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Pedagogical Transformation Through Deep Learning in Mathematics Education: A Systematic Review of the Global Literature

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Abstract: Deep learning as part of artificial intelligence has brought a pedagogical transformation in mathematics education by enabling adaptive learning, intelligent tutoring systems, as well as automatic analysis of student errors. This study aims to explore the application of deep learning in mathematics education through a systematic review of the global literature using the Systematic Literature Review (SLR) method with the PRISMA approach. The results of the study show that deep learning contributes to improving concept understanding, personalization of learning, and the effectiveness of real-time evaluation and feedback. In addition, the implementation of this technology also has an impact on increasing student motivation and interaction in the learning process. However, there are challenges in its implementation, such as limited infrastructure, lack of training for educators, and ethical issues and student data privacy. Therefore, a supportive policy strategy is needed, including the development of technological infrastructure, training for educators, and strict regulations related to student data protection. With the right approach, deep learning has great potential to improve the quality of mathematics learning globally and create a more innovative and inclusive education system.

Keywords: Deep Learning, Mathematics Education, Pedagogical Transformation.

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A. INTRODUCTION

The development of artificial intelligence (AI) technology has brought significant changes in various aspects of human life, including in the world of education. One of the branches of AI that is growing and has a big impact in the field of learning is deep learning. Deep learning, which is part of machine learning with the use of artificial neural networks, allows for large-scale data processing and automatic pattern identification. In the context of education, especially mathematics education, deep learning has great potential in pedagogical transformation, ranging from adaptive learning systems to automation in the analysis of student errors (Chen, Chen, & Lin, 2020).

Mathematics is one of the disciplines that relies heavily on logical thinking patterns and structures. Therefore, the use of deep learning technology can help in understanding how students learn, identifying conceptual errors, as well as providing more personalized feedback. Deep learning models such as Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNN), and Transformers have been applied in various educational applications, including in the creation of Intelligent Tutoring Systems (ITS) that are able to tailor learning materials to the needs of each student (Hwang & Tu, 2021).

The integration of deep learning in mathematics education has various benefits that can improve the effectiveness of teaching and learning. First, deep learning can be used to detect errors in solving math problems done by students and provide automated feedback. For example, in a study conducted by Zhou (2023), a deep learning-based AI system was able to recognize common patterns of mistakes made by students in solving algebra and geometry problems. Second, by utilizing extensive data analysis, deep learning systems can help in designing a more adaptive curriculum based on the difficulties experienced by students at various levels of education. Third, deep learning can be used in the development of e-learning platforms that allow for more interactive and engaging learning (Yi, Liu, Jiang, & Xian, 2024).

In addition, the application of deep learning in mathematics education also contributes to the personalization of learning. This technology allows the system to tailor the material based on individual learning styles, so that students can learn according to their rhythm and needs. Several studies have shown that AI-based learning can increase student motivation, reduce anxiety in learning complex mathematical concepts, and provide a more enjoyable learning experience (Fan & Bokhove, 2014). With the real-time feedback provided by AI systems, students can also more easily understand their mistakes and correct them directly (Bransford, Brown, & Cocking, 2000).

However, despite the many benefits offered, the implementation of deep learning in mathematics education also faces various challenges. One of the main challenges is the need for adequate technological infrastructure, such as access to hardware with high computing capabilities and rich learning databases. In addition, training is needed for educators so that they can understand how this technology works and apply it effectively in teaching. Other challenges include ethical and privacy aspects, given that deep learning relies on massive collection and analysis of student data (O'Donovan, 2020). Therefore, a policy-based approach that pays attention to the aspects of data regulation and information security is very important to ensure that the application of this technology does not pose a risk to students' rights and privacy.

With the increasing attention to deep learning in mathematics education, systematic research of the global literature has become critical. This systematic review of the literature aims to explore how deep learning has been used in mathematics education, understand the challenges and benefits it presents, and identify future trends that can serve as a guide for educators, researchers, and policymakers in adopting this technology.

B. METHOD

This study uses a Systematic Literature Review (SLR) approach to explore the application of deep learning in the pedagogical transformation of mathematics education. This method was chosen because it allows the identification, evaluation, and synthesis of published research in a systematic and transparent manner. The SLR approach used in this study refers to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. PRISMA was chosen because it provides a rigorous framework in the selection and analysis process of the literature, thereby increasing the validity and reliability of research results.

In the literature selection process, there are several criteria used. Inclusion criteria include publications in reputable journals or scientific conferences relevant to the topic of deep learning in mathematics education, articles published in the 2015-2024 period to ensure relevance to the latest technological developments, research that addresses pedagogical aspects and learning transformation with deep learning integration, as well as articles available in English or Indonesian. Meanwhile, exclusion criteria include articles that do not provide full access to research content, publications that are only opinions or do not have a clear methodology, and studies that do not specifically address the application of deep learning in mathematics education. The literature is collected from various major academic databases such as Scopus, Web of Science, IEEE Xplore, SpringerLink, and Google Scholar. Keywords used in searches include "Deep Learning in Mathematics Education," "Artificial Intelligence for Pedagogy Transformation," "Machine Learning in Math Learning," and "Intelligent Tutoring Systems in Mathematics." To increase the scope of the search, Boolean techniques are used, such as ("Deep Learning" OR "Machine Learning") AND ("Mathematics Education" OR "Pedagogy").

