# Leveraging Artificial Intelligence to Enhance Mathematics Education and Overcome Instructional Challenges

## Aprovechar la inteligencia artificial en la enseñanza de las matemáticas para abordar los retos didácticos

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### Highlights

- The integration of AI-powered tools enhances both instructional effectiveness and student learning outcomes in mathematics.
- A quasi-experimental study with 100 high school students demonstrated significantly higher math performance in the group that used AI-based support compared to the control group.
- AI applications in mathematics education support students' problem-solving abilities and improve their conceptual understanding.

Innovaciencia ISSN: 2346-075X

E- ISSN: 2346-075X
Innovaciencia 2025; 13(1);e5075
http://dx.doi.org/10.15649/2346075X.5075

ORIGINAL RESEARCH

**How to cite this article:**
Hetmanenko L., Khoruzha L. Leveraging Artificial Intelligence in Mathematics Education for Addressing Didactic Challenges, Innovaciencia 2025 (13);e5075
http://dx.doi.org/10.15649/2346075X.5075

**Received:** 18 March 2025
**Accepted:** 26 June 2025
**Published:** 29 August 2025

**Keywords:**

Artificial intelligence; Didactic tasks; Information technology; Mathematics; Teaching mathematics.

**Palabras clave:**

Inteligencia artificial; Tareas didácticas; Tecnología de la información; Matemáticas; Enseñanza de las matemáticas.

### ABSTRACT

**Introduction.** Mathematics has played a foundational role in the development of computer science, and its teaching now faces the challenge of integrating digital technologies—particularly artificial intelligence (AI)—for educational purposes. **Objective.** This study aims to evaluate the effectiveness of an AI-based tool in school-level mathematics instruction, particularly in addressing didactic challenges. **Materials and Methods.** A quasi-experimental, mixed-methods design was implemented during the 2023–2024 academic year with a sample of 100 secondary school students in Kyiv. Pre- and post-test results were compared between a control group and an experimental group that used the Photomath application. Additionally, a student perception survey was conducted. **Results.** The experimental group showed a statistically significant improvement in mathematics performance ($p < 0.001$) compared to the control group. Furthermore, 82% of students reported increased motivation, and 90% stated that Photomath facilitated their learning. These findings suggest that AI can serve as an effective support in the teaching and learning process. **Conclusions.** Integrating AI into mathematics education requires adaptations in curricula and teaching methodologies to meet the demands of today's digital learning environments. When supported by proper teacher training and pedagogical frameworks, AI can enhance student understanding, motivation, and academic achievement.

### RESUMEN

**Introducción.** Las matemáticas han sido fundamentales para el desarrollo de la informática, y su enseñanza enfrenta actualmente el reto de integrar tecnologías digitales, especialmente herramientas de inteligencia artificial (IA), con fines pedagógicos. **Objetivo.** Determinar la eficacia de una herramienta basada en IA en la enseñanza escolar de las matemáticas, en particular en la resolución de problemas didácticos. **Materiales y métodos.** Se implementó un diseño cuasi-experimental con enfoque mixto (cuantitativo y cualitativo) durante el año académico 2023–2024, con una muestra de 100 estudiantes de secundaria en Kyiv. Se compararon los resultados de pre y post-test entre un grupo control y uno experimental que utilizó la aplicación Photomath, junto con una encuesta sobre percepciones estudiantiles. **Resultados.** El grupo experimental mostró una mejora significativa en el rendimiento matemático ($p < 0.001$) en comparación con el grupo control. Además, el 82 % de los estudiantes reportó mayor motivación, y el 90 % afirmó que la herramienta facilitó su aprendizaje. Estos hallazgos sugieren que la IA puede ser una aliada efectiva en el proceso de enseñanza-aprendizaje. **Conclusiones.** La integración de IA en la enseñanza de las matemáticas requiere ajustar programas y metodologías para responder a las necesidades del entorno digital actual. Su uso puede mejorar la comprensión, la motivación y el rendimiento estudiantil, siempre que se cuente con formación docente adecuada y un marco pedagógico sólido.



