IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Generative Artificial Intelligence in Proof-Based Mathematics Learning: A Critical Review of Its Educational Potential

[1]Mrs M Drakshayani , [2]Mr K Thippeswamy

[1]Senior Grade Lecturer, [2]Senior Grade Lecturer

[1]Humanities and Sciences

[1]SANJAY GANDHI POLYTECHNIC , BALLARI , INDIA

Abstract: Mathematical proof is a fundamental component of mathematics education because it develops logical reasoning, justification, argumentation and conceptual understanding. However, learning and teaching mathematical proofs can be challenging because students are required to move beyond procedural problem solving and construct logically connected arguments based on definitions, theorems and previously established results. The emergence of Generative Artificial Intelligence (GenAI), particularly Large Language Model (LLM)-based systems, has created new possibilities for supporting mathematical learning through dialogue, explanation, feedback, problem solving and reasoning. This paper examines the potential use of Generative AI for teaching mathematical proofs through a review and synthesis of recent literature on artificial intelligence in mathematics education and the use of generative AI in mathematical reasoning and proving. The study discusses the ways in which GenAI can support proof learning by providing step-by-step explanations, suggesting alternative proof strategies, identifying errors, generating counterexamples, encouraging reflection and functioning as a conversational thought partner. At the same time, the literature indicates important limitations, including mathematically incorrect responses, hallucinations, over-reliance on AI-generated solutions, reduced student engagement in proof construction, lack of transparency and concerns related to academic integrity. The paper argues that Generative AI should be used as a pedagogical support tool rather than as a replacement for students' mathematical reasoning or teachers' instructional roles. Effective integration requires carefully designed prompts, verification of AI-generated proofs, teacher guidance and development of students' critical AI literacy. The study concludes that Generative AI has considerable potential to enrich the teaching of mathematical proofs when its use is grounded in sound mathematical pedagogy and focused on student reasoning, reflection and independent proof construction.

Index Terms - Generative Artificial Intelligence, Mathematical Proof, Mathematics Education, Large Language Models, ChatGPT, Mathematical Reasoning, Proof Construction, AI-Supported Learning.

I. INTRODUCTION

Mathematical proof is one of the fundamental components of mathematics because it provides a systematic method for establishing the validity of mathematical statements. Proof requires learners to move beyond obtaining an answer and develop logical arguments that explain why a mathematical statement is true. The process involves understanding definitions, identifying assumptions, selecting appropriate mathematical principles, establishing logical relationships, and communicating the reasoning in a coherent manner. Therefore, learning mathematical proof contributes not only to mathematical knowledge but also to the development of logical reasoning, critical thinking, justification, and problem-solving abilities.

However, mathematical proof is often challenging for students. The construction of a proof requires learners to coordinate several mathematical ideas simultaneously and to recognize whether each step follows logically from the previous one. Students may understand a mathematical concept at a procedural level but experience difficulty when they are required to formulate an independent proof. The transition from solving routine mathematical problems to constructing and evaluating formal mathematical arguments therefore represents an important challenge in mathematics education.

The emergence of Generative Artificial Intelligence (GenAI), particularly Large Language Models (LLMs), has introduced new possibilities for supporting mathematics learning. Generative AI systems can engage learners in conversational interaction and generate explanations, examples, solution pathways, hints, and feedback. Walkington's review of Generative AI in mathematics education identifies applications in mathematical problem solving, tutoring and feedback, mathematical task adaptation, and teacher support.

Recent research indicates that the application of AI in mathematics education is moving beyond procedural assistance toward mathematical thinking, reasoning, and proof construction. A systematic review of AI research in mathematics education found that AI tools such as ChatGPT and other mathematical technologies have been used to generate multiple solution pathways, provide step-by-step explanations, model reasoning, support proof verification, and identify misconceptions.

The use of Generative AI is particularly relevant to mathematical proof because students can potentially interact with AI during different stages of the proof process. Instead of simply receiving a completed solution, learners can use AI to obtain hints, explore alternative proof strategies, examine errors, generate counterexamples, and discuss the logical structure of an argument. Research identified in the reviewed literature also suggests that students can use Generative AI as a thought partner when working on mathematical proving.

