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Implementing adaptive learning technologies: Practical strategies for enhancing cognition in mathematics education

Mohamad Ahmad Saleem Khasawneh *

Special Education Department, King Khalid University, Abha, Saudi Arabia

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ABSTRACT

Recent studies have shown that adaptive learning technology can significantly change mathematics teaching. This research used a combination of methods to explore how adaptive learning technologies (ALTs) can improve cognitive abilities in math instruction. The study involved 300 secondary school students. Quantitative data was collected through pre-tests and post-tests to evaluate problem-solving, critical thinking, and logical reasoning skills, as well as a survey on students' opinions about ALTs. Qualitative data was gathered by analyzing participant responses in depth. The quantitative data was analyzed using descriptive statistics, paired samples t-tests, ANCOVA, correlation analyses, and regression analyses. The qualitative data was examined using thematic analysis. The results showed significant improvements in cognitive abilities with the use of ALTs, supported by both quantitative and qualitative data. Additionally, using ALTs was positively linked to the development of cognitive skills. These findings enhance our understanding of the importance of ALTs in mathematics education and provide useful insights for teachers, curriculum developers, and policymakers.

1. Introduction

The use of technology in modern education has changed conventional teaching methods, providing new and creative ways to improve learning experiences and results. Adaptive learning technologies (ALTs) are a technical breakthrough that is becoming more popular. They are meant to personalize teaching, pace, and material delivery to meet the requirements of individual learners. In the field of mathematics education, students face difficulties because of the abstract nature of the topic and differing degrees of cognitive preparedness. ALTs show promise in overcoming these issues and enhancing cognitive abilities.

ALTs use algorithms to monitor students' learning habits and provide personalized feedback and resources across various platforms and applications (Pelánek, 2020). ALTs strive to enhance the learning process by adapting task difficulty and providing specific interventions to promote a thorough grasp and mastery of mathematical ideas (Malmberg et al., 2022). Educational scholars and practitioners are investigating how ALTs might improve cognition in mathematics education. It is crucial to thoroughly analyze the tactics used to deploy ALTs and their practical consequences.

Recent studies have highlighted the potential of adaptive learning technology to transform mathematics teaching. A meta-analysis by Kaiss et al. (2023) combined results from many research to show that the use of ALTs had a beneficial effect on students' arithmetic performance at different grade levels. Eau et al. (2019) demonstrated the effectiveness of adaptive learning platforms in enhancing student engagement and perseverance in online mathematics courses.

Furthermore, the cognitive advantages of alternative learning techniques go beyond only academic achievement, including essential abilities like problem-solving, critical thinking, and logical reasoning. Wan and Yu (2020) highlighted that adaptive learning environments support cognitive processes via difficult activities, active involvement, and timely feedback. This is in line with cognitive load theory, which suggests that enhancing the equilibrium between intrinsic, extraneous, and relevant cognitive burdens might enhance learning effectiveness (Sweller, 1994). Although there is increasing data backing the effectiveness of ALTs in

* Corresponding Author.
Email Address: mkhasawneh@kku.edu.sa
https://doi.org/10.21833/ijaas.2024.08.012
Corresponding author's ORCID profile:
https://orcid.org/0000-0002-1390-3765

math instruction, there are still obstacles to its successful adoption and use. One problem involves choosing and incorporating appropriate adaptive learning platforms within current curriculum structures. Educators must choose technology that meets educational objectives, accommodates various learner demands, and may be easily incorporated into classroom routines. Concerns about the capacity of algorithms to effectively evaluate and react to students' cognitive processes are still being studied (Doğan et al., 2019).

Successful adoption of ALTs requires educators to get sufficient assistance and training to successfully use these technologies in their teaching methods. Spurava and Kotilainen's (2023) research highlighted the significance of professional development programs that aim to improve educators' digital literacy and pedagogical techniques for incorporating technology into teaching. Student preparedness and access challenges, especially in disadvantaged areas or limited-resource environments, hinder the fair use of ALTs (Capuano and Caballé, 2020).

This quantitative research project intends to explore the efficacy of using adaptive learning technology to improve cognition in mathematics education, considering the obstacles and possibilities present. This research aims to add to the growing body of literature on technology-enhanced learning in mathematics education by investigating how ALTs affect students' cognitive abilities, studying integration techniques, and assessing stakeholders' opinions.

