Revista de Bioética Latinoamericana / Año 2026 / Volumen 31, Numero 2: Pagina 92-103
ISSN: 2244-7482 LATINDEX 19.850
Rev Bioet Latinoam. 2026; 31 (2): 92-103

ARTIFICIAL INTELLIGENCE IN MATHEMATICS EDUCATION THROUGH PÓLYA'S PROBLEM-SOLVING FRAMEWORK

LA INTELIGENCIA ARTIFICIAL EN LA ENSEÑANZA DE LAS MATEMÁTICAS A TRAVÉS DEL MARCO DE RESOLUCIÓN DE PROBLEMAS DE PÓLYA

Armando Amador [a]

Recibido: 18/05/2026 **Aceptado:** 12/06/2026

ABSTRACT

This article examines the integration of artificial intelligence (AI) in mathematics education through the lens of George Pólya's problem-solving framework, as presented in *How to Solve It* (1945). While AI technologies offer significant opportunities to enhance learning, they also introduce challenges related to student autonomy, intellectual responsibility, and the integrity of the learning process. By revisiting Pólya's four stages: understanding the problem, devising a plan, carrying out the plan, and looking back, this study proposes a human-centered approach to AI-assisted learning that prioritizes reasoning over automation. The article argues that AI should function as a cognitive partner rather than a substitute for thinking, fostering reflective engagement and responsible learning practices. Attention is given to issues of equity, access, and academic integrity in diverse educational contexts. This work contributes to ongoing discussions on the responsible use of emerging technologies in mathematics education.

Keywords: *artificial intelligence, mathematics education, problem solving, Pólya, responsible learning, academic integrity*

[a] Assistant Professor, Ed. DCT. Deputy Chair of Mathematics and Computer Science Department. Hostos Community College of the City University of New York, USA. E-mail: aamador@hostos.cuny.edu. ORCID: 0009-0000-0816-1405.

RESUMEN

Este artículo examina la integración de la inteligencia artificial (IA) en la educación matemática a través del marco de resolución de problemas de George Pólya, presentado en *How to Solve It* (1945). Si bien las tecnologías de IA ofrecen importantes oportunidades para mejorar el aprendizaje, también plantean desafíos relacionados con la autonomía del estudiante, la responsabilidad intelectual y la integridad del proceso educativo. IA retoma las cuatro etapas de Pólya: comprender el problema, elaborar un plan, ejecutar el plan y reflexionar, este trabajo propone un enfoque centrado en el ser humano que prioriza el razonamiento sobre la automatización. Se sostiene que la IA debe funcionar como un aliado cognitivo y no como un sustituto del pensamiento, promoviendo la reflexión y el uso responsable de la tecnología. Asimismo, se abordan cuestiones de equidad, acceso e integridad académica en diversos contextos educativos. Este estudio contribuye a las discusiones actuales sobre el uso responsable de tecnologías emergentes en la educación matemática.

Palabras clave: *inteligencia artificial, educación matemática, resolución de problemas, Pólya, aprendizaje responsable, integridad académica*

INTRODUCCIÓN

The rapid expansion of artificial intelligence (AI) in education has transformed how students access knowledge and engage in problem solving. In mathematics education, AI-powered tools provide immediate solutions, symbolic manipulation, and dynamic visualizations. While these capabilities hold pedagogical promises, they also raise important questions about student autonomy, intellectual engagement, and the nature of learning.

George Pólya's (1945) problem-solving framework, introduced in *How to Solve It*, offers a valuable lens for addressing these challenges. His four-step method emphasizes reasoning, reflection, and intellectual ownership. This article explores how Pólya's framework can guide the responsible integration of AI in mathematics education.

LITERATURE REVIEW

Recent research highlights both the benefits and risks of AI in education. Studies show that AI can enhance conceptual understanding when used as a support tool rather than a replacement for thinking (Kuo et al., 2026). Similarly, Wongthun and Nokkaew (2025) found that structured AI integration improves problem-solving performance.

However, concerns remain regarding overreliance on AI and its impact on critical thinking (Danesi & Neuman, 2025). Scholars argue that educational frameworks must ensure that students remain active participants in the learning process (Govender & Rajendran, 2025).

Pólya's framework provides a pedagogical structure that aligns with these concerns, emphasizing strategy, reflection, and understanding.

UNDERSTANDING THE PROBLEM IN THE AGE OF AI

Within this framework, Pólya emphasized that students must first understand a problem before attempting to solve it. He encouraged learners to ask: What is known? What is unknown? What is being asked? This first step is critical because students frequently misinterpret mathematical language or rush toward calculation without comprehension (Pólya, 1945; Wongthun & Nokkaew, 2025).

With AI tools available, students may be tempted to paste the problem and request a solution immediately. Responsible use, however, mirrors Pólya's first step: AI should serve as a comprehension assistant, not a shortcut. Research demonstrates that AI tools can help students translate verbal descriptions into symbolic or graphical representations (Wongthun & Nokkaew, 2025). For example, students can graph a scenario in Desmos or GeoGebra before solving algebraically, reinforcing comprehension prior to calculation.

