Exploration of the Application of Artificial Intelligence in Mathematics Education

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Abstract. With the ever-changing nature of the digital age, Artificial Intelligence (AI) in Education has been an area of intense research, particularly in the field of Mathematics Education. Mathematics is an abstract concept that requires logical thinking, and it can cause anxiety in students and uneven progress in their learning. The current paper discusses how AI can be applied to teaching mathematics. It provides an overview of the main technologies: Intelligent Tutoring Systems (ITS), adaptive platforms, and educational data mining. All these tools enable personalized learning and enhance the efficiency and involvement of learners. These transform the role of teachers. Nevertheless, AI also presents issues including the privacy of information, bias in algorithms, and the digital gap. The present study offers some future directions. It points to the principles of ethics and the integration of AI with human instruction as the foundation of fair and successful math education.

Keywords: Artificial intelligence in education, Mathematics education, Personalized learning, Intelligent tutoring systems, Educational data mining

1 Introduction

The current age of digitalization recent progress in the sphere of artificial intelligence (AI) has significantly affected many spheres, in particular, education. The recent past has seen more and more AI technologies, including machine learning, natural language processing and data analytics, being incorporated into the educational setting, providing new opportunities in terms of personalized learning, intelligent tutoring and educational assessment. Because it is a background subject, there are a lot of challenges in mathematics education such as anxiety among students, differences in pace of learning, a requirement in different ways of instructing students. The conventional methods of teaching usually cannot overcome these challenges properly. Nevertheless, with the introduction of AI educational programs, one could hope that mathematics education and learning would be transformed in a positive manner because it can provide adaptive and supportive interactive, and data-driven assistance. Many researchers have expressed the fast-changing environment. One of them was how an innovative ICT technology to learn math was introduced into the school system in Sweden to give more insight into the way schools manage the digitalization effort and its outcome [1]. Although it is

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focused on institutional integration, this research also needs to look into some particular uses of technology in the classroom. To achieve this, Mohamed et al. provided input on the influence of AI, robotics, and computer programs in the process of teaching and learning mathematics to all levels of students [2]. But, the effective use of such methods depends much on the preparedness of teachers. Tashtoush et al., in their attempt to address this gap, have explored how mathematics teachers perceive the current AI systems, and found that AI can serve as a learning tool to support the process of teaching and enhance student performance [3]. Lastly, as a way of giving some structure to these results, Nurwahid and Ashar based their analysis on the Miles model in three stages, including collecting data, verifying and concluding. It is evident that the application of AI in mathematics education entails personalization of learning, automated assessment as well as game-based interactive learning [4].

Although those developments have taken place, there are no overall syntheses of all these developments which would outline the main AI technologies in a systematic way, evaluate the outcomes achieved by them critically, and bring together practical issues and the future orientations. This review will be addressing those gaps. To achieve a logical understanding of how AI can be applied in mathematics education is the focus of this paper. The next part of the paper will divide and discuss the main AI technologies such as the Intelligent Tutoring Systems, adaptive learning platforms and educational data mining. This will be followed by an evaluation of the outcomes of these applications in learning outcomes and engagement based on the empirical results of this application. Finally, the authors will describe the current challenges and suggest informed research and development perspectives, leading to the ultimate conclusion of the situation in the area, and possibilities.

2 Overview of Mainstream Technologies

AI in mathematics education is an assortment of various technologies that have different pedagogic purposes. The present section groups the current mainstream technologies that are transforming the field.

2.1 Intelligent Tutoring Systems

Intelligent Tutoring Systems (ITS) is one of the oldest and most developed applications of AI in the educational sphere. Based on earlier research conducted by Balacheff, ITS are intended to model the one-to-one teaching environment that would be offered by a human tutor [5]. In contrast to simple drill-and-practice software, an ITS has three fundamental models, the domain model (maths knowledge), student model (state of knowledge in the learner), and the tutoring model (pedagogical practices).