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## INTRODUCTION

As computer science has sought to define its identity as a discipline over the years, it has partly lost touch with its foundational roots. Simultaneously, the increasing focus on theoretical mathematics has led to challenges regarding the employability of graduates and their lack of practical skills [(1)]. In response, educational stakeholders from computer science, telecommunications, and mathematics are beginning to recognize the importance of restoring and strengthening the connections between these fields [(2)].

To address these concerns, alternative pedagogical approaches have emerged, involving curricular redesign and the integration of technological tools aimed at increasing student engagement [(3-5)]. These initiatives include the inclusion of programming courses and the modernization of traditional subjects—such as linear algebra, mathematical analysis, differential and difference equations, and probability theory—through specialized laboratories and instructional methods that emphasize visualization and practical application from the outset of university studies.

In this context, artificial intelligence (AI), defined as "intelligence demonstrated by machines," in contrast to natural intelligence [(6)], has gained relevance as an educational tool. AI can also be characterized by its capacity to understand, learn, and apply acquired knowledge in new situations [(7-9)]. From a technical standpoint, AI is a branch of computer science that investigates the principles underlying human cognitive behavior and develops systems capable of emulating such processes [(10)]. Consequently, AI is emerging as a valuable resource for education, enabling the simulation of human-like reasoning and adaptive behavior.

Its integration into education has occurred rapidly, as evidenced by the widespread adoption of ChatGPT among students for completing homework assignments [(11-12)]. This phenomenon has elicited varied institutional responses, from premature prohibitions to more thoughtful pedagogical debates concerning the role of homework in modern education [(13)]. Beyond these controversies, it is essential to assess the extent to which tools like ChatGPT can streamline repetitive tasks and free up time for more creative, reflective, and authentic knowledge construction.

AI offers broad pedagogical potential. It supports the generation of customized textual materials—including articles, summaries, and explanatory notes—adaptive assessment tools tailored to individual comprehension levels, and personalized instructional programs aligned with students' strengths and weaknesses. Additionally, AI facilitates the development of multimedia resources, such as podcasts, animations, and educational chatbots designed to simulate interactive learning environments [(14)]. Nonetheless, most of these applications have been explored in general educational contexts or in disciplines other than mathematics.

Recent research has begun to address the specific use of AI in mathematics education. For instance, Opesemowo and Ndlovu [15] identified both benefits, such as increased student interest and collaboration, and drawbacks, including technology dependency and a decline in autonomous problem-solving skills. Similarly, bin Mohamed et al. [16], through meta-analysis, observed a geographic concentration of empirical studies in the United States and Mexico, highlighting the need for broader international research in diverse educational settings.

In countries like China, policy-level strategies advocate for AI integration across all educational stages, often without differentiation among disciplines [17]. Studies on AI in biology (Netherlands) [18], history (Germany) [19], and chemistry (Australia, United States, China) [20-21] report encouraging outcomes, but their findings cannot be directly extrapolated to mathematics without subject-specific analysis. Furthermore, research by Li [22] in China, Egara and Mosimege [23] in Africa, and Nti-Asante [24] in the United States underscores the need for teacher training in AI tools and reveals a positive impact of AI on students' perception and understanding of mathematics.

Despite the growing interest, a review of the literature reveals that the effectiveness of AI in mathematics education remains underexplored, as most existing research focuses on other academic disciplines. However, mathematics education cannot afford to lag behind in the ongoing process of digitalization. This necessitates renewed investigations into how AI technologies can specifically enhance mathematics instruction, particularly in addressing pedagogical challenges. Although numerous international studies examine AI's role in education, relatively few offer rigorous, quantitative assessments of its direct impact on mathematics learning outcomes. This gap underscores the urgent need for focused empirical research.

Accordingly, the present study seeks to evaluate the effectiveness of artificial intelligence in school-level mathematics education, with particular emphasis on its capacity to support the resolution of didactic challenges and to improve students' academic performance through tools such as Photomath.