At the same time, the use of Generative AI for proof learning raises important concerns. Mathematical proofs require a high degree of logical precision, whereas Generative AI systems can generate incorrect proofs, misapply logical steps, or provide apparently convincing but invalid reasoning. The literature therefore emphasizes the importance of verification and critical evaluation of AI-generated mathematical content.

Another concern is that students may become dependent on AI-generated solutions. If students use AI primarily to obtain completed proofs, they may lose opportunities to develop the independent reasoning and productive struggle that are central to proof learning. Research on the use of Generative AI for mathematical proving has identified a tension between the convenience offered by AI and genuine student engagement in proof construction.

Therefore, the important question is not simply whether Generative AI can generate a mathematical proof, but how it can be used to support students in learning to construct, evaluate, and communicate mathematical proofs independently. This paper examines the potential role of Generative AI in teaching mathematical proofs, its applications, benefits, limitations, and the role of teachers in ensuring that AI supports rather than replaces mathematical reasoning.

II. Mathematical Proofs And Generative Ai In Mathematics Education

i) Mathematical Proof as a Form of Mathematical Reasoning

Mathematical proof represents a formal form of mathematical reasoning in which a conclusion is established from assumptions, definitions, axioms, and previously proven results. The ability to construct a proof requires students to understand the logical relationships between mathematical statements and to provide adequate justification for each step.

Proof learning therefore involves several interconnected skills. Students need to understand the mathematical statement, identify relevant conditions, determine an appropriate strategy, establish logical connections, and communicate the resulting argument clearly. They must also be able to distinguish between an intuitively convincing statement and a mathematically valid proof.

This makes proof education different from routine mathematical problem solving. In a routine problem, a student may be able to apply a known procedure to obtain an answer. In proof construction, however, the student must determine how the argument should be developed and why each step is justified.

The use of AI in this context is therefore potentially valuable because AI systems can interact with students during the reasoning process. However, the central objective should remain the development of students' own mathematical reasoning.

ii) Generative AI in Mathematics Education

Generative AI is a category of artificial intelligence capable of generating new outputs based on patterns learned from large amounts of training data. Large Language Models are one important form of Generative AI and are capable of producing natural-language responses to user prompts. Walkington notes that the release of ChatGPT generated considerable interest in its potential applications within mathematics education.

The literature shows that Generative AI has been investigated for mathematical problem solving, tutoring, feedback, task generation, and teacher planning. Its conversational nature allows learners to interact with mathematical content through questions and follow-up responses rather than relying only on fixed instructional materials.

A systematic review of AI in mathematics education similarly found that AI applications are increasingly concerned with conceptual understanding and mathematical reasoning rather than only procedural fluency. AI tools have been reported to support structured reasoning, exploratory problem solving, multiple solution pathways, and mathematical verification.

iii) Relevance of Generative AI to Mathematical Proofs

Mathematical proof provides a particularly important context for examining Generative AI because proof requires students to reason, justify and evaluate arguments. Generative AI can potentially participate in this process by providing explanations and prompts that help learners consider different approaches. The systematic review literature specifically identifies proof construction and proof verification among the emerging applications of AI in mathematics education. However, the role of AI needs to be carefully defined. If AI simply generates the entire proof, the student may become a passive recipient of an answer. If AI instead provides a hint, asks a question, points to a definition, or challenges a logical step, it can become a tool that supports the learner's own reasoning. This distinction is important because the purpose of proof education is not merely to expose students to correct proofs but to develop their ability to **construct and evaluate mathematical arguments**.

III. Applications Of Generative Ai In Teaching Mathematical Proofs

i. Explaining Proof Concepts

One application of Generative AI is to provide explanations of fundamental proof concepts. Students can use conversational AI to request explanations of different proof techniques, including direct proof, proof by contradiction, proof by contra positive, mathematical induction, and the use of counterexamples. The conversational nature of Generative AI allows students to ask follow-up questions when an initial explanation is not sufficient. For example, a learner can ask the system to explain why a particular assumption is necessary or why a specific theorem is applicable. However, AI-generated explanations should not automatically be accepted as correct. Mathematical explanations need to be evaluated against established definitions and mathematical principles because AI systems can generate incorrect reasoning.

ii. Step-by-Step Proof Guidance

Generative AI can provide step-by-step guidance during proof construction. Instead of requesting a complete proof, students can ask for a starting point, a relevant definition, or a possible next step.

