ARTIFICIAL INTELLIGENCE IN GEOMETRY EDUCATION: A SYSTEMATIC REVIEW OF PUBLICATIONS (2023–2025)

INTELIGÊNCIA ARTIFICIAL NA EDUCAÇÃO EM GEOMETRIA: UMA REVISÃO SISTEMÁTICA DAS PUBLICAÇÕES (2023–2025)

Olha Matiash
https://orcid.org/0000-0002-7149-9545
Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University, VSPU; Department of Algebra and Mathematics Teaching Methods
Vinnytsia, Ukraine
matyash_27@ukr.net

Liubov Mykhailenko
https://orcid.org/0000-0001-5051-5561
Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University, VSPU; Department of Algebra and Mathematics Teaching Methods
Vinnytsia, Ukraine
liubov.mykhailenko@vspu.edu.ua

Andrii Matiash
https://orcid.org/0009-0006-6244-1620
Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University, VSPU; Department of Algebra and Mathematics Teaching Methods
Vinnytsia, Ukraine
matyashandrey1987@gmail.com

Abstract. The presence of artificial intelligence (AI) in education is an undeniable reality that affects all participants in the learning process. Geometry, as a subject with specific features and abstract concepts, presents a particularly promising field for exploring the potential of AI to enhance teaching and learning conditions. However, there is a lack of clear methodological guidance for the effective integration of AI in geometry education, highlighting the need for systematic and up-to-date reviews that synthesize current knowledge and provide practical insights for teachers and researchers. This study presents a systematic review of research on AI applications in geometry education conducted between 2023 and 2025. Following PRISMA guidelines, peer-reviewed journal articles published in English during this period were identified, resulting in a final sample of 20 studies. Thematic analysis was conducted to address key research questions, including the most studied topics, active regions of research, effective AI methods, strategies and tools, practical outcomes for teachers, and directions for future investigation. The review indicates that AI in geometry education has attracted global attention, with the most active studies originating from Europe and Asia. Research activity increased notably in 2024. The findings highlight the considerable potential of AI to support student learning through interactive modeling, automated feedback, and visualization of complex geometric concepts. At the same time, effective integration requires that teachers develop awareness and practical skills to maximize AI benefits while avoiding overreliance and superficial learning. The review provides validated methods, strategies, and tools for AI use in geometry education, concrete recommendations for teachers, and examples of practical outcomes from recent studies. These insights offer valuable guidance for educators seeking to implement AI effectively and point researchers toward emerging trends and priorities in improving geometry teaching and learning.

Keywords: artificial intelligence; geometry education; systematic review

Resumo. A presença da inteligência artificial (IA) na educação é uma realidade inegável que afeta todos os participantes do processo de aprendizagem. A geometria, enquanto disciplina com características específicas e conceitos abstratos, apresenta um campo particularmente promissor para explorar o potencial da IA no aprimoramento das condições de ensino e aprendizagem. No entanto, observa-se a falta de orientações metodológicas claras para a integração eficaz da IA no ensino da geometria, o que evidencia a necessidade de revisões sistemáticas e atualizadas que sintetizem o conhecimento atual e forneçam contributos práticos para professores e investigadores. Este estudo apresenta uma revisão sistemática da investigação sobre aplicações da IA na educação em geometria realizada entre 2023 e 2025. Seguindo as diretrizes PRISMA, foram identificados artigos de revistas científicas revistos por pares, publicados em inglês durante este período, resultando numa amostra final de 20 estudos. Foi realizada uma análise temática para responder a questões de investigação-chave, incluindo os tópicos

mais estudados, as regiões mais ativas na investigação, os métodos de IA mais eficazes, as estratégias e ferramentas utilizadas, os resultados práticos para professores e as direções para investigações futuras. A revisão indica que a IA na educação em geometria tem atraído atenção global, com os estudos mais ativos provenientes da Europa e da Ásia. A atividade de investigação aumentou significativamente em 2024. Os resultados destacam o considerável potencial da IA para apoiar a aprendizagem dos alunos através de modelação interativa, feedback automatizado e visualização de conceitos geométricos complexos. Ao mesmo tempo, a integração eficaz exige que os professores desenvolvam consciência e competências práticas para maximizar os benefícios da IA, evitando a dependência excessiva e a aprendizagem superficial. A revisão fornece métodos, estratégias e ferramentas validadas para o uso da IA no ensino da geometria, recomendações concretas para professores e exemplos de resultados práticos de estudos recentes. Estas conclusões oferecem orientações valiosas para educadores que procuram implementar a IA de forma eficaz e apontam os investigadores para tendências emergentes e prioridades na melhoria do ensino e aprendizagem da geometria.

Palavras-chave: inteligência artificial; educação em geometria; revisão sistemática

1. INTRODUCTION

The emergence and rapid penetration of generative artificial intelligence (AI) into various spheres of human life is a phenomenon that requires a prompt response in the field of education. Today, the task of modernizing and improving mathematics education is widely recognized and substantiated, and scholars from different countries view its resolution in the methodologically sound and competent integration of modern digital technologies into both school mathematics education and the professional preparation of future mathematics teachers (Matiash et al., 2025; Mykhailenko et al., 2022). Generative artificial intelligence has become a revolutionary technology that challenges traditional teaching and learning practices (Parra et al., 2024).

Most studies on the use of AI in education provide insights into the potential of these new technologies, highlighting their advantages and disadvantages. However, there is a noticeable gap in the literature regarding the systematization of available AI tools that teachers can immediately apply to improve teaching and learning (Awang et al., 2025). Moreover, there is a lack of clear and concrete methodological guidelines for the effective use of AI in fostering relevant competencies among learners, particularly mathematical competence.

Research aimed at evaluating the effectiveness of AI in mathematics education generally offers only a broad understanding of its potential applications. There remains a lack of understanding of both the strengths and limitations of AI use, in the overall context and within specific areas of mathematics such as geometry (Parra et al., 2024). Geometry is a vital component of mathematics education, essential for the development of students' thinking, and must be thoroughly mastered as part of the mathematics curriculum.

There is thus a need for comprehensive, up-to-date reviews of publications that clarify the role and significance of AI in geometry education, supporting mathematics teachers in selecting appropriate AI tools and identifying effective methods and strategies for their classroom use. The specific features of geometry as a subject make it particularly suitable for testing the potential of AI systems to enhance teaching and learning conditions. Consequently, reviews of contemporary publications on AI in geometry education are of importance not only for teachers but also for researchers, as they help to identify current trends and future directions in mathematics education development.

Regarding existing systematic literature reviews that investigate the potential of AI in mathematics education, only a limited number have been conducted. Over the past five years, these include: Hwang (G.-J. Hwang & Tu, 2021); Mohamed (Mohamed et al., 2022); Hwang (S. Hwang, 2022); Niño-Rojas (Niño-Rojas et al., 2023); and Awang (Awang et al., 2025).