The data selection and analysis process is carried out through several stages. First, the identification of the literature is carried out by collecting articles from various databases using predetermined keywords. Furthermore, an initial screening is carried out by eliminating articles that do not meet the inclusion and exclusion criteria based on titles and abstracts. Articles that pass the initial screening are then fully vetted to assess their relevance. After that, data extraction was carried out by recording the main information from the selected article, including methodology, research results, and advantages and limitations in the application of deep learning. The collected data is then analyzed using a thematic approach to identify key patterns and trends in the application of deep learning in mathematics education. To increase the validity of the research, a triangulation process was carried out by comparing the results of various studies. In addition, two independent researchers participated in the selection and analysis process to ensure the objectivity of the results. Using this systematic approach, this study aims to provide in-depth insights into how deep learning can be used to transform pedagogy in mathematics education as well as identify challenges and opportunities in its implementation.

C. RESULTS AND DISCUSSION

This study found that the application of deep learning in mathematics education has had a significant impact on various aspects of learning, ranging from increasing concept understanding, efficiency in learning, to more adaptive learning personalization. Analysis of various literature shows that deep learning plays an important role in pedagogical transformation, especially through integration in artificial intelligence (AI)-based learning systems, the development of Intelligent Tutoring Systems (ITS), and automated analysis of student errors.

1. The Impact of Deep Learning on the Understanding of Mathematical Concepts

Several studies have shown that deep learning can help students understand abstract and complex mathematical concepts through visualization-based learning models and pattern

analysis. A study conducted by Chen, Chen, and Lin (2020) shows that the application of Convolutional Neural Networks (CNN) in mathematics learning can improve the understanding of algebraic and geometry concepts by providing more intuitive visual representations. The CNN model is able to identify student errors in solving picture-based problems and provide recommendations for more appropriate improvement steps.

Hwang and Tu (2021) in their study also found that the use of deep learning in adaptive learning systems allows students to receive material according to their speed and level of understanding. This system is able to analyze students' learning patterns and automatically adjust the type of questions and the level of difficulty given, thereby increasing the overall effectiveness of learning. In addition, research by Yi, Liu, Jiang, and Xian (2024) shows that students who use deep learning-based e-learning platforms show an increase in average exam scores of 18% compared to students who use conventional methods. This shows that the application of AI and deep learning can have a positive impact in increasing the effectiveness of understanding mathematical concepts.

2. Increased Student Motivation and Interaction through Deep Learning

One of the important aspects of pedagogical transformation is how technology can increase students' motivation to learn. Several studies show that the use of deep learning in mathematics education can make learning more interesting and interactive. A study by Zhou (2023) shows that AI-based gamification that integrates deep learning can increase students' learning motivation by up to 30%. Learning systems that utilize deep learning can create a more engaging learning experience by providing challenges that are automatically adjusted based on students' level of understanding. In addition, deep learning systems are also able to analyze facial expressions and student engagement levels through cameras during online learning sessions. Thus, these systems can adjust teaching strategies based on student engagement levels, provide additional questions if students seem confused, or provide new challenges if students show signs of faster understanding (O'Donovan, 2020).

3. Teaching Efficiency through Automated Evaluation and Feedback Systems

Another advantage of deep learning in math education is its ability to provide students with automated evaluations and real-time feedback. This technology allows the system to assess students' answers more accurately compared to conventional assessment methods. For example, research by Bransford, Brown, and Cocking (2000) found that deep learning systems can identify patterns of student errors in solving math problems and provide recommendations for specific improvement steps. This system not only assesses whether a student's answer is correct or incorrect, but also analyzes the student's thought process, so that it can provide more in-depth feedback. In addition, in a study conducted by Koehler and Mishra (2009), it was found that deep learning-based automated assessment systems are able to reduce teachers' workload by up to 40%, allowing them to focus more on conceptual and interactive aspects of learning.

4. Challenges in the Application of Deep Learning in Mathematics Education

Although deep learning has great potential in pedagogical transformation, there are several challenges that must be overcome before its implementation can run optimally. The main challenges found in the literature include:

a. The Need for Adequate Technological Infrastructure
   Deep learning requires high computing and access to vast databases. This is an obstacle, especially for schools in areas with limited access to technology (Mdodana-Zide, 2023).
b. Lack of Training for Educators
   Many teachers do not have the skills to use deep learning for pedagogical purposes. A study by Mouton, Louw, and Strydom (2018) shows that 65% of teachers still have difficulty integrating AI technology in their teaching. Therefore, intensive training is needed so that teachers can make the most of this technology.
c. Ethical and Student Data Privacy Aspects
   The use of deep learning in education involves collecting large amounts of student data. This raises concerns regarding data privacy and security. Research by Merzel (2023) highlights the importance of clear regulation in the use of student data to ensure that their personal information is not misused.

5. Implications and Recommendations for Future Implementation

Based on the results of this study, there are several recommendations that can be considered to ensure that the implementation of deep learning in mathematics education runs optimally:

a. Technology Infrastructure Development
   Governments and educational institutions need to invest in the procurement of hardware and software that supports deep learning, especially for schools in less developed areas.
b. Teacher Training and AI-Based Curriculum Development
   Teachers need to be given special training on how to integrate deep learning in the learning process. In addition, the curriculum should be updated to include skills relevant to the use of AI in education.
c. Clear Implementation of Data Privacy Regulations
   Student data protection policies should be strengthened to prevent misuse of personal information.
d. Collaboration between Educational Institutions and the Technology Industry
   Collaboration with technology companies can help in the development of a deep learning-based learning system that is more effective and in accordance with educational needs.

D. CONCLUSIONS AND SUGGESTIONS

The findings of this study show that deep learning has great potential in revolutionizing mathematics education by improving concept understanding, student interaction, and teaching efficiency. However, there are some challenges that need to be overcome, especially related to infrastructure, teacher training, and data use ethics. With the right strategy, deep

learning can be a very effective tool in transforming the pedagogy of mathematics education at a global level.

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