For example, a student may ask:

“Give me a hint for how to begin this proof without giving the complete solution.”

This type of interaction can provide scaffolding while allowing students to remain responsible for the construction of the argument.

The reviewed literature indicates that AI can provide step-by-step explanations and model structured reasoning.

For proof learning, the value of such support lies in helping students overcome a specific difficulty without removing the entire reasoning process.

iii. Suggesting Proof Strategies

A mathematical statement may sometimes be established using different proof methods. Generative AI can help students explore possible approaches by suggesting whether a direct proof, contradiction, contrapositive, induction, or another strategy may be appropriate. The student can then compare the proposed strategies and decide which one is mathematically suitable. This use can encourage students to think about proof strategy rather than simply follow a predetermined procedure. The literature reports that AI can generate multiple solution pathways and support exploratory reasoning. However, students must evaluate whether a suggested strategy actually works for the given mathematical statement.

iv. Identifying Errors in Student Proofs

Students can also use Generative AI to examine their own proof attempts. Rather than asking AI to rewrite an entire proof, students can ask it to identify a possible logical gap or unsupported statement.

For example:

“Identify the first step in my proof that requires additional justification.”

This approach can help students focus on the quality of their reasoning.

The literature identifies AI-supported error detection and misconception identification as emerging applications in mathematics education.

Nevertheless, AI-generated error identification must itself be checked. A system can incorrectly identify a valid step as an error or fail to recognize a subtle logical problem.

v. Generating Counterexamples

Counterexamples are an important component of mathematical reasoning because they can demonstrate that a universal mathematical statement is false. Generative AI can assist learners by suggesting possible examples that they can subsequently test. Students can use these examples to examine the limits of a conjecture and determine whether additional assumptions are required. This activity can promote mathematical exploration because students are encouraged to question whether a statement is universally valid rather than simply attempting to prove it.The responsibility for checking the counterexample should remain with the student because AI-generated examples may not satisfy all the conditions of the original statement.

vi. Providing Alternative Proofs

Generative AI can also generate alternative approaches to the same mathematical statement. Students can compare these approaches and examine differences in structure, assumptions, efficiency, and clarity.

For example, a student who has developed a direct proof may ask whether the same statement can be established using contradiction or contra positive reasoning.

The educational value of alternative proofs is not simply that students obtain more solutions. Rather, comparison can help students recognize that mathematical statements can sometimes be approached from different logical perspectives.

vii. Generative AI as a Mathematical Thought Partner

One of the most relevant applications of Generative AI in proof learning is its use as a mathematical thought partner. Rather than treating AI as an answer generator, students can use it to discuss ideas, test possible strategies, and receive questions that stimulate further reasoning. The reviewed literature identifies this dialogic use of AI as an important direction in mathematics education. AI-supported interaction can facilitate inquiry, scaffolding and reflective thinking when students are encouraged to interrogate and refine AI-generated responses. In this approach, the student remains the primary mathematical reasoned. AI provides prompts and suggestions, while the student decides which ideas are mathematically valid.

IV. Benefits Of Generative Ai For Proof Learning

i. Immediate Support and Feedback

One important advantage of Generative AI is its ability to provide immediate responses to student questions. Students do not necessarily need to wait for classroom feedback before receiving an explanation or hint. Immediate feedback can be particularly useful during proof construction because students may encounter difficulties at individual steps of an argument.

ii. Support for Difficult Mathematical Concepts

Proofs frequently involve abstract concepts that students may find difficult to understand. Generative AI can provide explanations using different levels of detail and can respond to requests for clarification. This may help students approach difficult concepts from more than one perspective.

iii. Multiple Reasoning Pathways

AI can present alternative strategies and solution pathways. The literature indicates that AI-supported mathematics learning can involve multiple representations and structured solution pathways. For proof learning, exposure to multiple approaches may help students understand that proof construction is not always a single linear process.

iv. Support for Reflection

When students critically examine AI-generated proofs, they can be encouraged to ask whether every step is justified and whether the assumptions have been used correctly.The systematic review indicates that AI-supported learning can promote reflective thinking when students are given opportunities to verify and interrogate AI-generated responses.

v. Development of Error-Detection Skills

AI-generated solutions can also become material for mathematical critique. Students can examine a generated proof and identify whether it contains a logical gap. This changes the role of AI from a source of answers into an object of analysis.

vi. Supporting Student Engagement

Dialogic interaction with AI may provide students with additional opportunities to ask questions and explore mathematical ideas.The literature suggests that interactive AI use can support inquiry and engagement when it is accompanied by appropriate pedagogical guidance.

vii. Supporting Independent Learning

Generative AI can potentially provide students with additional opportunities to explore mathematical ideas outside direct classroom interaction. Students can ask for clarification, request examples, and revisit difficult concepts.However, independent use should not mean unsupervised acceptance of AI-generated mathematics. Independent learning must include the ability to verify and critically evaluate AI output.