## MATERIALS AND METHODS

### Research Design and Sample

This study employed a quasi-experimental design incorporating both quantitative and qualitative methods. During the 2023–2024 academic year, pre- and post-intervention assessments were conducted at a secondary school in Kyiv to evaluate the use of the AI-powered Photomath application in solving didactic tasks. These assessments were administered during mathematics classes for high school students (grades 9 to 11). A total of 100 students participated by completing online instruments. Participants were randomly selected based on their level of mathematical knowledge. The sample consisted of students with comparable average scores in mathematics at the basic (intermediate) level, ensuring data consistency across the group. Gender distribution was balanced within both groups: 65% female and 35% male, eliminating gender as a confounding factor.

## Tool Description

Photomath is an artificial intelligence-based mobile application that allows users to scan mathematical equations using a smartphone camera and receive step-by-step solutions with detailed explanations. The key features employed in this study included: i) Scanning of printed and handwritten math problems; ii) Step-by-step solution breakdowns; iii) Handwriting recognition; iv) Interactive graph plotting of functions; v) A user-friendly interface facilitating quick access to solutions. The application was regularly used during lessons to support students in solving algebraic and arithmetic problems (**Figure 1**).

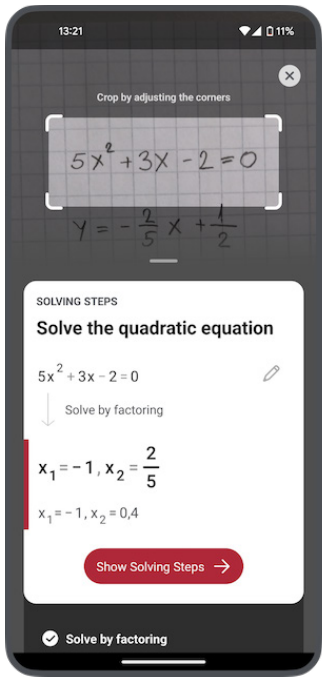


**Figure 1. User interface of the artificial intelligence application used to solve quadratic equations.**

## Experimental Design

Participants were divided into two groups: an experimental group (n = 50) and a control group (n = 50). The control group followed a traditional mathematics curriculum without the use of AI tools, while the experimental group incorporated Photomath into classroom instruction. Students' mathematical knowledge was assessed both before and after the intervention using a standardized 100-point scale. Photomath served as a supplementary tool for the experimental group, integrated under teacher supervision.

## Complementary Qualitative Study

In parallel with the quasi-experimental design, a student survey was conducted to explore perceptions of AI tools in mathematics education and to better understand student motivation and engagement in a technology-enhanced learning environment.

### Data Analysis and Statistical Processing

Data analysis was performed using SPSS software (version 21.0). Paired and unpaired t-tests were used to compare students' mathematical knowledge before and after the intervention. Additionally, Levene's test for equality of variances was employed to evaluate differences between the experimental and control groups.

### Methodological Limitations

The study's primary limitations included the relatively small sample size (100 students) and the restriction to a single school in Kyiv, which limited the generalizability of findings across geographic locations or school types (urban vs. rural). Furthermore, the focus on high school students with intermediate-level mathematics proficiency constrained the scope of the results.

An additional limitation was the complexity and resource intensity required to validate theoretical findings in a broader student population across multiple educational institutions. Future research should aim to explore the potential of digital tools—particularly AI—through large-scale studies involving diverse educational contexts and extended timeframes.

## RESULTS

Table 1 presents the pre- and post-test scores of the experimental and control groups. The statistical analysis included calculations of mean, standard deviation, and median scores.

