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Investigation of recent advances related to AI in mathematics education

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Abstract. The integration of mathematics and Artificial Intelligence (AI) is an immensely promising field, making a comprehensive overview in this domain highly essential. This article provides an overview of two methodologies: Sofia and ITS. Sofia is an AI mathematical analysis model that engages in dialogues with multiple components and robots, performing calculations by processing sentences through Unix file system paths. ITS, on the other hand, is an intelligent tutoring system, comprising domain, student, tutor, and interface components, facilitating interactions within the teaching and learning processes. This article intricately delineates the implementation and functionalities of these two methodologies, encompassing their constituents, applications, and limitations. The applications of these methodologies are far-reaching in both mathematics and AI domains. For instance, in the realm of education, ITS can furnish personalized learning experiences by offering feedback and suggestions tailored to students' knowledge and behaviors. In the arena of mathematical analysis, Sofia can aid in analyzing and solving intricate mathematical problems, rendering support and guidance to students and professionals alike. In conclusion, this article offers a comprehensive overview of the amalgamation of mathematics and AI, introducing the implementations and applications of the Sofia and ITS methodologies. These approaches hold substantial potential within the fields of mathematics and AI, providing valuable references for future research and applications.

Keywords: Artificial Intelligence, Sofia, ITS, Education, Mathematics.

1. Introduction

Mathematics is a comprehensive and multifaceted discipline that involves the exploration of numbers, quantities, structures, patterns, and logical reasoning [1-3]. It serves as a foundation for understanding and describing the fundamental principles that govern the world. With its application spanning across various fields such as engineering, physics, finance, and computer science, mathematics is recognized as an indispensable subject for individuals to possess. As technology continues to advance, the integration of artificial intelligence has opened up new possibilities and avenues for problem-solving in the field of mathematics. This convergence has created a new era of opportunities, allowing for innovative approaches and solutions.

The history of Artificial Intelligence development (AI) has witnessed significant advancements, leading to the emergence of various branches such as computer vision [4, 5], natural language processing [6, 7], and more. These branches have given rise to numerous algorithms, including random forests, neural networks, and others. These artificial intelligence algorithms have found

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widespread applications across various fields, including finance, business, and notably, education. In recent years, research has been conducted on the application of artificial intelligence in the realm of mathematics education, furthering the understanding and exploration of this interdisciplinary domain. By utilizing artificial intelligence in mathematics education, students can benefit from enhanced learning experiences and receive personalized feedback, allowing them to grasp mathematical concepts more effectively. Numerous studies have examined the potential use of artificial intelligence in math education. For instance, Steven et al. provide an overview of contemporary AI techniques in digital mathematics education tools, discussing a taxonomy of four classes and highlighting the influence of machine learning [8]. They also explore parallels between AI and mathematics education research, address the need for ME-focused AI techniques, and anticipate the emergence of standard AI-based applications for ME in the future. Knill et al. conducted experiments in the Fall of 2003 and the spring of 2004 using calculus chat bots [9]. These chat bots were equipped with an extensive glossary of mathematics definitions and general knowledge, enabling them to solve simple mathematical template problems posed in everyday language. Additionally, the chat bot named "Sofia" had the capability to interact with computer algebra systems such as Pari or Mathematica to solve basic pre-configured calculus problems. Mohamed et al. conducted a review on the application of artificial intelligence in mathematics education [10].

The second part of this article delves into the various methodologies and approaches employed to integrate AI technologies into the teaching and learning of mathematics. By examining these cutting-edge methods, this section aims to provide a deeper understanding of the potential benefits and challenges associated with leveraging AI in mathematics education. The third part of the paper explores the application scenarios of artificial intelligence in mathematics education, and the conclusion is provided in the last section.

2. Method

2.1. Sofia-based AI model in college math education

Knill, Oliver, and others have proposed an AI mathematical analysis model named Sofia. Firstly, they embedded this model into a larger "wrapper" using existing AI components to facilitate simultaneous use of different components, conversations between robots, and overcoming limitations of interaction with computer algebra systems. Secondly, they built a web interface that allows Sofia to interact with the web, more robots, and computer algebra systems, while handling information exchanged in previous conversations. Knill, Oliver, and others observed limitations in existing robots, including memory constraints, lack of scalability, programming language dependencies, and challenges in expansion and error-proneness. They proofread and simplified sentences, then translated them into paths within the Unix file system and executed corresponding programs along these paths. These programs formed nodes in a neural network. They manually generated parts of the Unix file tree, while other parts were generated by machines from simple text files. Different individuals could work on different subtrees. Furthermore, Knill, Oliver, and others constructed a parsing tree to find meaning in sentence structures, constraining the world model to predefined structural categories. Sentence simplification was governed by context-free rules, integrated as filters. Their approach involved interaction with computer algebra systems, enhancing answers by allowing AI agents to access these systems. They experimented with computer algebra systems such as Mathematica, Pari, and Maxima, interacting through a shell interface. They encoded strings from the computer algebra systems as common words, enabling machines to process these words in a conversational manner.