V. Challenges And Limitations

i. Incorrect Mathematical Proofs

The most important limitation of Generative AI in proof education is the possibility of incorrect mathematical reasoning. The reviewed literature specifically reports that Generative AI systems can produce incorrect proofs, misapply logical steps, and generate flawed mathematical simplifications.This is particularly serious in proof education because a single invalid logical step can make an entire proof incorrect.

ii. Hallucinated or Unsupported Reasoning

Generative AI can produce responses that appear convincing because they are expressed fluently and confidently. However, fluency does not guarantee mathematical validity. Students who lack sufficient mathematical knowledge may have difficulty distinguishing a valid proof from a plausible but incorrect explanation.Therefore, AI output must be treated as **provisional rather than authoritative**.

iii. Over-Reliance on AI

If students consistently request complete proofs from AI, they may become dependent on generated solutions.The reviewed research identifies a tension between convenience and genuine engagement in proof construction.This creates a major pedagogical concern because proof learning requires students to experience the process of constructing and revising arguments themselves.

iv. Reduced Independent Reasoning

A student who copies a complete AI-generated proof may produce a correct answer without developing the ability to construct the argument independently. Therefore, the use of AI should be designed to preserve student reasoning. The literature emphasizes that AI should enhance rather than replace mathematical reasoning.

v. Difficulty in Verifying AI Responses

Students may assume that an AI-generated proof is correct simply because it appears logically organized.However, verification requires mathematical knowledge. Students must be able to check definitions, assumptions, theorem applications and logical implications independently.

vi. Academic Integrity

Generative AI also creates concerns regarding academic integrity. If students submit AI-generated proofs as their own work, teachers may not be able to determine whether the students have actually developed the required reasoning skills.This suggests that proof assessment should place greater emphasis on the student's explanation of reasoning and ability to defend the proof rather than simply evaluating the final written product.

vii. Need for Critical AI Literacy

Students require the ability to use AI critically. They should understand that an AI system can be useful while still being fallible.The literature emphasizes the importance of critical AI literacy and ethical guidelines when Generative AI is used for mathematical proving.

VI. Role Of The Teacher And Effective Integration Of Generative Ai

The introduction of Generative AI does not eliminate the role of the mathematics teacher. Instead, it creates a need for stronger teacher guidance because students require support in interpreting and evaluating AI-generated mathematical content.

i. Teacher as a Guide

Teachers should establish clear expectations regarding appropriate AI use. Students should understand that AI is a support tool and not a replacement for mathematical reasoning.The systematic review emphasizes that AI-supported mathematics learning is most effective when it is grounded in pedagogical objectives and supported by teacher expertise.

ii. Teaching Students to Verify AI-Generated Proofs

Teachers should explicitly teach students how to verify AI-generated proofs.

Students can be asked to:

- Check every logical step;
- Identify the assumptions;
- Verify definitions;
- Confirm theorem applications;
- Test examples and counterexamples; and
- Determine whether the conclusion actually follows from the premises.

This process turns AI use into an opportunity for mathematical evaluation.

iii. Using AI for Hints Rather Than Complete Answers

A particularly useful strategy is to encourage students to request hints rather than complete solutions.

For example, instead of asking:

“Give me the proof,”

students can ask:

“Give me one hint for beginning the proof.”

This preserves the student's responsibility for constructing the argument.

iv. Developing Critical AI Literacy

Teachers should help students understand the limitations of Generative AI. Students need to recognize that AI can make mistakes and that mathematically correct reasoning must be independently verified. Research on AI-supported mathematics education emphasizes the importance of critical engagement with AI-generated responses rather than passive acceptance.

v. Designing AI-Supported Proof Activities

Teachers can design activities in which students are required to evaluate AI-generated proofs.