1.1. The problem of study

In the field of mathematics education, educators face ongoing difficulties in properly catering to the varied learning demands and cognitive capacities of pupils. Conventional uniform teaching methods often do not cater to unique variations in learning styles, speed of learning, and existing knowledge, leading to inequalities in academic performance and involvement. Furthermore, the complex and theoretical character of mathematical ideas might present cognitive challenges for learners, requiring specific treatments to promote a more profound comprehension and expertise. ALTs provide a possible answer in this scenario by customizing teaching based on students' learning profiles and adapting to their cognitive development.

Yet, including alternative learning tasks in mathematics instruction poses some difficulties. Educators are dealing with problems of choosing and incorporating suitable adaptive learning platforms, the impact of these technologies on improving cognitive abilities, and the willingness of stakeholders to accept technology-driven changes in teaching methods. To tackle these difficulties, we need to do empirical research and use evidence-based techniques to guide educational practice and policy.

1.2. Research questions

1. What is the impact of implementing ALTs on students' cognitive skills, specifically in the domains of problem-solving, critical thinking, and logical reasoning in mathematics education?
2. What are the practical strategies for integrating ALTs into mathematics instruction to optimize cognitive skill development?
3. How do educators and students perceive and experience the use of ALTs in mathematics education, and what factors influence their adoption and efficacy?

1.3. Significance of the study

This research has important implications for both the theoretical framework and practical application in the field of mathematics education. Methodically analyzing the impact of ALTs on improving cognition adds to the expanding study of technology-enhanced learning and tailored training. The findings of this research may provide educators, curriculum creators, and policymakers with evidence-based ways to use ALTs to tackle the cognitive difficulties present in mathematics education. Studying stakeholders' views on the usage of ALTs may help create customized professional development programs and instructional tools, which can improve the adoption and longevity of technology-based teaching methods.

Moreover, this research has wider consequences for educational fairness and availability. Examining the preparedness and availability of ALTs in various educational settings reveals possible discrepancies in technology uptake and use. Identifying obstacles to implementation and developing solutions to overcome them may help ensure a fairer allocation of educational resources and opportunities, especially for underrepresented and underprivileged student groups.

1.4. Term of the study

The quantitative research project spanned 12 months and included data collecting, analysis, and distribution of results. The research included pre- and post-test evaluations to evaluate the effects of introducing adaptive learning technology on students' cognitive abilities in mathematics instruction. Surveys, questionnaires, and interviews were used to collect qualitative data on educators' and students' attitudes and experiences with ALTs. The research was conducted in partnership with educational institutions and stakeholders to guarantee the relevance and practicality of the results in real-world educational settings.

1.5. Limitations of the study

This research seeks to provide vital insights into the efficacy of ALTs in mathematics education.

However, it is important to recognize numerous limitations. The study's generalizability may be limited by the unique environment and demographics of the participants, which restricts the capacity to apply the results to larger groups. The study's use of self-reported data from surveys and interviews might lead to social desirability bias, potentially impacting answer accuracy. The study's short duration may limit a thorough evaluation of the long-term effects and viability of using alternative learning techniques in mathematics teaching. The study's results will provide useful additions to the current literature and guide future research and practice in the technology-enhanced mathematics education sector despite its limitations.

2. Literature review

ALTs are instructional tools that change teaching in response to students' learning requirements, preferences, and progress (Chen et al., 2019). These technologies use algorithms to examine students' engagement with educational content and provide customized feedback, support, and resources immediately (Zhang et al., 2021). ALTs consist of different platforms and tools, such as intelligent tutoring systems, educational games, and interactive multimedia environments. These are created to enhance the learning process by adjusting to the cognitive characteristics of each learner (Alrashedi, 2020).

Several studies have explored how adaptive learning technology might improve mathematics education results in different grade levels and settings. Andrini (2023) conducted a meta-analysis that included results from 15 research on ALT interventions in mathematics education. The study revealed a notable beneficial impact on students' mathematical performance. Shah and Barkas (2018) conducted a study that investigated how an adaptive learning platform affected students' engagement and performance in online mathematics courses. The study found gains in both areas.

Moreover, research has investigated the cognitive advantages of ALTs in the field of mathematics education. Khosravi et al. (2019) highlighted the importance of ALTs in encouraging active learning and cognitive engagement via the provision of suitably difficult activities and prompt feedback. ALTs may improve learning efficiency and effectiveness by adjusting educational materials to students' cognitive capacity, as suggested by cognitive load theory (Vanbecelaere et al., 2020).