For example, Mohamed, Hidayat, Suhaizi, Sabri, Mahmud, and Baharuddin reviewed 20 articles on the application of AI in the teaching and learning of mathematics, published between

2017 and 2021. Liz Awang, Farrah Yusop, and Mahmoud Danaee carried out a systematic review of 32 articles (2019–2024) with a particular focus on commercial AI tools that have already demonstrated their effectiveness in mathematics education.

The purpose of the present review is to contribute to the ongoing discussion by offering an overview of the use of AI in geometry education during the period 2023–2025. We selected this three-year timeframe to identify the most recent AI tools and technologies that have been tested in educational research. The findings of this review are intended to provide mathematics teachers with valuable information that will facilitate more effective integration of AI into geometry teaching and to point mathematics education researchers toward contemporary trends in enhancing the teaching and learning of geometry.

Research Questions

1. What themes related to the use of AI in geometry education are most frequently studied during 2023–2025?
2. In which regions is research on AI in geometry education most active?
3. Is there evidence of growing research activity in the field of AI in geometry education?
4. Which methods, strategies, and tools for using AI in geometry education have proven effective?
5. What specific recommendations for AI use in geometry teaching are justified by the authors?
6. What concrete practical outcomes, relevant to mathematics teachers, have been reported in the studies?
7. What directions are most relevant for future research?

2. RELATED WORKS

Systematic reviews of articles on the use of AI in mathematics education have been conducted from various research perspectives. Over the past five years, several such reviews have been devoted to AI in mathematics education. In particular, Hwang and Tu (G.-J. Hwang & Tu, 2021) carried out a systematic review of the roles and trends of AI research in mathematics education. Their review addressed the following research questions: Which leading journals publish studies on AI in mathematics education? Which are the most cited articles in this field? Who are the most productive and cited authors? What keywords are most frequently used in AI and mathematics education research? What connections exist among these keywords? What are the domains of application of AI research in mathematics education? What research samples are employed in studies on AI in mathematics education? What research methods are used? What roles does artificial intelligence play in mathematics education? Which AI algorithms are applied? What research problems are being addressed? (G.-J. Hwang & Tu, 2021). In their conclusions, Hwang and Tu noted that the most prominent AI tools are adaptive learning systems, intelligent tutoring systems, chatbots, augmented reality (AR), virtual reality (VR), educational games, learning analytics, and mathematical problem-solving applications. Their review also revealed that although AI integration into educational games and problem-solving apps is less common, these directions are promising and hold potential for future development (G.-J. Hwang & Tu, 2021).

In addition, Sunghwan Hwang (S. Hwang, 2022) conducted another study—a meta-analysis—focused on the impact of various types of AI, including adaptive learning systems, intelligent tutoring systems, and robotics, on elementary students' mathematics achievement. The research questions were: Does the use of AI significantly improve elementary students' mathematics performance? Which variables moderate the overall impact of AI on mathematics achievement? Among the conclusions of this study were several practical recommendations:

• Teachers should integrate AI into mathematics teaching, as its use positively influences elementary students' mathematics achievement. Teachers should acquire the necessary knowledge and skills and redesign their lessons to incorporate AI into daily practice.

• School administrators should support mathematics teachers so that they can confidently implement AI. This includes organizing professional development to explain AI and its instructional uses, as well as providing financial support for devices and AI-related tools.

Mohamed, Hidayat, Suhaizi, Sabri, Mahmud, and Baharuddin (Mohamed et al., 2022) carried out a systematic review of articles focused on different AI approaches applied in mathematics education. Their review addressed the following research questions: Which AI approaches are applied in mathematics education for the studied samples? How is AI applied across different countries? How is AI use distributed according to research methodologies? How has the use of AI in mathematics education evolved across years of publication? What research themes are currently being addressed? (Mohamed et al., 2022). In their conclusions, Mohamed et al. stated that AI can be integrated into mathematics education through various approaches: systems, learning agents, autonomous agents, machine learning models, digital technological devices, and comprehensive approaches. Among all these, robotics was found to be the most commonly used approach for learners, teachers, and researchers in mathematics (Mohamed et al., 2022). At the same time, the authors caution against assuming that robotics will be the main driver of mathematics learning. Rather, it is important for teachers and learners to fully explore its educational potential to deepen mathematical understanding. Otherwise, the addition of "seductive details" offered by robots may even hinder students' learning of mathematics (Mohamed et al., 2022).

Niño-Rojas, Lancheros-Cuesta, Jiménez-Valderrama, Mestre, and Gómez (Niño-Rojas et al., 2023) conducted a systematic review of articles dedicated to the use of intelligent tutoring systems (ITS) in mathematics learning. Their review addressed the following research questions: What are the goals, benefits, and limitations of applying ITS in mathematics education at the higher education level? Do studies account for the inclusion of user modeling and adaptive processes in ITS implementation? What elements of research methodology are applied during the integration of ITS in mathematics learning at universities? They identified several widely used ITS platforms, including ALEKS, PAT2Math, GeoGebra Tutor, and MATHia. These systems play an important role in enhancing mathematics education through personalized and adaptive learning. The review found that the most common AI techniques applied for adaptation in these ITS are expert systems, predictive models, and neural networks (Niño-Rojas et al., 2023).

Liz A. Awang, Farrah D. Yusop, and Mahmoud Danaee (Awang et al., 2025) conducted a systematic review of current practices and future directions of artificial intelligence applications in mathematics education. Their research questions were as follows: How is AI research in mathematics education distributed across different educational levels? Which AI tools are currently used in mathematics learning, and how are they categorized? What commercialized AI tools in mathematics education are available online, and what are their functions? What emerging trends and future directions in mathematics education with AI can be identified from recent literature? In their conclusions, Liz Awang et al. emphasize that future research should focus on the need for long-term studies on the impact of AI and on understanding how AI can best complement traditional teaching methods (Awang et al., 2025).

The above-mentioned review studies generally highlight the potential of AI to create more personalized, adaptive, and effective learning environments, thereby fostering greater student engagement and achievement in mathematics.

The study most closely aligned with our research is the systematic literature review conducted by Gladys Sunzuma (Sunzuma, 2023). This review presents a comprehensive

analysis of 29 articles on the integration of digital technologies in the teaching and learning of geometry at the secondary school level, published between 2010 and 2022. The review was structured around the following research questions: What publication trends in technology integration into the teaching and learning of geometry emerged between 2010 and 2022? Which leading technologies have been integrated into geometry instruction? What types of contributions were made in these studies: implementation, design, or evaluation of effectiveness in geometry education? What learning domains were covered in geometry teaching research? Which research methods were employed to investigate technology integration in geometry education? (Sunzuma, 2023). In her conclusions, Gladys Sunzuma notes that GeoGebra is the most widely used tool in teaching geometry, followed by augmented reality. One of the most effective ways to enhance the learning of geometry is through the integration of technology into the teaching and learning process. The use of technology allows students to explore, solve, and explain geometric concepts in multiple forms within a technology-rich environment (Sunzuma, 2023). The limited use of digital technologies in geometry teaching is often associated with insufficient teacher training (Sunzuma, 2023).