They attempted to address context issues in dialogues by transmitting contextual information back and forth through hidden variables sent over the network, which the robots could access. However, the challenge remained to extract information from the context for robots to search in the correct locations. Knill, Oliver, and others trained the Sofia model through methods including hardcoding knowledge into the robots' brains, incorporating learning through recorded dialogue feedback, enabling robots to mutually teach through conversations, and searching for information online.

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2.2. Intelligent tutoring systems

A classification of artificial intelligence systems for mathematics education. The article summarizes Intelligent Tutoring Systems (ITS) that consist of four components: (i) the domain component for encoding expert knowledge, (ii) the student component to represent student knowledge and behavior, (iii) the tutor component for selecting optimal teaching actions, and (iv) the interface for interacting with students.

The domain component includes expert knowledge, task databases, and error databases. The student component comprises student models and student data. The tutor employs a reasoning engine to track student reasoning processes, detect errors, provide feedback, and offer personalized learning paths based on data from both students and the domain component. The modeling of ITS employ's probability and approximation techniques, such as Bayesian networks or fuzzy modeling.

Currently, many practical applications of ITS are designed and adapted using data-driven methods to enhance the learning experience. Literature on student modeling is extensive, and numerous student models exist in actual ITS. However, most student models focus only on specific aspects of students, lacking comprehensiveness. Comprehensive student models should encompass a complete model of student knowledge as well as a model of their behavior, requiring more advanced artificial intelligence.

Interaction with ITS ensures that learning occurs, and target performance is achieved. Exploration and creativity play crucial roles in AI and require a degree of randomness. In reinforcement learning, exploration is used to determine how to maximize rewards. The demand for exploration in artificial intelligence technology suggests that AI can exhibit creative behavior. Randomness can be employed to initiate exploration of solution spaces in neural networks.

3. Application and discussion

AI is revolutionizing mathematics education across multiple dimensions:

Personalized Learning: Utilizing AI-driven platforms, students' learning patterns and performance are scrutinized to forge personalized learning paths. This ensures that each student is presented with targeted exercises and explanations aligned with their specific strengths and weaknesses.

Adaptive Assessments: AI-powered assessment systems dynamically adjust questions based on students' responses in real-time. This dynamic approach yields a more precise evaluation of students' skill levels and knowledge.

Intelligent Tutoring: Intelligent Tutoring Systems (ITS) employ AI algorithms to furnish students with immediate feedback and guidance during the resolution of mathematical problems. These systems adeptly identify perplexing areas and provide pertinent explanations.

Problem Solving: AI assists students in tackling intricate mathematical problems by proposing pertinent strategies, step-by-step solutions, and alternative methodologies.

Visualizations: AI fabricates interactive visualizations and simulations that aid students in comprehending abstract mathematical concepts more effortlessly. These visual aids substantially enhance understanding and engagement.

Automated Grading: AI streamlines the grading process for assignments, quizzes, and exams, alleviating the burden on educators and ensuring prompt feedback to students.

Natural Language Processing: AI-driven chatbots and virtual assistants adeptly address students' math-related queries in natural language. This facilitates instantaneous clarification and learning.

Data Analysis: In advanced mathematics, AI tools analyze extensive datasets to unearth patterns, trends, and correlations, profoundly impacting domains such as statistics and data science.

Game-Based Learning: AI is seamlessly integrated into educational games, infusing an element of enjoyment and interaction into the learning of mathematics.

Language Translation: AI bridges language barriers by rendering mathematical content into various languages, thereby enhancing the global accessibility of educational resources.

Concept Mapping: AI aids in constructing visually appealing concept maps or mind maps that effectively organize and interlink diverse mathematical ideas.

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Assistive Technology: AI lends support to students with special needs by furnishing supplementary explanations, visual aids, or customized learning trajectories.

Research and Exploration: AI algorithms aid mathematicians in navigating complex mathematical theories, generating hypotheses, and conducting experimental analyses.

Automated Content Generation: AI generates mathematical exercises, practice problems, and educational content, resulting in time savings for educators and a richer variety of learning materials.

4. Conclusion

The integration of mathematics and artificial intelligence (AI) is an immensely promising field, making a comprehensive overview of this domain highly necessary. This article provides a review of two approaches: Sofia and Intelligent Tutoring Systems (ITS). Sofia is an AI mathematical analysis model that engages in dialogue with multiple components and robots, performing calculations by processing sentences through Unix file system paths. ITS, on the other hand, is an intelligent tutoring system encompassing domain, student, tutor, and interface components, facilitating interactions within the teaching and learning process. This article thoroughly delineates the implementation and functions of these two approaches, including their compositions, applications, and limitations. These methods find wide-ranging applications in both the realms of mathematics and AI. For instance, in the realm of education, ITS can furnish personalized learning experiences, providing feedback and suggestions based on students' knowledge and behaviors. In mathematical analysis, Sofia can assist in analyzing and solving intricate mathematical problems, offering support and guidance to students and professionals.

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