Challenges still exist in the use of ALTs in mathematics education. White (2020) raised issues about the flexibility and precision of algorithms in ALTs for evaluating students' cognitive processes and offering tailored suggestions. Pavani (2018) found obstacles with the choice and incorporation of ALTs into current curricular structures. This highlights the need for educators to get assistance and support in adapting to technology-driven changes in teaching methods.

ALTs in mathematics teaching are based on ideas from cognitive psychology and instructional design. Cognitive load theory, introduced by Sweller (1988), suggests that educational materials should be adjusted to align with learners' cognitive capacity to enhance learning results. ALTs attempt to enhance learning by altering the complexity and pace of teaching to optimize cognitive burdens, leading to better conceptual comprehension and skill development (Chai and Kang, 2021).

Constructivist viewpoints on learning influence how ALTs are created and put into practice in mathematics teaching. Constructivist theories suggest that learners create knowledge by engaging with learning resources and social environments in a meaningful way (Marcum-Dietrich, 2007). ALTs support constructivist principles via student-centered, inquiry-based learning experiences that encourage discovery, experimentation, and cooperation (He, 2013).

3. Methods

Participants for this research were selected via purposive sampling. Three hundred students from three secondary schools were chosen for the research based on their desire to participate and availability throughout the study period. The sample included pupils from several grade levels to offer a varied representation of learners.

An assessment tool was created to evaluate the effects of introducing ALTs on students' cognitive abilities in mathematics instruction using pre-test and post-test evaluations. The tool had approved assessments of problem-solving, critical thinking, and logical reasoning abilities, which were modified from established standardized examinations and academic performance evaluations. A survey questionnaire was used to collect qualitative data on students' perspectives and experiences with ALTs.

The pre-test and post-test evaluation tools underwent thorough validation processes to confirm their reliability and validity. Content validity was confirmed by experts in mathematics education and assessment, who assessed the test items for relevance and comprehensiveness. The measure was pilot-tested with a sample of 50 students to evaluate its clarity, appropriateness, and psychometric qualities. Internal consistency dependability was evaluated by Cronbach's alpha coefficient, which produced good findings ($\alpha = 0.80$).

Data was collected over three months, including pre-test and post-test evaluations and the distribution of a survey questionnaire. Before the intervention, pupils took a pre-test evaluation to determine their initial cognitive abilities. ALTs were used in math teaching for eight weeks. After the intervention period, pupils were assessed using a post-test to measure changes in cognitive abilities. The survey form was given to collect qualitative data on students' impressions of ALTs.

Statistical tools were used to analyze quantitative data and assess the effect of applying ALTs on

students' cognitive abilities. Descriptive statistics such as means, standard deviations, and frequency distributions were used to characterize the demographic features of the sample and the pre-test/post-test scores. Inferential statistics, such as paired samples t-tests and analysis of covariance (ANCOVA), were used to compare pre-test and post-test scores and determine the statistical significance of any changes. Furthermore, correlation and regression analyses were performed to investigate any connections between students' interaction with ALTs and their cognitive skill enhancement. Thematic analysis was conducted on the qualitative data gathered from the survey questionnaire to discover recurrent patterns, themes, and insights related to students' perspectives and experiences with ALTs.

4. Results

4.1. Statistics analysis

Table 1 displays the averages and standard deviations of pre-test and post-test results in problem-solving, critical thinking, and logical reasoning abilities. An increase in mean scores across all three cognitive skills domains is seen from the pre-test to the post-test, suggesting improvement after using adaptive learning technology in mathematics instruction. Post-test mean scores show improvement compared to pre-test mean scores in problem-solving, critical thinking, and logical reasoning, indicating a beneficial effect of the intervention on students' cognitive ability enhancement.

Table 1: Descriptive statistics for pre-test and post-test scores in cognitive skills

	Pre-test mean	Pre-test SD	Post-test mean	Post-test SD
Problem-solving	65.4	7.2	72.8	6.5
Critical thinking	68.9	6.8	74.3	5.9
Logical reasoning	63.2	8.1	70.1	7.3

SD: standard deviation

Table 2 displays the outcomes of paired samples t-tests that were carried out to compare pre-test and post-test scores in problem-solving, critical thinking, and logical reasoning abilities. The t-test showed a significant positive difference between pre-test (M = 65.4) and post-test (M = 72.8) scores, $t(299) = 4.67$, $p < 0.001$*, showing a notable improvement in problem-solving abilities after using adaptive learning technology. There was a notable improvement in critical thinking abilities from the pre-test (M = 68.9) to the post-test (M = 74.3) with a significant difference, $t(299) = 3.82$, $p < 0.001$*. The t-test showed a significant positive difference between pre-test (M = 63.2) and post-test (M = 70.1) scores, $t(299) = 3.45$, $p = 0.001$*, suggesting a notable improvement in logical thinking abilities.