However, in this systematic literature review, Gladys Sunzuma does not address the application of artificial intelligence in geometry education. Our systematic review aims to fill this gap—both in terms of the focus on AI in geometry education and in terms of the time period under consideration, covering 2023 to 2025. The emphasis on identifying ready-to-use methodological guidelines as well as highlighting effective strategies and practices for applying AI in geometry teaching further enhances the value of our systematic literature review.

3. RESEARCH METHODOLOGY

In accordance with the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses—an international standard for transparent and comprehensive reporting of systematic reviews and meta-analyses), we conducted a systematic search that ensured the proper reporting of systematic reviews. PRISMA is structured around four key phases: identification, screening, eligibility, and inclusion. This study considered only publications from the period 2023–2025; articles published prior to this period were excluded.

The search was performed using the following keywords: “geometry learning,” “artificial intelligence,” “technologies,” and “teaching and learning.”

Inclusion criteria were as follows: journal articles; systematic reviews; publications written in English; published within the period 2023–2025.

The initial search yielded 354 articles. After a detailed review of titles, abstracts, methodologies, results, and discussions:

- 266 articles were excluded because they did not meet the criteria (e.g., books, conference proceedings, or outside the specified time frame);
- 13 articles were excluded because their focus was geometry as a science, rather than the teaching and learning of geometry;
- 52 articles were excluded because they examined the application of artificial intelligence in mathematics education in general, without specific reference to geometry learning;
- 20 articles met the inclusion criteria.

As a result, a final sample of 20 articles was included and subjected to thematic analysis to address our research questions.

4. RESULTS

4.1 Research Question 1:

What topics related to the use of AI in geometry learning are most frequently explored in the period 2023–2025?

An analysis of the twenty articles included in the review allowed us to group them, according to the focus of the research, as follows:

- The use of AI for research in geometry learning (Ding et al., 2024; Polydoros et al., 2025)
- AI and problem solving in geometry learning (Gao et al., 2025; Mouselinos et al., 2024; Parra et al., 2024; Sinha et al., 2024; Xu et al., 2024).
- Identifying gaps in AI's geometric reasoning (Gao et al., 2025; Parra et al., 2024).
- AI in inclusive geometry learning (Wulandari et al., 2024).
- The impact of AI on geometry achievement among learners (Polydoros et al., 2025).
- The use of AI in preparing students for geometry olympiads (Sinha et al., 2024; Trinh et al., 2024; Zhang et al., 2024).
- Expanding the possibilities of geometry learning through the integration of augmented reality and machine learning (Cunha et al., 2025; Ding et al., 2024; Nadzeri et al., 2024; Uriarte-Portillo et al., 2023).
- AI as a tool for addressing proofs in geometry learning (Botana et al., 2024; Dilling & Herrmann, 2024; Sinha et al., 2024; Trinh et al., 2024; Zhang et al., 2024).
- Integration of technologies into geometry learning (Dimitriadou & Lanitis, 2025; Sunzuma, 2023).

When analyzing the content of these articles in relation to different levels of education (primary, lower secondary, upper secondary, and higher education), the distribution is presented in the table 1:

Table 1. Distribution of Studies by Educational Level

Level of Education	Number of Articles	References
Primary school	4	Sousa, 2024; Nadzeri, 2024; Cunha, 2024; Polydoros, 2025
Lower secondary	1	Parra, 2023
Upper secondary	1	Xu, 2024
Undergraduate (pre-service mathematics teachers)	1	Dilling, 2024
Not specified	13	Botana, 2024

Thus, it can be concluded that the largest number of articles addressing the use of AI in geometry learning in the period 2023–2025 focus on:

- AI as a tool for exploring proofs in geometry learning (5 articles),
- AI and problem solving in geometry learning (5 articles),
- expanding geometry learning through augmented reality and machine learning (4 articles),
- and the use of AI in preparing students for geometry olympiads (3 articles).

In the majority of these studies (65%), the use of AI in geometry learning is discussed without explicit reference to a particular educational level.

Given that the majority of studies included in the present review focus on primary education or do not specify the educational level, particular attention should be paid to the need for further research on the feasibility and appropriateness of using artificial intelligence in teaching geometry at the lower and upper secondary school levels. Geometry education for students aged 12–18 offers distinctive opportunities for the development of mathematical thinking and

spatial reasoning. It also contributes to the cultivation of critical thinking skills, particularly through fostering the ability to construct arguments and provide proofs, and serves as a foundation for further education in STEM fields. Therefore, identifying effective approaches to the use of artificial intelligence in geometry education at the lower and upper secondary levels remains an important direction for future research.

4.2 Research Question 2:

In which regions are the most active studies on the use of AI in geometry education being conducted?

The analysis of the authorship of the 20 articles that underwent thematic analysis revealed that they involved 78 researchers from different countries: England, Argentina, Brazil, Greece, Zimbabwe, India, Indonesia, China, Cyprus, Malaysia, Mexico, Nigeria, Germany, Poland, Portugal, USA, Singapore, and Uzbekistan. The following diagram (Figure 1) shows the frequency of research according to continental distribution:

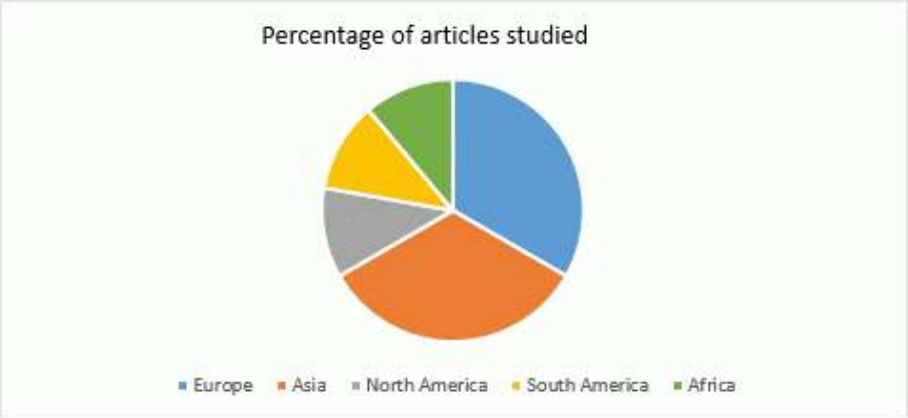


Figure 1. Continental distribution of authors of 20 studies on the use of AI in geometry education (2023–2025)

We can state that the issue of using AI in geometry education (2023–2025) has attracted the attention of researchers from all populated continents except Australia. The largest number of such studies has been published by scholars from Europe (7 articles) and Asia (8 articles). From other continents represented in the diagram, during the specified period, we identified two articles each addressing the use of AI in geometry education. Among the 20 articles included in our review, two were co-authored by international research teams, which is reflected in the table 2:

Table 2. Studies on AI in geometry education co-authored by researchers from multiple countries (2023–2025)

Article Title	Authors	Countries	Year of Publication
Wu's Method can Boost Symbolic AI to Rival Silver Medalists and AlphaGeometry to Outperform Gold Medalists at IMO Geometry	Sinha S., Prabhu A., Kumaraguru P., Bhat S., Bethge M.	India, Germany, England	2024
Beyond Lines and Circles: Unveiling the Geometric Reasoning Gap in Large Language Models	Mouselinos S., Michalewski H., Malinowski M.	England, Poland, Germany	2024

Let us now focus on the number of articles, according to the topic and the review period, published by authors from different countries. Information about the countries with the largest number of relevant articles is presented in the table 3:

Table 3. Countries with the highest number of publications on AI in geometry education (2023–2025)

Country	Number of Articles	Number of Authors	Year(s) of Publication
Germany	3	4	2024, 2024, 2024
China	3	18	2023, 2024, 2024
Greece	2	7	2024, 2025
England	2	2	2024, 2024

From other countries (Argentina, Brazil, Zimbabwe, India, Indonesia, Cyprus, Malaysia, Mexico, Nigeria, Poland, Portugal, Singapore, USA, Uzbekistan), our review identified one article each.

