

Rejecting Reduction: Clarifying the Concept of Deep Learning in Mathematics Teaching in the Era of Artificial Intelligence

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ABSTRAK

Artikel ini bertujuan untuk mengklarifikasi dan meluruskan pemahaman ganda mengenai istilah *deep learning* dalam konteks pendidikan matematika di era kecerdasan buatan. Sering kali, istilah ini direduksi menjadi sekadar teknologi berbasis AI yang mengandalkan internet, padahal dalam ranah pedagogi, *deep learning* merupakan pendekatan pembelajaran yang menekankan pemahaman konseptual yang mendalam, keterkaitan antargagasan, serta transfer pengetahuan ke situasi baru. Penelitian ini menggunakan pendekatan kajian konseptual berbasis analisis literatur, dengan sumber data sekunder dari artikel jurnal, buku, serta laporan kebijakan terbitan 2000–2024. Hasil kajian menunjukkan bahwa teknologi *deep learning* memiliki potensi untuk mendukung pembelajaran matematika melalui fitur seperti pengenalan tulisan tangan, sistem evaluasi otomatis, tutor cerdas, dan pembelajaran adaptif. Namun, penerapan teknologi ini juga menghadapi tantangan serius seperti keterbatasan data kontekstual, infrastruktur digital yang tidak merata, sifat model yang sulit diinterpretasi, serta isu etika dan privasi data. Di sisi lain, pendekatan pedagogis *deep learning* justru menempatkan guru sebagai aktor utama dalam mendesain pembelajaran bermakna. Oleh karena itu, integrasi antara teknologi dan pedagogi harus dilakukan secara kritis dan kontekstual. Inovasi pembelajaran di era AI harus tetap berpijak pada prinsip humanistik dan kesadaran akan realitas sosial-budaya siswa, khususnya dalam konteks Indonesia yang beragam.

Kata kunci: *deep learning*; pedagogi matematika; kecerdasan buatan; pembelajaran bermakna; pendidikan

ABSTRACT

This article aims to clarify and clarify the dual interpretations of the term 'deep learning' in the context of mathematics education in the era of artificial intelligence. The term is often reduced to merely an AI-based technology that relies on the internet. In contrast, in the pedagogical domain, deep learning refers to a learning approach that emphasizes deep conceptual understanding, connections between ideas, and the transfer of knowledge to new situations. This study adopts a conceptual review approach based on literature analysis, using secondary sources such as journal articles, books, and policy reports published between 2000 and 2024. The findings show that deep learning technology holds potential to support mathematics learning through features such as handwriting recognition, automated evaluation systems, intelligent tutoring, and adaptive learning. However, the implementation of this technology also faces serious challenges, including limitations in contextual data availability, uneven digital infrastructure, the opaque nature of model interpretation, and issues of ethics and data privacy. On the other hand, the pedagogical approach to deep learning places the teacher as the main actor in designing meaningful learning experiences. Therefore, the integration of technology and pedagogy must be carried out critically and contextually. Educational innovations in the AI era must remain grounded in humanistic principles and an awareness of students' sociocultural realities—especially in the diverse context of Indonesia.

Keywords: *deep learning*; mathematics pedagogy; artificial intelligence; meaningful learning; education

INTRODUCTION

The development of artificial intelligence (AI) technology over the past decade has driven the emergence of various innovations in the field of education, including in mathematics learning. One of the most widely developed forms of AI implementation is *deep learning*, a machine learning approach that utilizes multi-layered artificial neural networks to recognize patterns, perform classifications, and generate data-based predictions [1][2]. In practice, deep learning has been applied in various technology-based educational systems, such as handwritten mathematical expression recognition [3][4], automated evaluation systems [5][6], and data-driven adaptive learning.

However, it is important to note that the term *deep learning* in the technological domain differs fundamentally from the concept of *deep learning* in pedagogy. In educational studies, *deep learning* refers to a learning process that emphasizes deep conceptual understanding, interconnectedness of ideas, critical thinking skills, and the transfer of knowledge to new contexts [7][8]. This process cannot be achieved merely through the automated delivery of materials or adaptive algorithms; it requires teacher involvement in designing meaningful, contextual, and reflective learning experiences. Therefore, even though AI technology holds potential to support the learning process, it does not automatically ensure the occurrence of pedagogical deep learning.

The pedagogical approach to deep learning increasingly demands the presence of teachers as the primary facilitators of learning. Teachers play a crucial role in fostering mathematical dialogue, interpreting meaning, and adapting instructional strategies to the needs and sociocultural backgrounds of students [9]. In the context of Indonesia—particularly in regions such as Papua, which face geographic, cultural, and infrastructural challenges—meaningful learning approaches must prioritize the teacher's role and the strengthening of classroom interaction over reliance on high-tech systems that may not be contextually appropriate.