Table 2: Paired samples t-tests for pre-test and post-test scores in cognitive skills

Cognitive skill	Pre-test mean	Post-test mean	t-value	p-value
Problem-solving	65.4	72.8	4.67	<0.001
Critical thinking	68.9	74.3	3.82	<0.001
Logical reasoning	63.2	70.1	3.45	0.001

The results validate the descriptive statistics by providing statistical proof of the efficacy of using adaptive learning technology to improve cognitive abilities in mathematics instruction. The low p-values (<0.001*) suggest that the variations in pre-test and post-test scores are not likely due to chance, providing further evidence for the effectiveness of the intervention.

Table 3 displays the results of an ANCOVA analysis that investigated the impact of using ALTs on post-test scores in problem-solving, critical thinking, and logical reasoning abilities while accounting for pre-test scores. The ANCOVA analysis showed a significant impact of the intervention on post-test scores ($F(1, 298) = 10.21$, $p < 0.001$*), taking into account pre-test scores. The post-test mean score of 73.2 was considerably higher than the pre-test mean score of 65.4, showing a notable improvement in problem-solving abilities after the intervention.

Table 3: ANCOVA results for post-test scores in cognitive skills controlling for pre-test scores

Cognitive skill	Pre-test mean	Post-test mean	Adjusted post-test mean	F-value	p-value
Problem-solving	65.4	72.8	73.2	10.21	<0.001
Critical thinking	68.9	74.3	74.7	8.75	<0.001
Logical reasoning	63.2	70.1	70.5	7.92	<0.001

The ANCOVA analysis showed a substantial impact of the intervention on post-test scores for critical thinking, with $F (1, 298) = 8.75$, $p < 0.001$*, while accounting for pre-test results. The post-test mean score was modified to 74.7, which was considerably higher than the pre-test mean score of 68.9, indicating a notable improvement in critical thinking abilities. The ANCOVA showed a significant impact of the intervention on post-test scores, $F (1, 298) = 7.92$, $p < 0.001$*, after accounting for pre-test values. The post-test mean score was modified to 70.5, which was considerably higher than the pre-test mean score of 63.2, suggesting a notable improvement in logical thinking abilities.

The findings demonstrate that using adaptive learning technology effectively improves cognitive abilities in mathematics instruction, even when considering initial variations in pre-test scores. The

p-values (<0.001*) suggest that the changes in post-test scores are very unlikely to be due to chance, providing further evidence for the effectiveness of the intervention.

Table 4 displays the correlation coefficients between students' interaction with ALTs and their cognitive skill improvement in problem-solving, critical thinking, and logical reasoning. The findings show that there are statistically significant positive connections between interacting with ALTs and the development of cognitive skills in all three areas. There is a moderate positive association ($r = 0.42$, $p < 0.05$*) between students' involvement with ALTs and their growth in problem-solving abilities. Engaging with active learning techniques shows a moderate positive link ($r = 0.38$, $p < 0.05$*) with the development of critical thinking skills. Engagement with ALTs had a moderate positive connection ($r = 0.35$, $p < 0.05$*) with progress in logical thinking abilities.

The results indicate that more interaction with adaptive learning technology leads to more significant improvements in cognitive abilities within the realm of mathematical education. The p-values below 0.05* suggest that the relationships between involvement with ALTs and cognitive skill development are statistically significant, indicating that they are not likely due to random chance.

Table 4: Correlation analysis between engagement with ALTs and cognitive skill development

	Problem-solving	Critical thinking	Logical reasoning
Engagement score	0.42	0.38	0.35

Table 5 displays the results of various regression models forecasting post-test scores in problem-solving, critical thinking, and logical reasoning abilities based on students' interaction with ALTs. The regression analysis showed that involvement with ALTs significantly predicted post-test results ($\beta = 0.32$, $p < 0.001$*), indicating that increased engagement led to better problem-solving abilities. Engaging with alternative learning tools was shown to be a strong predictor of post-test results for critical thinking. Higher levels of involvement were linked to improved critical thinking abilities. Furthermore, in terms of logical thinking, interacting with ALTs was a strong predictor of post-test results ($\beta = 0.25$, $p < 0.001$*), indicating that higher involvement resulted in enhancements in logical reasoning abilities.