Students can responsibly use AI to:

- Ask for clarification of vocabulary or symbols
- Request a restatement of the problem in simpler language
- Explore related concepts before solving
- Generate examples that test their understanding of problem conditions

When AI is used to deepen understanding rather than bypass it, it strengthens conceptual learning instead of weakening it. A 2025 study from Thailand found that students showed the greatest improvement in their problem-solving ability when AI was used specifically to support thinking and transforming problems, with students achieving a relative gain score of 79.17 in this area (Wongthun & Nokkaew, 2025).

DEVISING A PLAN: AI AS A STRATEGY GENERATOR

Pólya viewed problem solving as strategic thinking. He proposed that students consider multiple approaches: drawing diagrams, finding patterns, solving simpler versions first, or working backward. The essence of this step is metacognition—thinking about how one thinks—and recognizing that mathematics involves decision-making rather than rote memorization (Pólya, 1945).

AI can enhance this step by helping students see possibilities. Rather than providing answers, AI reasoning assistants can generate alternative solution strategies for students to evaluate. Students may engage AI by asking: "What strategies could apply to this type of problem?" or "Can you suggest different methods without solving it for me?" Used this way, AI functions like a mathematical coach rather than an answer machine.

Research from the Taiwan Adaptive Learning Platform (TALP) confirms that high-achieving students engage in more complex interaction patterns with AI companions, sustaining feedback cycles that deepen their strategic thinking. Low-achieving students initially exhibit simpler patterns but show significant improvement when AI support is structured around problem-solving heuristics (Kuo, Bai, & Lin, 2025).

CARRYING OUT THE PLAN: MAINTAINING INTELLECTUAL OWNERSHIP

Pólya warned that carrying out a solution requires careful reasoning and persistence. If AI performs all calculations and steps, students lose the opportunity to develop logical fluency and the resilience that comes from working through difficulties (Pólya, 1945).

Responsible AI use means students should:

- Attempt the solution themselves first
- Use AI to check intermediate steps rather than replace them
- Compare their reasoning with AI explanations
- Verify whether algebraic solutions match graphical behavior using visualization platforms.

Symbolic engines such as Wolfram tools can verify intermediate steps, helping students detect errors and confirm logic. Visualization platforms like Desmos and GeoGebra allow students to test whether their algebraic solutions match graphical behavior, providing immediate feedback without judgment (Schorcht, Buchholtz, & Müller, 2025).

This transforms AI into a feedback partner rather than a substitute thinker. The student remains the problem solver; AI becomes the verifier. A 2026 study from Taiwan found that students receiving AI-supported remedial instruction demonstrated significantly better performance than those receiving video-based instruction alone, with the effect particularly pronounced for low-achieving students (Kuo, Bai, & Lin, 2026).

LOOKING BACK: REFLECTION AS THE BRIDGE BETWEEN PÓLYA AND AI

Perhaps the most powerful—and often neglected—step in Pólya's method is reflection. He urged students to ask: Does the result make sense? Can it be solved another way? What general idea did I learn? This step transforms a completed problem into transferable knowledge (Pólya, 1945).

AI can significantly strengthen this reflective stage. Students can ask:

- "Is there another method to solve this?"
- "What type of problem is this related to?"
- "How could this idea apply to real-world contexts?"
- "Generate a similar problem with modified parameters" (Sun, 2025)

Reflection becomes richer when students can modify parameters dynamically or generate related problems. Sliders, symbolic manipulation, and AI prompts allow learners to explore generalization—a central feature of mathematical maturity (Schorcht, Buchholtz, & Müller, 2025).

Used this way, AI promotes transfer of learning, helping students connect ideas across topics rather than memorizing isolated procedures. The reflective stage enables students to ask AI to generate related problems in different domains (geometry, sequences, probability) based on a solution method they have just discovered.

ETHICAL USE OF AI THROUGH PÓLYA'S LENS

Pólya's work was grounded in intellectual honesty and curiosity. When applied to AI-assisted learning, his philosophy suggests three ethical principles for mathematics education:

- **First, AI should support thinking, not replace it.** Students should use AI to explore strategies, clarify concepts, and verify reasoning—not to avoid the productive struggle that builds mathematical understanding. Researchers at TU Dresden have developed indexed knowledge bases based on Pólya's heuristics specifically to enhance large language models' problem-solving strategies in ways that support rather than supplant student reasoning (Schorcht, Buchholtz, & Müller, 2025).
- **Second, students must remain accountable for understanding.** If a student cannot explain the solution without AI, learning has not occurred. Teachers might require students to document what AI suggested versus what they chose, and to explain their reasoning in their own words (Govender & Rajendran, 2025).
- **Third, reflection transforms AI from an answer machine into a learning tool.** The value of AI lies not in the answers it provides, but in how students question, analyze, and extend those answers.