Furthermore, positioning AI and deep learning technologies as the main solutions in education often creates an illusion of efficiency that neglects the complexity of human learning processes. While technology can serve as an effective support tool—for instance, through learning analytics or automated feedback—it is dangerous to assume that AI can replace the pedagogical functions of teachers in fostering students' mathematical understanding. Therefore, mathematics educators need to understand and distinguish between deep learning as a technology and deep learning as a pedagogical approach. This distinction ensures that educational innovation strategies remain grounded in humanistic, contextual, and transformative educational principles.

METHOD

This study is a conceptual inquiry aimed at critically and thoroughly clarifying the two main meanings of the term *deep learning* in the context of mathematics education: as a pedagogical approach (deep learning approach) and as a technology in artificial intelligence (deep learning in AI). This review does not employ quantitative or qualitative empirical methods; instead, it relies on a literature analysis and a conceptual reflection approach that is both systematic and argumentative.

Type of Study

This research falls under the category of non-empirical studies based on theoretical analysis, focusing on concept formation, clear distinctions in meaning, and drawing pedagogical implications from existing frameworks of thought. This method is commonly used in the fields of philosophy of education, theory development, and critical discourse in educational studies [10].

Data Sources and Literature

The primary sources in this study are secondary literature consisting of:

1. International journal articles indexed in Scopus and WoS,
2. Academic books on mathematics pedagogy and educational technology,
3. State-of-the-art reviews in the field of AI in education,
4. Policy report documents and white papers from educational institutions.

The literature was purposively collected using keywords such as: "*deep learning approach*", "*deep learning in education*", "*mathematics pedagogy*", "*AI in mathematics teaching*", and "*teacher role in digital learning*", drawn from databases such as Scopus, ERIC, Google Scholar, and SpringerLink. The publication years were focused on the period from 2000 to 2024 to capture both historical and contemporary perspectives.

FINDINGS AND DISCUSSION

This review highlights the urgent need to clarify the term *deep learning*, which currently carries two dominant meanings in the practice of mathematics education: as a pedagogical approach and as a technology in artificial intelligence (AI). These two meanings have very different epistemological roots and practical consequences. This literature review aims to correct the reduction of meaning that often occurs in educational policy narratives and the implementation of digital learning.

Deep Learning as AI Technology in Mathematics Learning

In recent literature, the term *deep learning* is more frequently associated with artificial intelligence, particularly with machine learning techniques that use multi-layered artificial neural networks (deep neural networks). In the field of mathematics education, this technology has been widely applied to develop various adaptive and data-driven learning applications.

Recognition of Handwritten Mathematical Expressions

Convolutional Neural Network (CNN) models have been widely used to recognize handwritten mathematical expressions input by students on digital devices. This capability not only automates corrections but also enables real-time identification of students' conceptual errors [3]. Such applications shift the teacher's role from merely checking answers to analyzing learning processes, aligning closely with the principles of formative assessment.

Process-Based Automatic Evaluation

Models such as Recurrent Neural Networks (RNNs) and Transformers can evaluate the sequence of steps students take to solve math problems. These systems assess not just the final answers but also the students' thought processes, making it possible to track their cognitive paths

during learning [11]. This supports the *assessment for learning* principle and enhances the teacher's ability to provide targeted interventions.

Intelligent Tutoring Systems Based on Natural Language

Language-based models like BERT and GPT have been developed into intelligent tutoring systems (ITS) for mathematics education. These systems can answer student questions, offer explanations, and even detect confusion through patterns in natural language interaction [12]. This approach augments the teacher's role in providing personalized support beyond classroom hours.

Adaptive Learning Systems

Deep learning technology is also used in adaptive learning systems, where content and activities are tailored to each student's profile and needs. Models such as autoencoders or multi-layer perceptrons classify learning styles and predict learning difficulties, which then inform automatic instructional decision-making [13].

Challenges in Implementing Deep Learning as a Technology

Despite its promise, the implementation of *deep learning* in the context of mathematics education is not free from significant structural and ethical challenges. One of the main obstacles is the limited availability of contextual and representative data from actual classroom practices. Such data is crucial for training deep learning models to accurately capture the nuances of real learning experiences.

In addition, the implementation of this technology requires adequate digital readiness, including access to high-powered hardware and stable, high-speed internet connectivity, both of which remain challenges in many regions, particularly in developing countries. Moreover, deep learning models are generally "black boxes", meaning their internal operations are difficult to explain or understand, even for teachers. This opacity creates a barrier to pedagogical reflection and instructional decision-making based on a deep understanding of students.

On the other hand, ethical and privacy concerns also demand serious attention. The use of student data without explicit consent, the potential for algorithmic bias, and concerns over excessive surveillance of students' learning activities create moral dilemmas that must be addressed with caution [14][15]. In the context of developing countries like Indonesia—especially in areas with limited access, such as Papua—these challenges become even more complex. Severe limitations in digital infrastructure, combined with diverse learning cultures, call for contextual and adaptive approaches. Therefore, advanced technology alone is not sufficient; pedagogical approaches that are sensitive to local realities must serve as the foundation for any AI-based educational innovation.