**Table 1. Descriptive Statistics of Pre- and Post-test Scores in Control and Experimental Groups**

| Parameter | Experimental Pre-test | Experimental Post-test | Control Pre-test | Control Post-test |
|---|---|---|---|---|
| **Mean** | 77.60 | 86.94 | 78.26 | 78.05 |
| **N** | 100 | 100 | 100 | 100 |
| **Standard deviation** | 6.774 | 6.453 | 6.574 | 7.181 |
| **Median** | 77.00 | 87.00 | 78.00 | 78.00 |

A paired samples t-test revealed a statistically significant improvement in the experimental group ($p < 0.001$), whereas no significant change was observed in the control group ($p = 0.812$). An independent samples t-test comparing post-test results between groups also showed a statistically significant difference ($p < 0.001$).

Further analysis using paired samples t-tests provided detailed comparisons of pre- and post-test scores within each group. For the control group, the mean difference was 0.21 points, with a standard deviation of 2.924 and a standard error of 0.207. The 95% confidence interval ranged from -0.198 to 0.618. A t-statistic of 1.016 with 199 degrees of freedom resulted in a two-tailed $p$-value of 0.311, indicating no significant change. In contrast, the experimental group showed a significant improvement of 9.34 points, with a 95% confidence interval between -9.765 and -8.915 (**Table 2**).

**Table 2. Comparison of Pre- and Post-test Scores Within Groups (Paired Samples t-test)**

| Comparison | Pairwise differences | | | | | t | df | p (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | SE | 95% CI Lower | 95% CI Upper | | | |
| **Control**: Pre-test – Post-test | 0.210 | 2.924 | 0.207 | -0.198 | 0.618 | 1.016 | 199 | 0.311 |
| **Experimental:** Pre-test – Post-test | -9.340 | 3.045 | 0.215 | -9.765 | -8.915 | -43.381 | 199 | 0.000 |

**SD**= Standard deviation; **SE**= Standard Error **CI** = Confidence Interval; ***t*** = t-value (Student's t-test statistic); **df** = degrees of freedom; ***p*** = p-value, (2-tailed significance)

Independent samples t-tests were also conducted to compare the control and experimental groups before and after the intervention, evaluating both mean scores and variance assumptions (**Table 3**).

**Table 3. Independent samples t-test results (equality of means and variances)**

| Comparison | Levene's F | p (F) | t | df | p (2-tailed) | Mean Difference | Std. Error | 95% CI Lower | 95% CI Upper |
|---|---|---|---|---|---|---|---|---|---|
| **Pre-test: Control vs Experimental** (equal variances assumed) | 0.065 | 0.798 | 0.981 | 398 | 0.327 | 0.655 | 0.667 | -0.657 | 1.967 |
| **Pre-test: Control vs Experimental** (equal variances not assumed) | | | 0.981 | 397.6 | 0.327 | 0.655 | 0.667 | -0.657 | 1.967 |
| **Post-test: Control vs Experimental** (equal variances assumed) | 0.547 | 0.460 | -13.030 | 398 | 0.000 | -8.895 | 0.683 | -10.237 | -7.553 |
| **Post-test: Control vs Experimental** (equal variances not assumed) | | | -13.030 | 393.5 | 0.000 | -8.895 | 0.683 | -10.237 | -7.553 |

***p*** (F) = p-value from the F-test for homogeneity of variances, ***t*** = t value (Student's t-test statistic); **df** = degrees of freedom; ***p*** = p-value, (2-tailed significance), **CI** = Confidence Interval.

Levene's test confirmed the assumption of equal variances for both the pre- and post-test scores. The t-test for equality of means showed no significant differences between groups at baseline. However, post-test results indicated a statistically significant difference between the control and experimental groups. The mean difference of 8.895 points with a standard error of 0.683 was consistent across both variance assumptions, as confirmed by the 95% confidence interval.

### Complementary Qualitative Results

The qualitative survey administered to the experimental group included the following items: i) Did Photomath increase your motivation in math lessons; ii) Did you understand math concepts better with step-by-step explanations?; iii) Did you manage to detect and correct your own mistakes using the app; iv) Did Photomath help you learn more effectively overall?. Results indicated that 82% of students responded positively to the first question, 75% to the second, 68% to the third, and 90% to the fourth. These outcomes highlight how students perceived the AI tool as a facilitator of motivation, comprehension, self-correction, and general learning effectiveness. This qualitative feedback complements the quantitative results, indicating that the integration of Photomath not only improved academic outcomes but also fostered positive attitudes and greater autonomy in the learning process.