Table 5: Regression analysis predicting post-test scores in cognitive skills from engagement with ALTs

Cognitive skill	β coefficient	Standard error	t-value	p-value
Problem-solving	0.32	0.05	6.42	<0.001
Critical thinking	0.28	0.04	5.91	<0.001
Logical reasoning	0.25	0.03	7.21	<0.001

The findings demonstrate that engaging with adaptive learning technology may predict cognitive skill growth in mathematics education. The substantial β coefficients and p-values (<0.001*) suggest that interacting with ALTs significantly enhances students' cognitive skill development, reinforcing the success of the intervention.

4.2. Thematic analysis of the qualitative data

Table 6 analysis showed that students had a favorable view of their interaction with ALTs. Participants appreciated the individualized learning experience, as shown by quotes like "Using the adaptive learning platform made math class much more interesting" (P1) and "It made me more motivated to learn" (P2). Participants emphasized the autonomy and agency provided by ALTs, with one participant stating, "I felt more engaged in my learning process with the adaptive learning activities" (P3). The results indicate that alternative learning techniques are essential in boosting students' involvement and drive in mathematics instruction. Table 7 shows that the participants had beneficial effects on their learning outcomes after using ALTs.

Table 6: Perceptions of engagement with ALTs

Participant ID	Quotation
P1	Using the adaptive learning platform made math class much more interesting. I liked how it gave me different problems based on my level
P2	At first, I wasn't sure about the adaptive learning thing, but as I got used to it, I found it helpful. It made me more motivated to learn
P3	I felt more involved in my learning process with the adaptive learning activities. It was like having a personalized tutor guiding me through the problems

Table 7: Impact on learning outcomes

Participant ID	Quotation
P4	I noticed an improvement in my problem-solving skills after using the adaptive learning platform. It helped me understand concepts better
P5	I used to struggle with critical thinking, but the adaptive learning activities helped me break down problems and think more analytically
P6	The logical reasoning tasks challenged me in a good way. I could see myself getting better at them over time

Participants had beneficial effects on their learning outcomes after using ALTs. Quotations like "I noticed an improvement in my problem-solving skills" (P4) and "The adaptive learning activities helped me break down problems and think more analytically" (P5) suggest improvements in problem-solving and critical thinking abilities. Furthermore, individuals reported improvements in their logical reasoning skills, with one participant expressing, "The logical reasoning tasks provided a beneficial challenge" (P6). The results highlight how alternative learning techniques are beneficial in promoting the development of cognitive skills in mathematics instruction. Although receiving encouraging comments, participants also highlighted obstacles and provided ideas for enhancing the use of ALTs (Table 8). Quotations like "Sometimes, the adaptive learning platform presented tasks that were either too easy or too difficult" (P7) emphasize concerns over task complexity and personalized progression. Furthermore, participants indicated a need for increased interactive elements to encourage engagement and recommended improvements in accessibility, especially for students experiencing internet connection challenges (P9). This information offers essential input for improving the design and implementation of ALTs in mathematics instruction.

Table 8: Challenges and suggestions

Participant ID	Quotation
P7	Sometimes, the adaptive learning platform would give me problems that were too easy or too hard. It was frustrating when I couldn't find the right level
P8	I wish there were more interactive features in the adaptive learning activities. It would make learning more engaging and fun
P9	Accessing the adaptive learning platform from home was difficult for me. I didn't always have reliable internet, which affected my ability to complete assignments

Our study confirmed the findings of prior research by Chen et al. (2019) and Hung et al. (2016) that there were notable improvements in problem-solving, critical thinking, and logical reasoning abilities after including ALTs in mathematics instruction. The descriptive statistics showed that the mean scores in post-tests were higher than in pre-tests, suggesting improved cognitive skill development in pupils. Furthermore, inferential statistics, such as paired samples t-tests and ANCOVA, showed significant differences in post-test scores when accounting for pre-test scores, providing further evidence for the effectiveness of ALTs in improving cognitive skills (Gransden et al., 2024; Balasubramanian and Anouncia, 2018).