In actuality, when a student is solving a linear equation, an ITS not only marks the answer as incorrect but also determines the precise spot where the error occurred. It might be a simple arithmetic error or an issue with understanding the variables. The system provides prompt and specific feedback to assist the student in improving. As pointed out by Verbruggen et al., these systems have found to be most effective in the early stages of mathematics education in supporting the development of basic numeracy skills whereby learners can work on their own with the provision of guided support [6].

2.2 Adaptive Learning Systems

Although ITS is about instant assistance with a task, Adaptive Learning Systems (ALS) are functioning on a macro level where the curriculum changes dynamically according to how the students perform. Such systems make use of elaborate algorithms that generate an individualized learning pathway as regards the learner in each instance.

According to the research of Guo and Zhang [7], in higher education engineering mathematics courses adaptive systems are able to evaluate a student competency in prerequisite concepts (e.g., calculus differentiation), prior to presenting complex analysis concepts [7]. When a gap is identified, the system will automatically guide the student back to the remedial modules. The non-linear system makes sure that students do not advance to more advanced level when some foundations are missing which is the major cause of failure in cumulative subjects such as mathematics.

2.3 Educational Data Mining (EDM) and Learning Analytics

Educational Data Mining (EDM) is used as an analytical engine of most AI interventions. This includes the use of statistical analysis on massive volumes of data created by students interacting with digital systems to identify trends and forecast results.

Yıldız and Körpeoğlu underline the fact that EDM can help researchers and educators to find out the so-called "at-risk" students much earlier than when they fail an exam [8]. By examining the variables of time taken to complete tasks, number of attempts, and error pattern AI models are able to forecast dropout rates or learning disabilities with a high level of precision. The technology converts raw data into practical information that allows teachers intervening proactively.

2.4 Conversational AI and Virtual Teaching Assistants

The latest round of AI development is Generative AI and Large Language Models (LLMs) which drive state-of-the-art chatbots and virtual teaching assistants. These agents are not fixed as menu-based bots but can comprehend natural language questions.

Jančařík et al.'s topic is about discussing the appearance of AI assistants capable of dialoguing with students and providing them conceptual explanations instead of just answers to questions such as why do people turn the fraction when dividing [9]. Nevertheless, the problem is how to make these so-called hallucinating models offer mathematically correct facts, an issue that makes math education unique compared to other humanities-oriented subjects.

3 Analysis of Application Results

The combination of the above-mentioned technologies has given important empirical effects. The analysis of this section is how AI affect three important dimensions, which are learning outcomes, student engagement, and the change in teaching roles.

3.1 Enhancement of Learning Outcomes

The main measure of any educational program is academic performance. There is a general

agreement in the literature, as well as in the systematic review by Mohamed et al., that AI integration tends to be associated with positive learning results in mathematics [2].

The study by Tashtoush et al. demonstrated that students who used AI-based tools had significant progress in problem-solving skills in comparison with the control group that used conventional approaches [3]. This enhancement is frequently explained by the mechanism of the mastery learning strategy which is enabled by AI whereby students are not allowed to continue until they understand and comprehend the current concept thus forming a strong base. Moreover, Viberg et al. found that when it came to Sweden, the application of digital technology assisted on leveling the educational level across different places so that people in remote regions enjoyed the same excellent teaching materials as those in the cities [1].

3.2 Student Engagement and Motivation

The fear of math is an important obstacle to education. AI has proven to be promising to alleviate it by providing low-stakes non-judgmental settings. According to Engelbrecht and Borba, many digital environments have incorporated gamification features that are based on AI algorithms with the purpose of keeping the zone of proximal development [10]. Through the maintenance of proper difficulty level (it is neither too monotonous, nor too daunting); AI systems can promote students' motivation.

Furthermore, in their report, Nurwahid and Ashar claim that game based interactive learning with an AI support can greatly boost student involvement [4]. AI has an immediate feedback loop which minimizes the frustration of waiting on a teacher to grade the homework and keeps the learner in flow state. The given psychological factor is quite important because when the students regard math as a challenging task that can be overcome instead of an unattainable goal, their intrinsic motivation increases.