## DISCUSSION

This study provides robust empirical evidence supporting the effectiveness of artificial intelligence (AI) tools—specifically Photomath—in improving mathematics learning outcomes within real-world school settings. Unlike broader studies addressing general AI use in education, this research focuses on a single resource, allowing for a more detailed analysis of its immediate instructional impact and pedagogical implications.

Statistical analysis revealed significant improvements in the experimental group's scores following the intervention, compared to the stable performance in the control group. This difference reinforces the hypothesis that integrating AI can effectively complement traditional teaching methods. These findings align with recent research showing that AI-based interactive learning systems promote personalized learning, increase student engagement, and enhance problem-solving abilities [(1-4, 15-16, 27, 29-30, 34-36)].

The comparable baseline scores between groups confirm initial equivalence. The observed post-test improvement exclusively in the AI-supported group suggests a strong association between the intervention and academic progress, although the quasi-experimental design cautions against asserting direct causality, as also noted in the context of AI-driven educational systems at the university level [(26)]. This supports previous findings that AI can serve mathematical learning processes effectively [(37)].

In addition to the quantitative analysis, a complementary student survey enriched the study with qualitative insights into learner perceptions of AI use. This dimension adds valuable understanding regarding the motivational, autonomous, and perceptual effects of AI, echoing findings from recent studies on ChatGPT and other AI systems [(4-5, 13, 23)].

This study also contributes to the discourse on scalability and cultural contextualization of AI in education. Conducted in an Eastern European secondary school, it broadens the geographic and cultural base of AI-in-education research, which is typically concentrated in Western contexts [(14, 16, 18, 39)]. This highlights the potential for AI tools to be effectively adapted across different educational systems and demographic profiles. These findings reaffirm the evolving role of mathematics in AI-enhanced educational environments [(40)].

The findings offer practical implications for educators and institutional decision-makers. Integrating AI tools such as Photomath into classroom practice can support differentiated instruction and provide additional scaffolding for students with diverse learning needs. However, successful implementation requires alignment with teacher training programs. Equipping educators with the knowledge and skills to meaningfully incorporate AI into pedagogical strategies will maximize the benefits of these technologies (22-23, 38).

Nevertheless, AI integration also presents ethical and pedagogical challenges. Excessive reliance on AI may reduce the development of independent learning and critical thinking skills, and raise concerns about data privacy (6, 9, 11). Establishing clear ethical guidelines and preparing educators for responsible use is essential.

While the results are promising, they should be interpreted with caution given methodological limitations such as sample size, geographic scope, and the absence of longitudinal tracking. Future research should explore the application of AI tools in other subject areas (31), analyze their impact on diverse demographic groups, and incorporate qualitative methods—such as interviews or focus groups—to gain deeper insights into the experiences and perceptions of students and teachers (24-25, 28, 31, 41).

## CONCLUSION

This study confirms that AI tools like Photomath can significantly enhance mathematics learning when thoughtfully integrated into instructional practice. The findings support their value as complementary educational resources, especially in diverse learning environments. While the outcomes are promising, further research is needed to evaluate their long-term impact and broader applicability, ensuring the responsible and effective adoption of AI in education.

## ETHICAL CONSIDERATIONS

This study complied with established ethical guidelines for research involving human participants. Informed consent was obtained from the parents or legal guardians of all student participants. Students were clearly informed of their right to withdraw from the study at any point without consequence. Anonymity and confidentiality were strictly maintained throughout data collection and analysis.

## FUNDING

This research was carried out with the support of the Institute of In-Service Teachers' Training and Borys Grinchenko Kyiv Metropolitan University

## DECLARATION OF COMPETING INTEREST

The authors have declared no conflict of interest.

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