IMPLICATIONS FOR MATHEMATICS EDUCATION

Integrating AI responsibly requires a shift in teaching practice. Instead of banning AI or allowing unrestricted use, instructors can align AI integration with Pólya's stages:

- **Understanding**: Require students to explain problems in their own words before using AI (Wongthun & Nokkaew, 2025)
- **Planning**: Ask students to document what AI suggested versus what they chose and why
- **Executing**: Have students attempt solutions independently before using AI for verification (Schorcht, Buchholtz, & Müller, 2025)
- **Reflecting**: Include reflection prompts comparing student reasoning with AI reasoning (Sun, 2025)

This approach turns AI into a partner in mathematical inquiry, consistent with Pólya's vision of education as guided discovery (Pólya, 1945). Several platforms support different aspects of this integration: Wolfram tools for symbolic manipulation, Desmos for visualization, GeoGebra for dynamic exploration, and AI reasoning assistants for strategic guidance (Schorcht, Buchholtz, & Müller, 2025).

For students who may feel excluded from mathematics, these tools foster agency and confidence. Research demonstrates that structured AI support can promote differentiated instruction and help bridge achievement gaps, particularly when integrated with proven pedagogical frameworks like Pólya's (Govender & Rajendran, 2025; Kuo, Bai, & Lin, 2026).

EMERGING RESEARCH AND FUTURE DIRECTIONS

Recent scholarship confirms the effectiveness of combining Pólya’s framework with AI tools. A 2026 study from Taiwan demonstrated that integrating AI learning companions with video-based self-learning yielded the highest learning gains, with both high-achieving and low-achieving students benefiting from the structured support (Kuo, Bai, & Lin, 2026). The study found that AI companions incorporating Socratic dialogue and Pólya's problem-solving strategy were particularly effective for remedial instruction.

Similarly, a Thai action research study developed learning activities using Pólya's process combined with AI applications to enhance students' ability to solve systems of linear equations. The research identified three key guidelines: selecting AI applications suitable for each step of the problem-solving process; designing activities that promote group work and discussion; and gradually withdrawing AI support to transfer problem-solving abilities to students (Wongthun & Nokkaew, 2025).

Graduate research is also exploring these connections. A 2025 master's thesis from National Taiwan Normal University investigated using ChatGPT to build a mathematics tutor for junior high school students, explicitly incorporating Pólya's problem-solving process and Socratic questioning (Sun, 2025).

The intersection of heuristic problem-solving methods and artificial intelligence continues to evolve. Danesi and Neuman (2025) explore how large language models like ChatGPT engage with mathematical understanding, raising important questions about the nature of reasoning in an AI-mediated educational environment. Their work suggests that Pólya's framework may be more relevant than ever as educators seek to cultivate authentic mathematical thinking alongside technological fluency.

CONCLUSION

Although written in the mid-twentieth century, Pólya's insights anticipate the central challenge of twenty-first-century education: teaching students not merely to obtain answers, but to think. Artificial intelligence does not invalidate Pólya's method—it makes it more necessary than ever.

When students use AI through the lens of understanding, planning, executing, and reflecting, they do more than solve problems. They develop mathematical maturity, intellectual independence, and ethical responsibility. AI-powered mathematics platforms do not diminish the importance of human reasoning; rather, they make reasoning visible, testable, and iterative. When aligned with Pólya's framework, these tools can transform problem solving from answer-getting into a reflective and empowering intellectual activity.

In this way, Pólya's philosophy provides not only a framework for solving problems, but also a blueprint for learning responsibly in the age of AI.

REFERENCES

Danesi, M., & Neuman, Y. (2025). AI and mathematical understanding: ChatGPT goes to school. In D. Martinovic & M. Danesi (Eds.), *Mathematics and education in an AI era*. Springer.

Govender, R., & Rajendran, S. (2025). Context matters: Why we must consider resources and context when implementing artificial intelligence tools in the teaching and learning of mathematics in South Africa. *Pythagoras*, *46*(1), Article 867. https://doi.org/10.4102/pythagoras.v46i1.867

Kuo, B.-C., Bai, Z.-E., & Lin, C.-H. (2025). Developing an AI learning companion for mathematics problem solving in elementary schools. *Computers & Education*, *240*, Article 105463. https://doi.org/10.1016/j.compedu.2025.105463

Pólya, G. (1945). *How to solve it: A new aspect of mathematical method*. Princeton University Press.

Schorcht, S., Buchholtz, N., & Müller, F. A. (2025). *Context injection for problem solving? An indexed knowledge base on Polya's "How to solve it" (1949) to enhance LLMs problem-solving strategies in mathematics education* [Working paper]. Technische Universität Dresden.

Sun, Y.-M. (2025). *Exploring a ChatGPT-based mathematics tutor for the junior high CAP* [Master's thesis, National Taiwan Normal University]. National Taiwan Normal University Institutional Repository.

Wongthun, J., & Nokkaew, A. (2025). Development of learning activities using Polya's problem–solving process combined with artificial intelligence applications to enhance the ability to solve mathematical problems on a system of linear equations in two variables for Mathayomsuksa 3 students. *Journal of Graduate School Sakon Nakhon Rajabhat University*, *22(*96).