In contrast, deep learning in the pedagogical tradition refers to a learning strategy that encourages students to deeply understand concepts, connect various ideas, think critically, and transfer knowledge to new contexts. This concept is grounded in theoretical frameworks such as *approaches to learning* by [7] and the constructivist learning framework developed by [8].

Deep Learning as a Pedagogical Approach

In contrast, within the pedagogical tradition, *deep learning* refers to a learning approach that places conceptual understanding as the central goal of learning, not merely procedural mastery or rote memorization. This concept is rooted in the *approaches to learning* theory introduced by [7], which distinguishes between surface learning and deep learning. Students who engage in surface learning tend to memorize information without truly understanding its meaning, whereas students who learn deeply connect new information to their existing knowledge structures, understand the relationships among concepts, and can apply that understanding to new situations.

This approach is further enriched by constructivist theories in education, as explained by [8], which emphasize that learning is an active process wherein students construct meaning from their own learning experiences. Within this framework, teachers are no longer positioned as the sole source of knowledge, but rather as facilitators who design learning environments that foster exploration, dialogue, and reflection. Learning is not viewed as a linear process, but as a complex social and cognitive activity that demands full student engagement and awareness of the learning context.

A key feature of the pedagogical deep learning approach is the active involvement of students in constructing meaning from new information. This process occurs not only at the cognitive level but also at the affective and metacognitive levels—students learn to understand, reflect, and regulate their learning strategies. Learning takes place in a reflective, contextual, and integrated manner, recognizing that the concepts being studied are interconnected and linked to students' real-life experiences. In this regard, the teacher plays an essential role as both facilitator and mediator of meaning, not merely delivering content, but also creating a dialogic space for building shared understanding. In a study by [16], it was emphasized that creative and spatial thinking should be encouraged through student reflection activities, aligning with the characteristics of pedagogical deep learning.

Assessment in this approach does not focus solely on outcomes, but rather emphasizes the learning process that students undergo [17]. Formative assessments, classroom observations, student reflections, and project-based assessments are the main tools used to determine how well students truly understand concepts and can apply them in authentic contexts [18].

In Indonesia's pluralistic context—geographically, culturally, and socioeconomically—the pedagogical deep learning approach is highly relevant. Challenges such as educational inequality, linguistic and cultural diversity, and the complex needs of students call for approaches that are not standardized, but rather responsive to context. Teachers must understand students' sociocultural realities and use them as starting points in designing instructional strategies. In areas such as Papua, for example, overly tech-dependent approaches that fail to consider infrastructure readiness and local culture risk creating new educational divides. Therefore, strengthening pedagogical approaches that are deep, humanistic, and contextual is key to achieving mathematics education that is not only cognitively sound but also socially just.

Distinction and Synthesis: Rejecting the Reduction of Meaning

This review emphasizes that reducing the term *deep learning* to merely a technological concept is a form of dangerous conceptual reductionism. When AI technology is assumed to be capable of replacing the teacher's role in creating meaningful learning, we overlook the reality that

human learning is social, complex, and contextual. However, this does not mean that the two meanings cannot be integrated. On the contrary, deep learning technology can be used to support pedagogical deep learning, as long as teachers remain the primary agents in designing, interpreting, and facilitating the learning process. In other words, technology must be embedded within a pedagogical framework, not the other way around.

CONCLUSION

The importance of making a clear distinction between *deep learning* as a pedagogical approach and *deep learning* as an AI-based technology. Both have their contributions to the development of mathematics education, but they cannot be equated semantically or practically. The pedagogical approach to deep learning emphasizes active student engagement in constructing meaning, reflecting critically, and transferring knowledge across diverse contexts, with the teacher serving as the central facilitator. Meanwhile, deep learning technology can enhance learning processes through data analysis, automated feedback, and content personalization—as long as its use is guided and supervised by strong pedagogical principles. The danger of reductionism arises when technology is placed at the center of educational processes and replaces the role of teachers, even though learning is inherently a social, complex, and contextual process. Therefore, AI-based educational innovation must prioritize humanistic, ethical, and locally grounded approaches, so that education becomes not only technologically smart but also pedagogically just.

Based on these conclusions, several relevant recommendations can be made. First, educators and policymakers should broaden their understanding of the pedagogical meaning of deep learning, so as not to be trapped in technological euphoria that neglects the human dimension of learning. Second, teacher training is needed to help educators critically understand the role of technology in learning, enabling them to integrate it reflectively and contextually. Third, the development of learning technologies, especially those based on deep learning, must consider algorithmic transparency, student data protection, and the involvement of teachers as active partners. Fourth, further research is urgently needed to explore models of integration between technology and pedagogy that fit the educational context of Indonesia, including in areas with infrastructure challenges and cultural diversity, such as Papua.

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