Overall, we can conclude that the use of AI in geometry education has been actively studied by researchers from different continents and countries over the past three years (2023, 2024, and 2025). This is evidenced both by the number of published articles and by the number of authors. The most active research in this area has been conducted in Europe (Germany, Greece, England) and Asia (China).

It is worth noting that in Ukraine there is a growing interest in exploring effective approaches to the use of artificial intelligence in teaching geometry. This interest can be partly explained by the structure of the national curriculum, in which geometry has traditionally been taught as a separate subject starting from Grade 7 (approximately age 13). Initially, students undertake a systematic course in plane geometry (Grades 7–9), followed by a systematic course in solid geometry (Grades 10–11).

However, despite this growing interest, publications by Ukrainian scholars in leading international journals indexed in Scopus or Web of Science remain scarce.

4.3 Research Question 3:

Is there an increasing trend in studies on the use of AI in geometry education?

The number of articles by year, along with their authors and the countries they represent, is presented in the table 4:

Table 4. Distribution of publications on AI in geometry education by year, authors, and countries (2023–2025)

Year of Publication	Number of Articles	Number of Authors	Countries
2023	4	18	Argentina, China, Mexico, Zimbabwe
2024	12	46	England, Brazil, Greece, India, China, Cyprus, Malaysia, Germany, Poland, Portugal, USA, Singapore, Uzbekistan
2025	4	14	Nigeria, Greece, Indonesia, Cyprus

It should be noted that the number of publications for 2025 may increase, as our review is conducted as of August 2025. Nevertheless, it can be stated that compared to 2023, the interest of researchers in studying the use of AI in geometry education has increased significantly.

In our view, scholarly interest in the use of artificial intelligence in geometry education is likely to continue growing, given its considerable potential to influence the teaching and learning of geometry. AI can support the individualization and differentiation of instruction, thereby opening up new directions for pedagogical research, including both opportunities and challenges for school geometry education.

4.4 Research Question 4:

Which methods, techniques, and tools for using AI in geometry education have demonstrated their effectiveness?

- Generative AI is well-suited for conducting remote lessons that require advanced visualization and interactivity. This supports the teaching of geometry when physical access is

limited, for example, due to pandemic restrictions, weather conditions, or mobility challenges of students (Dimitriadou & Lanitis, 2025).

- Dynamic geometry environments facilitate the teaching and learning of geometry. They help overcome or even prevent certain learning difficulties (Cunha et al., 2025).
- Using AI in the form of videos or images allows visualization of objects, enhancing the necessary skills of students, particularly when solving geometry problems (Wulandari et al., 2024).
- Research indicates that generative AI can accommodate different learning styles by offering personalized content adapted to individual needs. This adaptability is especially important in geometry, where students often encounter abstract concepts (Dimitriadou & Lanitis, 2025).
- One way to create high-quality geometry learning materials is through the Thunkable application (Wulandari et al., 2024).
- Augmented reality (AR) is a valuable tool for assisting in the teaching and learning of geometry and helps achieve several educational goals, which can generally be divided into two categories: stimulating student motivation and engagement in learning geometry, and improving students' spatial intelligence. The AR software Geo+ allows students to form teams and collaboratively explore a solid geometric figure, sharing and discussing their investigations, questions, and ideas with each other based on multimedia information (Ding et al., 2024)
- Considering the challenges students face in learning geometry, AR represents a promising approach for improving understanding and supporting the educational process. Augmented reality technology enables virtual objects to be embedded into the physical world, allowing them to coexist in real time in a shared space. AR technologies have the potential to create immersive learning environments in mathematics, helping students grasp concepts more deeply, particularly in geometry (Nadzeri et al., 2024).
- Students using the ARGeoITS intelligent learning system achieved higher academic performance compared to those using ARGeo (Uriarte-Portillo et al., 2023).
- Wu's Method is capable of solving any problem whose hypotheses and conclusions can be expressed as algebraic equations, while automatically generating non-degeneracy conditions. This unique feature allows Wu's Method to work not only with plane geometry problems but also with spatial and multidimensional tasks, where synthetic methods require additional effort and constraints. Combining AlphaGeometry with Wu's Method established a new level of automated theorem proving, becoming the first AI method to surpass an IMO gold medalist (Sinha et al., 2024).
- The innovative GeoMath dataset combines reasoning steps from existing resources and materials obtained from a Chinese educational website for high school students, thereby filling a critical gap in available resources (Xu et al., 2024).
- The G-LLaVA model demonstrated exceptional effectiveness in solving geometry problems, significantly outperforming GPT-4-V on the MathVista benchmark (Gao et al., 2025).
- Generative AI supports automated assessment of geometry tasks, providing immediate feedback essential for student development. Traditional assessment methods often delay feedback, potentially hindering the learning process. In contrast, AI-based assessment systems provide real-time analysis of student performance, identifying strengths and weaknesses (Dimitriadou & Lanitis, 2025).

The systematic review indicates that certain applications of artificial intelligence in geometry education are already supported by empirical evidence of their effectiveness. In particular, prior studies have demonstrated the effectiveness of dynamic geometry environments in addressing students' difficulties with the development of spatial reasoning. AI

has also proven effective in the delivery of online instruction, especially in contexts that require advanced visualization and interactivity. Researchers in geometry education further highlight the notable effectiveness of specific AI models in solving geometric problems. In addition, the review shows that recent studies provide evidence supporting the effectiveness of AI-based assessment systems in the context of geometry learning.

The findings also suggest that the use of augmented reality (AR) technologies has the potential to create a supportive learning environment in geometry education, facilitating a deeper understanding of geometric concepts.

4.5 Research Question 5:

What specific recommendations for using AI in geometry education are justified by the authors?