For example, students may be given an AI-generated proof containing one or more errors and asked to identify and correct them.

Another activity can require students to compare two AI-generated proof approaches and determine which one is mathematically valid.

Such activities position AI as an object of mathematical investigation rather than merely a source of solutions.

vi. Maintaining Student Ownership

The final proof should be constructed and understood by the student.AI may provide explanations, hints and suggestions, but the learner should remain responsible for the mathematical argument. This approach is consistent with the literature's emphasis on AI as a mediating tool that supports inquiry, scaffolding, collaboration and reflective thinking rather than replacing human reasoning.

VII. Discussion

The literature reviewed in this paper indicates that Generative AI has considerable potential for supporting the teaching and learning of mathematical proofs. Its conversational nature enables students to interact with mathematical ideas through questions, explanations, hints and alternative approaches. The broader literature on AI in mathematics education demonstrates that AI tools can support structured reasoning, multiple solution pathways, proof construction and proof verification.

The potential value of Generative AI in proof education lies particularly in its ability to provide support during the reasoning process. Students can use AI to clarify definitions, identify possible proof strategies, examine errors, generate counterexamples and compare alternative approaches. Such uses can provide additional opportunities for mathematical exploration.

However, the literature also makes clear that Generative AI should not be treated as a reliable mathematical authority. AI systems can produce incorrect proofs and misapply logical reasoning. Consequently, students must be taught to verify AI-generated mathematical arguments.

A central issue is the difference between **using AI to obtain a proof** and **using AI to learn how to construct a proof**. The first approach may encourage dependency, whereas the second can potentially support mathematical reasoning. Research on students' use of Generative AI for proving has identified precisely this tension between convenience and genuine engagement in proof construction.

Therefore, the most educationally valuable approach is to use AI as a scaffold or thought partner. Students should remain responsible for developing and validating their own arguments. Teachers should provide guidance, design appropriate activities, and ensure that AI interaction contributes to rather than replaces mathematical thinking.

The reviewed literature also suggests that the field is still developing. Although AI-supported proof construction and verification have emerged as important research areas, further evidence is needed concerning the long-term effects of Generative AI on students' independent proof abilities.

VIII. Research Gap

Existing research on Generative AI in mathematics education has expanded rapidly, but much of the literature addresses general problem solving, tutoring, feedback and mathematical learning. Comparatively focused research on the pedagogical use of Generative AI for mathematical proof remains an emerging area.

The systematic review of AI in mathematics education identifies proof construction, reasoning and verification as important applications, but also highlights the need for further research into how AI can be meaningfully integrated with mathematical pedagogy.

A particularly important gap concerns whether AI-supported proof activities actually improve students' independent ability to construct and evaluate proofs. More research is required to distinguish between short-term performance gains obtained through AI assistance and genuine development of mathematical reasoning.

Future studies should therefore examine how different forms of AI interaction—such as hints, questioning, error analysis, proof verification and complete solution generation—affect students' proof learning.

IX. Conclusion

Generative AI represents a significant emerging technology for mathematics education and has particular potential in the teaching and learning of mathematical proofs. The reviewed literature indicates that AI can support students by explaining mathematical concepts, providing step-by-step guidance, suggesting proof strategies, identifying possible errors, generating counterexamples, offering alternative approaches and facilitating mathematical dialogue. At the same time, Generative AI has important limitations. It can produce incorrect proofs, unsupported reasoning and misleading explanations. Excessive dependence on AI may also reduce students' independent engagement with proof construction. Therefore, the value of Generative AI in proof education should not be measured by its ability to generate a correct proof alone. Its greater educational potential lies in helping students think about proofs, question mathematical reasoning, identify errors, compare strategies, and construct their own arguments. The teacher remains central to this process. Effective integration requires teacher guidance, critical evaluation of AI output, appropriate prompting, verification of mathematical reasoning and clear expectations regarding academic integrity. Overall, Generative AI should be viewed as a supportive mathematical learning partner rather than a replacement for the learner's reasoning or the teacher's expertise. When carefully integrated into proof instruction, it has the potential to create more interactive and reflective learning experiences while maintaining the central goal of mathematics education: developing students who can reason, justify, and construct mathematical arguments independently.

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