cadelina, F. A., Uberas, A. D., Karkkulainen, E. A., Vallejo, R. G., & Galingana, C. D. (2024). Ai-powered tutoring systems : revolutionizing individualized support for learners. *Library Progress International, 43*(2), 344–355. https://doi.org/10.48165/bapas.2024.44.2.1

Ng, C. T., Chen, Y. H., Wu, C. J., & Chang, T. T. (2022). Evaluation of math anxiety and its remediation through a digital training program in mathematics for first and second graders. *Brain and Behavior*, *12*(5), 1–17. https://doi.org/10.1002/brb3.2557

Nilimaa, J. (2023). New examination approach for real-world creativity and problem-solving skills in mathematics. *Trends in Higher Education*, *2*(3), 477–495. https://doi.org/10.3390/higheredu2030028

Opesemowo, O. A. G., & Ndlovu, M. (2024). Artificial intelligence in mathematics education: The good, the bad, and the ugly. *Journal of Pedagogical Research*, *8*(3), 333–346. https://doi.org/10.33902/JPR.202426428

Podsakoff, P. M., & Organ, D. W. (1986). Self-reports in organizational research: problems and prospects. *Journal of Management*, *12*(4), 531–544. https://doi.org/10.1177/014920638601200408

Son, T. (2024). Intelligent tutoring systems in mathematics education: a systematic literature review using the substitution, augmentation, modification, redefinition model. *Computers*, *13*(10), 270. https://doi.org/10.3390/computers13100270

Stohlmann, M., & Yang, Y. (2024). Growth mindset in high school mathematics: A review of the literature since 2007. *Journal of Pedagogical Research, 8*(2), 357–370. https://doi.org/10.33902/JPR.202424437

Suvendu, R., & Deb, P. S. (2024). AI-driven flipped classroom: revolutionizing education through digital pedagogy. *British Journal of Education, Learning and Development Psychology*, *7*(2), 169–179. https://doi.org/10.52589/bjeldp-ltdjflih

Ramo, J. P., & Carmen, M. (2025). Unraveling the link : math anxiety's role in the relationship between math self-efficacy and math achievement. *Diversitas Journal*, *10*(1), 259–273. https://doi.org/10.48017/dj.v10i1.2994

Rane, N. (2023). *Enhancing mathematical capabilities through Chatgpt and similar generative artificial intelligence: roles and challenges in solving mathematical problems* (Publicaiton no: 4603237). SSRN Electronic Journal. https://doi.org/10.2139/ssrn.4603237

Rizvi, M. (2023). Investigating ai-powered tutoring systems that adapt to individual student needs, providing personalized guidance and assessments. *The Eurasia Proceedings of Educational and Social Sciences*, *31*, 67–73. https://doi.org/10.55549/epess.1381518

Scheibe, D. A., Was, C. A., Dunlosky, J., & Thompson, C. A. (2023). Metacognitive cues, working memory, and math anxiety: the regulated attention in mathematical problem solving (RAMPS) framework. *Journal of Intelligence*, *11*(6), 117. https://doi.org/10.3390/jintelligence11060117

Simanjuntak, M. P., Hutahaean, J., Marpaung, N., & Ramadhani, D. (2021). Effectiveness of problem-based learning combined with computer simulation on students' problem-solving and creative thinking skills. *International Journal of Instruction*, *14*(3), 519–534. https://doi.org/10.29333/iji.2021.14330a

Soesanto, R. H., Dirgantoro, K. P. S., & Priyanti, N. (2022). Indonesian students' perceptions towards AI-based learning in mathematics. *Journal on Mathematics Education*, *13*(3), 531–548. https://doi.org/10.22342/jme.v13i3.pp531-548

Su, S. W., Hung, C. H., Chen, L. X., & Yuan, S. M. (2024). Development of an ai-based system to enhance school counseling models for asian elementary students with emotional disorders. *IEEE Access*, *12*, 159121–159136. https://doi.org/10.1109/ACCESS.2024.3483456

Szczygieł, M. (2022). Not only reliability!: the importance of the ecological validity of the math anxiety questionnaire for adults. *European Journal of Psychological Assessment*, *38*(2), 78–90. https://doi.org/10.1027/1015-5759/a000646

Trung, L. T. B. T., Thanh Trung, T., & Dung, T. M. (2025). ChatGPT in Vietnamese math classrooms: What are the influencing factors behind teachers' adoption?. *Journal of Pedagogical Research, 9*(2), 72-88. https://doi.org/10.33902/JPR.202531924

Tsiani, M., Lefkos, I., & Fachantidis, N. (2025). Perceptions of generative AI in education: Insights from undergraduate and master's-level future teachers. *Journal of Pedagogical Research, 9*(2), 89-108. https://doi.org/10.33902/JPR.202531943

Ukobizaba, F., Nizeyimana, G., & Mukuka, A. (2021). Assessment strategies for enhancing students' mathematical problem-solving skills: a review of literature. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(3), 1–10. https://doi.org/10.29333/ejmste/9728

Wang, S., Christensen, C., Cui, W., Tong, R., Yarnall, L., Shear, L., & Feng, M. (2023). When adaptive learning is effective learning: comparison of an adaptive learning system to teacher-led instruction. *Interactive Learning Environments*, *31*(2), 793–803. https://doi.org/10.1080/10494820.2020.1808794

Zakariya, Y. F. (2018). Development of mathematics anxiety scale: Factor analysis as a determinant of subcategories. *Journal of Pedagogical Research, 2*(2), 135-144.

Zhang, R., Chen, Z., & Deng, C. (2024). Gender differences in elementary school students' fraction learning: roles of spatial ability and mathematical anxiety. *Frontiers in Psychology*, *15*, 1464501. https://doi.org/10.3389/fpsyg.2024.1464501

Zhou, Y., Ye, X., & Liu, Y. (2022). The influence of personalized learning intervention system on student learning a study of junior middle school. *Interactive Technology and Smart Education*, *19*(4), 441–459. https://doi.org/10.1108/ITSE-10-2021-0192

Živković, M., Pellizzoni, S., Mammarella, I. C., & Passolunghi, M. C. (2022). Executive functions, math anxiety and math performance in middle school students. *British Journal of Developmental Psychology*, *40*(3), 438–452. https://doi.org/10.1111/bjdp.12412

Živković, M., Pellizzoni, S., Mammarella, I. C., & Passolunghi, M. C. (2023). The relationship betweens math anxiety and arithmetic reasoning: The mediating role of working memory and self-competence. *Current Psychology*, *42*(17), 14506–14516. https://doi.org/10.1007/s12144-022-02765-0

Zuo, S., Huang, Q., & Qi, C. (2024). The relationship between cognitive activation and mathematics achievement: mediating roles of self-efficacy and mathematics anxiety. *Current Psychology, 43,* 30794-30805. https://link.springer.com/10.1007/s12144-024-06700-3