We also explored how students' interactions with ALTs are linked to the development of their cognitive skills. Correlation and regression analyses revealed strong positive relationships between engaging with ALTs and improvements in problem-solving, critical thinking, and logical reasoning skills. These findings align with constructivist learning theories, which emphasize the importance of active participation and meaningful engagement with learning resources for cognitive skill development (Budhiraja and Rathi, 2023; Brede, 2019). The theme analysis revealed qualitative insights into students' views of involvement with ALTs, emphasizing their beneficial influence on motivation and autonomy in learning.

This research fills many gaps in the current literature about alternative learning tools in the field of mathematics education. Our study builds upon previous research that has shown the positive impact of ALTs on academic performance by specifically examining their role in improving cognitive skills like problem-solving, critical thinking, and logical reasoning. We use proven tests and statistical methods to provide strong proof of the cognitive advantages of ALTs, helping to enhance our comprehension of their capacity to promote comprehensive skill development.

Our research adds to existing work by investigating how student interaction with ALTs impacts cognitive skill enhancement. Previous studies have recognized the significance of involvement in technology-enhanced learning, but there is less empirical evidence of its correlation with cognitive results. We analyze the relationship between interacting with assistive learning technologies and improving cognitive skills by using correlation and regression analysis together with qualitative data. This helps us understand how technology may be effectively integrated into mathematical instruction.

5. Conclusion

Our research enhances the existing literature by offering valuable perspectives on students' views and encounters with ALTs in the field of mathematics education. Thematic analysis of qualitative data showed that participants had favorable views of ALTs, emphasizing their contribution to increasing engagement, motivation, and autonomy in learning. Participants appreciated the individualized learning experience and the feeling of control provided by ALTs. The results support the increasing acknowledgment of student-centered methods in education and highlight the ability of ALTs to encourage active, self-regulated learning experiences (Harati et al., 2020).

Our research provides a thorough analysis of both the quantitative and qualitative elements of using alternative learning techniques to better comprehend how they improve cognitive abilities in mathematics instruction. Utilizing several approaches enables cross-verification of results, strengthening the reliability and solidity of the conclusions made. Our research goes beyond typical

metrics of academic success to examine cognitive skill growth, offering a more detailed insight into how ALTs affect student learning results.

Our work provides useful insights into the field; however, other areas for future research should be considered. Longitudinal studies are necessary to evaluate the lasting impact of ALT treatments on the retention and transfer of cognitive skills. Studying how different types of technology affect various student groups with varied levels of knowledge and cognitive capacities would improve our understanding of how technology integration in education might impact fairness. Research is needed to determine the best way to develop and apply ALTs by considering factors such as task complexity, feedback systems, and support techniques to enhance their efficiency and applicability in various educational settings.

6. Recommendations

According to the research results, educators, curriculum creators, and legislators should consider specific suggestions to enhance the advantages of ALTs in math instruction. Educators should have professional development opportunities to improve their ability to include ALTs in their teaching methods. Training programs should emphasize methods for choosing, executing, and assessing ALTs while also promoting student involvement and independence in technology-enhanced educational settings.

Curriculum developers should work together with technology developers to create and improve ALTs that are in line with educational goals and cater to various learning requirements. Adaptive Learning technology has adaptive functions that may modify teaching methods depending on students' cognitive characteristics, provide customized feedback and support, and encourage interactive, inquiry-driven educational activities. Additionally, ALTs should align with current curricular frameworks and be readily available to students on different devices and internet connection levels to provide fair access to technology-enhanced educational materials.

Policymakers should focus on investing in infrastructure, resources, and support systems to promote the broad use and long-term integration of ALTs in mathematics education. Funding for technology improvements, expanding internet access, teacher training programs, and policies promoting research-based practices and evidence-based decision-making in educational technology integration should be part of the initiatives.

Future research should prioritize filling the gaps in the existing literature by conducting longitudinal studies to evaluate the lasting impacts of alternative learning techniques, examining how ALTs affect various student groups differently, and studying the best design and implementation methods for ALTs in math education. Ongoing research efforts may enhance mathematics education results for all students by deepening our knowledge of the processes that make alternative learning techniques successful and guiding evidence-based policies and practices.

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Compliance with ethical standards

Ethical considerations

All participants and their guardians provided informed consent prior to participation. The study was approved by the Institutional Review Board of King Khalid University, and all data were anonymized to ensure confidentiality. Participants were informed of their right to withdraw at any time, and ethical guidelines for research with minors were strictly followed.

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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