- During geometry lessons, teachers can visualize geometric objects using AI. One strategy for using AI to solve geometry problems is to teach students to compare geometric figures with real-world objects and to determine the heights of geometric figures by representing them through AI technologies such as Canva and GeoGebra (Wulandari et al., 2024).
- Generative AI opens significant opportunities to enhance visualization in geometry, particularly through immersive and interactive 3D modeling. By integrating generative AI with emerging technologies such as extended reality (XR), educators can create more engaging learning experiences that go beyond traditional teaching methods (Dimitriadou & Lanitis, 2025).
- It is necessary to shift the approach to learning from mechanical content acquisition and to review and reform curriculum content and teaching methods according to the modern student profile in the technological era, which will improve the learning process (Sousa et al., 2024).
- In the context of Euclidean geometry statements, it would be useful to develop close collaboration between chatbots and GeoGebra Discovery, where the latter verifies the correctness of proof steps described by the bot and offers the human user the possibility to check, via a proof certificate, the corrections of ChatGPT solutions using other computational tools (Botana et al., 2024).
- The integration of AI into educational resources should go beyond games — including personalized learning platforms and virtual assistants, enabling continuous and adaptive learning necessary for competence development according to Sustainable Development Goal 4 (SDG 4) and modern digital literacy requirements (Sousa et al., 2024).
- Students with intellectual disabilities require more interactive learning tools that promote better understanding of material and development of creative thinking. Using AI, teachers can design more effective learning resources for such students (Wulandari et al., 2024).
- Using AI as an educational tool can help teachers foster student interest and learning abilities. In teaching geometry to children with mild intellectual disabilities, AI is typically applied through visualizations of objects or multimedia materials in the form of videos and quizzes (Wulandari et al., 2024).
- Using chatbots to solve geometry problems without critical analysis by teachers and students is inappropriate (Dimitriadou & Lanitis, 2025).
- The application of generative AI in geometry lessons may lead to three types of errors. The first type is construction errors, which occur due to inconsistencies between the textual answer and the actual geometric figures, including graphical representations. The second type is conceptual errors related to incorrect definitions (e.g., confusing units of length with units of angle measurement). The third type is contradiction errors (Parra et al., 2024).

- The advantage of generative AI lies in geometric design and architectural tasks, where AI can generate new geometric patterns. These solutions can assist both teachers and students in solving geometry problems (Dimitriadou & Lanitis, 2025).
- When students ask generative AI models to provide two contradictory solutions to geometry problems, it can help them realize that generative AI may make mistakes, thereby improving their critical thinking (Dimitriadou & Lanitis, 2025).
- Generative AI models can facilitate remote learning by providing automated feedback, personalized lessons, and interactive problem-solving support, making geometry education more accessible (Dimitriadou & Lanitis, 2025).
- TongGeometry is effective and accessible for use on standard computers, democratizing the solving of high-complexity problems and expanding opportunities for application in education and research (Zhang et al., 2024).
- Assistance provided by augmented reality (AR) technology in geometry may not significantly affect grade differences in the short term. However, based on various studies and student feedback after lessons, AR helps students better understand geometry through composition, spatial representation, and other aspects. Learners need to continuously engage with and use AR technologies over time to achieve substantial improvement (Ding et al., 2024).
- Intelligent tutoring systems integrating augmented reality can serve as effective learning environments to help middle and high school students study complex topics such as geometry (Uriarte-Portillo et al., 2023).
- Combining XR (AR and VR) with machine learning (ML) enhances XR's potential, enabling insights that can be crucial for personalized understanding of students' learning difficulties in geometry and for identifying more appropriate strategies both in and out of the classroom (Cunha et al., 2025).
- Combining traditional teaching methods with AI-based tools such as ChatGPT can provide significant benefits, especially for students with well-aligned cognitive styles. This approach has proven particularly effective for developing higher-order cognitive skills, such as problem-solving and critical analysis, for students who learn best through interactive and inquiry-based learning (Polydoros et al., 2025).
- AI can support collaborative learning, fostering peer interaction that enriches the educational process and encourages diverse approaches to solving geometry problems (Dimitriadou & Lanitis, 2025).

The review indicates that the majority of studies primarily examine the potential of artificial intelligence to enhance visualization in geometry and to support the solution of geometric problems. Increasing attention is also being given to practical recommendations regarding the use of personalized learning platforms, virtual assistants, and augmented reality technologies. Some studies provide initial insights into how generative AI models can facilitate online learning, assist teachers in fostering students' engagement and learning capacities, and support geometry instruction for learners with certain intellectual disabilities. There is broad agreement among researchers that combining traditional instructional approaches with AI-based tools can lead to meaningful improvements in geometry learning, particularly in relation to the development of students' critical thinking skills. At the same time, the review shows that most publications converge on the conclusion that AI enables teachers to design more effective methods, strategies, and instructional tools for teaching geometry. However, there remains a clear shortage of well-developed and empirically grounded solutions that could be readily adopted by mathematics teachers in practice.

4.6 Research Question 6:

What specific practical results, interesting for mathematics teachers, have been obtained in the studies?

- A game called GeometrIA has been developed, which uses a machine learning educational model to recognize geometric solids with an accuracy ranging from 92% to 100%. GeometrIA meets the requirements for meaningful learning, as it is a digital tool with great potential to assist teachers in knowledge formation through visual content related to students' everyday life (Sousa et al., 2024).
- AI can transform learning by providing personalization and real-time monitoring of students' difficulties (Sousa et al., 2024).
- It has been found that student motivation and achievement can improve through the use of AI (Wulandari et al., 2024).
- When AI-assisted learning requires the use of mobile phones or laptops, some students with low motivation may become distracted by content unrelated to the learning tasks (Wulandari et al., 2024).
- The use of AI-based applications is very useful for developing learning programs for children with intellectual disabilities (Wulandari et al., 2024).
- DeepMind's AlphaGeometry system is an impressive example of wide potential, as it combines language models with symbolic reasoning. This innovative system achieved exceptional results, successfully solving 25 out of 30 geometry problems at the level of the International Mathematical Olympiad, significantly surpassing previous methods (Dimitriadou & Lanitis, 2025).
- For geometry learning, models such as GPT-3, T5, BART, DALL-E, and CLIP are suitable. In particular, DALL-E, primarily designed for image generation, has been used to visualize geometric figures for better conceptual understanding. CLIP can also be used for generating and interpreting geometric images (Dimitriadou & Lanitis, 2025).
- The use of generative AI in geometry education offers advantages (instant feedback, generation of learning materials, support for critical thinking, assessment of achievement, support for remote learning, enhanced 3D visualization, personalized content, improved pedagogical practices) but also carries risks (plagiarism, potential for providing incorrect content/answers, subscription costs, students working in isolation, overreliance of teachers and students on AI, privacy issues), which may jeopardize learning effectiveness and quality (Dimitriadou & Lanitis, 2025).
- Lack of reflection and limited critical thinking are two main challenges when using AI in education (Dilling & Herrmann, 2024).
- Many learners have misconceptions about how generative AI works. Many do not use prompt engineering or conversational AI features. Training in these prompt methods should be implemented to ensure the development of technological knowledge and competencies for AI use (Dilling & Herrmann, 2024).
- The AlphaGeometry geometric theorem prover generates human-understandable proofs, significantly surpassing previous modern computer programs for geometric theorem proving and approaching the performance of an average IMO gold medalist (Trinh et al., 2024).
- TongGeometry is a Euclidean geometry system that supports problem formulation and solving based on a search tree. This effective system has built the largest repository of geometric theorems to date. TongGeometry acts as a geometry coach that discovers, formulates, and proves theorems (Zhang et al., 2024).
- Most studies demonstrate that AR applications positively impact students' spatial abilities. Thus, there is a promising trend toward using AR in geometry learning (Nadzeri et al., 2024).
- Based on the obtained results, it can be stated that an ITS application enhanced with AR technology proved more effective than an AR application without the ITS module, both in helping students grasp basic geometry principles and in increasing motivation for learning activities (Uriarte-Portillo et al., 2023).