3.3 Transformation of Teacher Roles and Pedagogical Models

One of the popular fears is that AI will replace teachers. Nevertheless, according to the literature, it is expected that AI will be a transformation but not a replacement. Shin examined the perceptions of future mathematics teachers and discovered that they were moving towards viewing AI as a collaborator [11]. With this new pedagogical paradigm, the teacher no longer is the sage of the stage (lecturing), but a guide at the side (supporting learning). Tashtoush et al [3]. AI has been reported to take over repetitive cognitive work. They are grading, simple explanations and skills practice. It enables teachers to pay attention to more significant activities. Teachers have the ability to mentor students, promote critical thinking and provide an emotional support. Teachers are also data interpreters. They have access to educational data mining system dashboards. It assists them in making better teaching choices with regard to the class.

4 Discussion

Although the advantages of AI in mathematics teaching can be seen, there are many obstacles to its implementation. In this section, the author explores the difficulties and prospects of the field.

4.1 Challenges

Initially, there are technical and financial barriers to the use of AI. Strong AI systems are expensive. The problem is discussed by Opesemowo and Ndlovu in their paper - The good, the bad, and the ugly [12]. This could be pointing to a threat of increasing the digital divide among people. The rich institutions have enough money to buy adaptive AI platforms. Poorly funded schools will lose competitiveness.

The second issue is the data privacy and ethics. Information is what drives AI-based systems. The collection of massive volumes of data concerning minors raises serious issues of privacy and surveillance ethics. A further important concern is algorithmic bias. Training data with bias can cause AI systems to discriminate against particular student groups.

The last third is that both teacher and student acceptance is a stumbling block. The usefulness of technology depends on people who use it. One popular obstacle to which Shin highlight refers. In case there is no appropriate training teachers can refuse AI [11]. They are afraid of the job becoming old-fashioned or have no technical confidence. The students have their problem as well. They can become too dependent on AI services, like the use of ChatGPT in doing homework. It has the potential to be detrimental to their critical thinking abilities in the long term.

4.2 Future Outlook

In the future, the convergence of technologies will offer even more immersive experiences. Engelbrecht and Borba forecast the integration of AI and Virtual Reality (VR) and Augmented Reality (AR) into the creation of 3D mathematical environments in which students may manipulate geometric objects in virtual space [10].

Moreover, the future belongs to Hyper-Personalization. Existing systems are adjusting the level of difficulty but future systems will be able to change the mode of explanation to a visual explanation to a visual learner and an algebraic explanation to a symbolic learner.

Ultimately, equity is still an objective. The future development of lightweight and able to operate offline AI solutions capable of functioning with limited resources should be prioritized by future studies because it allows making the advantages of AI in educational process of mathematics available to everyone as stated in international educational standards.

5 Conclusion

The paper has discussed how the use of Artificial Intelligence can be applied in a complex manner in the teaching of maths. As demonstrated in the paper, AI technologies are transforming education. Among these technologies are Intelligent Tutoring Systems and Learning Analytics. There is empirical support of their effectiveness. The tools enhance the results of learning. They make learning personalized to individual students.

They also enhance student involvement in the learning process. Nevertheless, AI integration cannot be seen as an elixir. This introduces serious issues such as ethical issues, privacy of data, and even the need to train teachers. The human in the loop still plays a central role. To sum up my thoughts, the future of mathematics education is not about deciding whether

human teachers or AI will be the choice, but about creating a symbiotic environment whereby AI can help with the mechanical and analytical parts of teaching and human beings can add empathy, context and creative direction.

The future of research in this field should focus more on longitudinal studies to comprehend the long-term cognition consequences of AI dependency and create effective models that will guarantee the moral and fair use of AI. With the ongoing development of AI, people also need to alter pedagogical approaches to make sure that technology becomes a bridge rather than a barrier to mathematical literacy.

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