• Overall, the use of AI in geometry teaching (computer programs, virtual environments, and robotics) provides students with great opportunities to develop creativity and optimize the learning process (Mambetova, 2024).

• A categorization of errors made by chatbots in geometric reasoning has been proposed. This categorization can serve as a basis for developing pedagogical approaches that facilitate the use of generative AI for learning and skill development (Parra et al., 2024)

• Results show that students who studied geometry with AI did not outperform those who learned without AI. Moreover, retention rates of students who learned without AI were higher. No significant differences in achievement and retention levels were found between boys and girls who learned geometry with AI. These results suggest that teachers and students should seek effective ways to use AI in mathematics education (Ogoke et al., 2025).

• Three methods help AI overcome current limitations in constructive geometry: a dynamic prompting mechanism that allows the model to rely on previous interactions instead of static and minimally informative examples; a variable renaming technique that neutralizes biases related to variable names; and scene description in the prompt, which improves models' ability to understand and manipulate spatial relationships in geometric contexts (Mouselinos et al., 2024).

• Results indicate that the proposed Geo-LLaVA-13B model outperforms several other models in solving geometry problems, particularly when using the combination of GeoMath-IC, GeoMath-QA, and GeoMath-Meta datasets for complex stereometry problems. Stepwise improvements highlight the effectiveness of sequentially incorporating these datasets and techniques. Additionally, model performance further increases due to in-context learning (ICL), indicating significant accuracy improvement when few-shot examples are provided during inference (Xu et al., 2024).

In summary, it can be stated that the number of research findings that are both of practical relevance and interest to mathematics teachers working in the field of geometry instruction remains rather limited. The review makes it possible to identify the following specific recommendations for teachers:

• GPT-3, T5, BART, DALL·E, and CLIP are suitable for teaching geometry.

• A taxonomy of errors made by chatbots in geometric reasoning has been developed.

• Students should be taught prompt-engineering techniques to foster the development of their technological knowledge of AI use.

• AR applications have a positive impact on the development of students' spatial reasoning skills.

4.7 Research Question 7:

What is relevant for future research?

• Establishing collaboration between ChatGPT and GeoGebra Discovery for better understanding of geometric statements is considered relevant (Botana et al., 2024).

• More research should be conducted on other aspects of integrating digital technologies into geometry education, beyond evaluating their effectiveness (Sunzuma, 2023)

• Since the scientific literature contains only a few documented attempts to use Gen-AI tools in the field of geometry, there is a need for systematic efforts aimed at implementing AI-based geometry lessons through the development of specialized platforms that integrate Gen-AI tools specifically designed for geometry education (Dimitriadou & Lanitis, 2025).

• Important aspects that require further study in relation to implementing Gen-AI-based geometry lessons include their effectiveness in improving learning outcomes. These aspects should be carefully documented and published to promote the development of the field and provide valuable recommendations for educators and researchers on the use and scaling of Gen-AI tools in geometry-related educational activities (Dimitriadou & Lanitis, 2025).

• A key direction for further research in methodological recommendations concerns how to best integrate generative AI into geometry curricula (Dimitriadou & Lanitis, 2025).

• There is a need for situational surveys regarding students' perceptions of AI use in learning (Dilling & Herrmann, 2024)

• TongGeometry does not function merely as a "student" solving problems, but as a "coach" that generates, formulates, and proves theorems — this distinction opens new avenues for further research (Zhang et al., 2024).

• Multi-agent systems with role-based and domain-specific specialization can effectively solve geometric problems and achieve comparable results in other domains. This outcome could form the basis for developing training systems operating in a multi-agent environment (Mouselinos et al., 2024).

• Future research may focus on enhancing GeoMath, expanding the dataset with new types of problems, and testing their applicability in different educational contexts, potentially transforming approaches to multimodal mathematical reasoning in both academic and practical settings (Xu et al., 2024).

The review enables the identification of key areas of current relevance for future research:

• There is a need for studies aimed at improving geometry lessons through the integration of artificial intelligence.

• The development of specialised platforms that integrate GenAI tools specifically designed for geometry education remains an important research direction.

• There is a need for evidence-based guidelines for teachers and researchers regarding the scalable implementation of GenAI tools in geometry-related educational practice.

• Situational surveys of students are required to investigate the impact of AI use on learning geometry.

• One promising line of inquiry concerns whether AI can serve as a "coach" in geometry education, capable of generating, formulating, and proving mathematical statements.

• The development of training systems for geometry learning operating within multi-agent environments represents another important and timely research direction.

5. DISCUSSION

Geometry is one of the key branches of mathematics studied by students from primary to secondary school. Despite its importance and popularity, researchers have noted numerous challenges associated with teaching and learning geometry, and most students encounter difficulties in learning it (Sunzuma, 2023). Ensuring access to technology is a crucial step for schools in the transition to digital learning. However, for this process to be successful, it is important to focus not on the technologies themselves, but on understanding how they can effectively and inclusively support teaching and learning (Cunha et al., 2025).

As our review demonstrates, there is already a body of scientific evidence providing useful practical recommendations for mathematics teachers regarding the effective use of AI in geometry education. In particular, Gao et al. (Gao et al., 2025) focused on solving geometry problems using input images in large language models (LLMs), including ChatGPT. The authors leveraged the specifics of geometry to create a new dataset aimed at solving geometry problems, based on GeoQA+ and Geometry3K. One advantage of using AI in teaching geometry is the ability to dynamically access complex figures that would otherwise be difficult to examine from different perspectives — knowledge becomes quick, easy, interactive, and accompanied by logical reasoning (Cunha et al., 2025).

AI models can generate geometric figures, prove theorems, and even discover new properties. Generative AI holds significant potential for geometry education. Interactive models created on AI-supported platforms allow students to explore various aspects of geometry and make them more concrete. Dynamic geometry tools enable students to verify

properties and theorems, enhancing their understanding of the material (Dimitriadou & Lanitis, 2025).

At the same time, geometric patterns and figures generated by AI can raise concerns about ownership and originality, especially if the models were trained on copyrighted materials (Dimitriadou & Lanitis, 2025). Several studies also indicate that for practical use of AI, many users need to realize that one of the main capabilities of these models is the possibility of longer interaction than a single prompt. The ability to ask questions about responses and generate results in a dialogical manner has remained underutilized by many (Dilling & Herrmann, 2024). Parra et al. (Parra et al., 2024) analyzed responses to school-level geometry problems in Spanish using various chatbots, such as OpenAI, ChatGPT, Microsoft Bing Chat (BingChat), and Google Bard. Their study showed that using chatbots to solve geometry problems is ineffective without critical analysis by teachers and students, highlighting the need for collaboration between chatbots and students in the learning process.

There is concern about the gradual decline of basic geometric instincts and knowledge among students and teachers. If generative AI tools become increasingly used in learning and professional practice, overreliance may develop, leading to only superficial understanding of geometric concepts. Moreover, such overdependence can displace critical thinking skills, thereby reducing the educational value of learning geometry (Dimitriadou & Lanitis, 2025). Research by Ogoke, Anyanwu, Okolie, Onuoha, and Vivian (Ogoke et al., 2025) shows that students who studied geometry with AI did not outperform those who learned without AI. Moreover, retention rates of students taught without AI were higher. No significant differences were found in performance and retention between boys and girls who learned geometry with AI. These findings suggest that mathematics teachers and students should seek effective ways to use AI in math education.

It should be emphasized that most researchers recognize the substantial potential of AI in teaching geometry, but mathematics teachers need to understand these possibilities and acquire practical skills for effectively using AI in students' geometry learning. Given the rapid pace of AI development, the tools themselves evolve, and perceptions of AI are likely to change over time (Dilling & Herrmann, 2024). Nevertheless, there is already a need to intensify research on the effective use of AI in teaching geometry.

In conclusion, the most significant studies for the practical application of AI by teachers in teaching geometry are those by Gao et al. (Gao et al., 2025), Parra et al. (Parra et al., 2024), and Dimitriadou et al. (Dimitriadou & Lanitis, 2025).

6. CONCLUSION

The 21st century demands a revolution in educational paradigms, providing innovative approaches to teaching and learning (Nadzeri et al., 2024). The presence of artificial intelligence (AI) in education is a reality that affects, to varying degrees, all participants in the educational process (Gurevych et al., 2025). In the context of education, generative AI (Gen-AI) models serve as tools that enhance teaching and learning experiences by continuously generating engaging educational content (Dimitriadou & Lanitis, 2025). Thanks to the revolutionary capabilities of Gen-AI, the field of geometry is currently undergoing significant transformation. These advanced technologies not only offer solutions for complex geometric problems but also facilitate breakthrough innovations in design.

However, the scientific literature still contains few attempts to apply Gen-AI specifically in the field of geometry (Dimitriadou & Lanitis, 2025).

Currently, there are several systematic reviews on the integration of digital technologies into mathematics education in general. For example: Zhong & Xia (Zhong & Xia, 2020), Ahmad & Junaini (Awang et al., 2025), Abebayehu & Hsiu-Ling (Abebayehu & Hsiu-Ling, 2023) Hwang et al. (G.-J. Hwang & Tu, 2021), Mohamed et al. (Mohamed et al., 2022), Hwang.

(S. Hwang, 2022), Niño-Rojas et al. (Niño-Rojas et al., 2023), Awang et al. (Awang et al., 2025). However, we did not identify any systematic reviews on the use of AI in geometry education for the period 2023–2025.

The aim of the review presented in this article is a systematic analysis of studies (from 2023 to 2025) on the application of AI in geometry education. We chose a three-year period to identify the newest AI tools and technologies that have been tested in research. The review provides a comprehensive overview of the topics most investigated during this period; the regions with the most active research; methods, techniques, and tools for using AI in geometry education that have proven effective; specific recommendations for teachers on using AI in teaching geometry; concrete practical research results; and relevant directions for future research indicated by the authors of published studies.

The results obtained provide mathematics teachers with valuable information that can promote more effective use of AI in geometry education, and they guide mathematics education researchers on current trends in improving the geometry learning process.

RECOMMENDATIONS

Although this review revealed much valuable information for teachers instructing students in geometry and for researchers studying AI use in geometry education, it has several limitations.

First, the number of available articles for analysis was small. Since the use of AI in geometry education is relatively under-researched, the results are limited, and it is difficult to draw general conclusions. Moreover, most studies only superficially address AI use in geometry education without deeply explaining the results. The research focused solely on articles explicitly dedicated to geometry learning. Naturally, AI use in geometry education may also be discussed in studies addressing AI in mathematics education more broadly. Finally, the studies reviewed exhibit considerable variation in examples and approaches. Due to diverse contexts, results may be biased. Additionally, the review was conducted within a specific time frame, which may not reflect rapid changes in education or technology. These limitations should be considered when interpreting the results of the review.

ACKNOWLEDGEMENT

The authors would like to thank Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University for its support in organizing and conducting the research. This article was prepared within the framework of the dissertation study of PhD student Andrii Matiash under the scientific supervision of Liubov Mykhailenko and the scientific consultancy of Olha Matiash.

FUNDING SUPPORT

Authors state no funding involved.

ETHICAL STATEMENT

This study does not contain any studies with human or animal subjects performed by any of the authors.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest to this work.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data werecreated or analyzed in this study.

AUTHOR CONTRIBUTION STATEMENT

Olha Matiash: Conceptualization, Methodology, Formal analysis, Resources, Writing - origimal draft, Writing - review & editing. Liubov Mykhailenko: Formal analysis, Writing - origimal draft, Validation, Supervision, Project admmistration. Andrii Matiash: Data curation, Visualization, Validation, lnvestigation.

REFERENCES

Abebayehu, Y., & Hsiu-Ling, C. (2023). GeoGebra in mathematics education: a systematic review of journal articles published from 2010 to 2020. *Interactive Learning Environments*, *31*(9), 5682–5697. https://doi.org/10.1080/10494820.2021.2016861

Awang, L. A., Yusop, F. D., & Danaee, M. (2025). Current practices and future direction of artificial intelligence in mathematics education: A systematic review. *International Electronic Journal of Mathematics Education*, *20*(2), em0823. https://doi.org/10.29333/iejme/16006

Botana, F., Recio, T., & Vélez, M. P. (2024). On Using GeoGebra and ChatGPT for Geometric Discovery. *Computers*, *13*(8), 187. https://doi.org/10.3390/computers13080187

Cunha, C. R., Moreira, A., Coelho, S., Mendonça, V., & Gomes, J. P. (2025). *Empowering the Teaching and Learning of Geometry in Basic Education by Combining Extended Reality and Machine Learning*. https://doi.org/10.1007/978-3-031-60224-5_11

Dilling, F., & Herrmann, M. (2024). Using large language models to support pre-service teachers mathematical reasoning—an exploratory study on ChatGPT as an instrument for creating mathematical proofs in geometry. *Frontiers in Artificial Intelligence*, *7*. https://doi.org/10.3389/frai.2024.1460337

Dimitriadou, E., & Lanitis, A. (2025). *On the potential of using generative artificial intelligence for geometry educational activities*. https://www.researchgate.net/publication/391230545

Ding, J., Hong, Z., & Yu, M. (2024). The Application and Effects of Augmented Reality in Geometry Learning. *Lecture Notes in Education Psychology and Public Media*, *74*(1), 34–42. https://doi.org/10.54254/2753-7048/74/2024BO0007

Gao, J., Pi, R., Zhang, J., Ye, J., Zhong, W., Wang, Y., Hong, L., Han, J., Xu, H., Li, Z., & Kong, L. (2025). *G-LLaVA: Solving Geometric Problem with Multi-Modal Large Language Model*.

Gurevych, R., Alekseiko, V., Murzina, O., Kusiy, M., Shakotko, V., & Vasilieva, S. (2025). The Role of Digitalisation in the Educational Process in the Creation and Functioning of Artificial Intelligence. *BRAIN. Broad Research in Artificial Intelligence and Neuroscience*, *16*(1 Sup1), 79. https://doi.org/10.70594/brain/16.S1/7

Hwang, G.-J., & Tu, Y.-F. (2021). Roles and Research Trends of Artificial Intelligence in Mathematics Education: A Bibliometric Mapping Analysis and Systematic Review. *Mathematics*, *9*(6), 584. https://doi.org/10.3390/math9060584

Hwang, S. (2022). Examining the Effects of Artificial Intelligence on Elementary Students' Mathematics Achievement: A Meta-Analysis. *Sustainability*, *14*(20), 13185. https://doi.org/10.3390/su142013185

Matiash, O., Mykhailenko, L., Tiutiunnyk, D., Yashchuk, K., & Kateryniuk, H. (2025). Advantages and disadvantages of laboratory lessons in mathematics teaching methodology under emergency remote teaching conditions. *Social Sciences & Humanities Open*, *11*, 101236. https://doi.org/10.1016/j.ssaho.2024.101236

Mohamed, M. Z. bin, Hidayat, R., Suhaizi, N. N. binti, Sabri, N. binti M., Mahmud, M. K. H. bin, & Baharuddin, S. N. binti. (2022). Artificial intelligence in mathematics education: A systematic literature review. *International Electronic Journal of Mathematics Education*, *17*(3), em0694. https://doi.org/10.29333/iejme/12132

Mouselinos, S., Michalewski, H., & Malinowski, M. (2024). *Beyond Lines and Circles: Unveiling the Geometric Reasoning Gap in Large Language Models*.

Mykhailenko, L., Matiash, O., Milian, R., Kalashnikov, I., & Horiashyn, A. (2022). Mathematics Teacher's Methodical Competence Development in the Conditions of the University and School Partnership. *Journal of Higher Education Theory and Practice*, *22*(12). https://doi.org/10.33423/jhetp.v22i12.5465

Nadzeri, M. B., Musa, M., Cheng Meng, C., & Ismail, I. M. (2024). The Effects of Augmented Reality Geometry Learning Applications on Spatial Visualization Ability for Primary School Pupils. *International Journal of Interactive Mobile Technologies (IJIM)*, *18*(16), 104–118. https://doi.org/10.3991/ijim.v18i16.47079

Niño-Rojas, F., Lancheros-Cuesta, D., Jiménez-Valderrama, M. T. P., Mestre, G., & Gómez, S. (2023). Systematic Review: Trends in Intelligent Tutoring Systems in Mathematics Teaching and Learning. *International Journal of Education in Mathematics, Science and Technology*, *12*(1), 203–229. https://doi.org/10.46328/ijemst.3189

Ogoke, C. J., Anyanwu, A., Okolie, A., Onuoha, E., & Vivian, D.-O. (2025). Application of artificial intelligence in the teaching and learning of mathematics: Implication for achievement and retention. *Eureka: Journal of Educational Research*, *3*(2), 134–141. https://doi.org/10.56773/ejer.v3i2.62

Parra, V., Sureda, P., Corica, A., Schiaffino, S., & Godoy, D. (2024). Can Generative AI Solve Geometry Problems? Strengths and Weaknesses of LLMs for Geometric Reasoning in Spanish. *International Journal of Interactive Multimedia and Artificial Intelligence*, *8*(5), 65. https://doi.org/10.9781/ijimai.2024.02.009

Polydoros, G., Galitskaya, V., Antoniou, A.-S., & Drigas, A. (2025). AI Technology Integration in Elementary Geometry and Its Effects on Performance, Anxiety Levels, Learning Styles, Cognitive Styles, and Executive Functions. *Scientific Electronic Archives*, *18*(2). https://doi.org/10.36560/18220252050

Sinha, S., Prabhu, A., Kumaraguru, P., Bhat, S., & Bethge, M. (2024). *Wu's Method can Boost Symbolic AI to Rival Silver Medalists and AlphaGeometry to Outperform Gold Medalists at IMO Geometry*.

Sousa, C. C. de, Sobrinho, M. F., & Silva, A. R. da. (2024). Inteligência Artificial no Ensino de Geometria Espacial. *EmRede - Revista de Educação a Distância*, *11*. https://doi.org/10.53628/emrede.v11i.1102

Sunzuma, G. (2023). Technology integration in geometry teaching and learning. *LUMAT: International Journal on Math, Science and Technology Education*, *11*(3). https://doi.org/10.31129/LUMAT.11.3.1938

Trinh, T. H., Wu, Y., Le, Q. V., He, H., & Luong, T. (2024). Solving olympiad geometry without human demonstrations. *Nature*, *625*(7995), 476–482. https://doi.org/10.1038/s41586-023-06747-5

Uriarte-Portillo, A., Zatarain-Cabada, R., Barrón-Estrada, M. L., Ibáñez, M. B., & González-Barrón, L.-M. (2023). Intelligent Augmented Reality for Learning Geometry. *Information*, *14*(4), 245. https://doi.org/10.3390/info14040245

Wulandari, D., Istadi, I., & Muttaqien, A. (2024). Proceedings of Universitas Muhammadiyah Yogyakarta Graduate Conference. *The Use of Artificial Intelligence in Numerical Learning of Geometry for Students with Mild Intellectual Disabilities*, 27–31.

Xu, S., Luo, Y., & Shi, W. (2024). *Geo-LLaVA: A Large Multi-Modal Model for Solving Geometry Math Problems with Meta In-Context Learning*. https://doi.org/10.1145/3688866.3689124

Zhang, C., Song, J., Li, S., Liang, Y., Ma, Y., Wang, W., Zhu, Y., & Zhu, S.-C. (2024). *Proposing and solving olympiad geometry with guided tree search*.

Zhong, B., & Xia, L. (2020). A Systematic Review on Exploring the Potential of Educational Robotics in Mathematics Education. *International Journal of Science and Mathematics Education*, *18*(1), 79–101. https://doi.org/10.1007/s10763-018-09939-y

Mambetova, N. S. (2024). THE ROLE OF ARTIFICIAL INTELLIGENCE IN THE CREATIVE ACTIVITY OF STUDENTS IN TEACHING GEOMETRY. *Вестник Иссык-Кульского Университета*. https://doi.org/10.69722/1694-8211-2024-58-225-232