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APPLYING DEEP LEARNING TO SUPPORT EARLY COGNITIVE DEVELOPMENT IN PRIMARY STUDENTS: INSIGHTS FROM AN INDONESIAN ISLAMIC SCHOOL CONTEXT

MENERAPKAN PEMBELAJARAN MENDALAM UNTUK MENDUKUNG PERKEMBANGAN KOGNITIF AWAL SISWA SEKOLAH DASAR: WAWASAN DARI KONTEKS SEKOLAH ISLAM DI INDONESIA

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Abstract

The rapid advancement of artificial intelligence (AI) offers new opportunities to enhance teaching and learning in early education. This study applies deep learning approaches to support early cognitive development among primary students in an Indonesian Islamic school. A hybrid Convolutional Neural Network (CNN) and Long Short Term Memory (LSTM) model was designed to analyse students' cognitive patterns, attention, and engagement. Using a mixed-methods design, the research involved 60 students aged 8–10 at MIS Terpadu Alhijrah Bintuju. The model processed multimodal classroom data to generate adaptive feedback and personalized learning pathways. Results showed significant improvements in attention (+18%), memory recall (+22%), and problem-solving (+25%) after eight weeks of AI-assisted learning. Qualitative findings revealed higher motivation, engagement, and self-regulation. The study demonstrates that culturally aligned AI systems can effectively enhance early cognitive development and promote learner autonomy in Islamic primary education.

Keywords: Deep learning, cognitive development, primary education, artificial intelligence, adaptive learning, Islamic school

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Abstrak

Kemajuan pesat kecerdasan buatan (AI) memberikan peluang baru untuk meningkatkan proses belajar-mengajar di pendidikan dasar. Penelitian ini menerapkan pendekatan *deep learning* untuk mendukung perkembangan kognitif awal pada siswa sekolah dasar di lingkungan sekolah Islam Indonesia. Model hibrida *Convolutional Neural Network* (CNN) dan *Long Short Term Memory* (LSTM) dirancang untuk menganalisis pola kognitif, perhatian, dan keterlibatan siswa. Dengan menggunakan desain metode campuran, penelitian melibatkan 60 siswa berusia 8–10 tahun di MIS Terpadu Alhijrah Bintuju. Model ini memproses data multimodal kelas untuk menghasilkan umpan balik adaptif dan jalur pembelajaran yang dipersonalisasi. Hasil penelitian menunjukkan peningkatan signifikan pada perhatian (+18%), ingatan (+22%), dan pemecahan masalah (+25%) setelah delapan minggu pembelajaran berbantuan AI. Temuan kualitatif menunjukkan motivasi, keterlibatan, dan regulasi diri yang lebih tinggi. Studi ini membuktikan bahwa sistem AI yang selaras dengan budaya dapat secara efektif meningkatkan perkembangan kognitif awal dan mendorong kemandirian belajar di pendidikan dasar Islam.

Kata kunci: *Pembelajaran mendalam*, perkembangan kognitif, pendidikan dasar, kecerdasan buatan, pembelajaran adaptif, sekolah Islam

1. INTRODUCTION

The rapid advancement of artificial intelligence (AI) has transformed the global education landscape, providing opportunities to personalize instruction and improve learning outcomes through data-driven insights. Among AI technologies, deep learning has gained attention for its ability to simulate human neural processes and recognize complex cognitive patterns (LeCun, Bengio, & Hinton, 2015). Deep learning algorithms, particularly Convolutional Neural Networks (CNN) and Long Short-Term Memory (LSTM) networks, can analyze multimodal data such as speech, text, and visual behaviour to assess and support students' cognitive development in real time (Goodfellow, Bengio, & Courville, 2016). Owing to its capacity to emulate human neural architectures and to process complex multimodal data, deep learning represents a highly sophisticated domain of artificial intelligence with substantial potential to facilitate real-time assessment and advancement of students' cognitive development within contemporary educational contexts.

In early childhood and primary education, cognitive development forms the foundation for subsequent academic success. Classic theorists such as Piaget (1972) and Vygotsky (1978) highlight that early cognitive processes including memory, attention, reasoning, and problem-solving emerge through active engagement and guided learning. However, in many developing countries, instructional practices remain largely teacher-centered and standardized, making it difficult to address individual cognitive differences (Zawacki-Richter et al., 2019). The use of deep learning in education offers an opportunity to overcome these limitations by providing adaptive feedback, individual learning trajectories, and continuous assessment based on cognitive performance data (Holmes et al., 2022). Consequently, the integration of deep learning technologies in early education offers a transformative avenue to transcend traditional teacher-centered limitations by

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enabling adaptive, individualized, and data-informed approaches to fostering children's cognitive development.

Several studies have demonstrated the potential of AI and deep learning in enhancing student learning outcomes. For instance, Su et al. (2021) developed a CNN-based attention detection system that successfully monitored student focus levels during online classes, while Wang and Chen (2022) implemented LSTM-based models to predict learning trajectories and tailor instructional recommendations. In Indonesia, Nugroho et al. (2023) found that AI-based adaptive tutoring systems significantly improved elementary students' cognitive fluency and engagement. Similarly, Al-Khalifa (2021) explored the integration of AI tools in Islamic education, concluding that such technologies could strengthen both cognitive and affective dimensions of learning when contextualized with local cultural and moral values. Collectively, these studies underscore the pedagogical efficacy of AI and deep learning applications in diverse educational contexts, demonstrating their capacity to enhance cognitive performance, foster learner engagement, and harmonize technological innovation with cultural and moral values.

Despite these promising findings, research on deep learning in Islamic primary schools (Madrasah Ibtidaiyah) remains limited. These institutions play a crucial role in Indonesia's education system, combining formal academic learning with moral and spiritual development (Nata, 2019; Azra, 2018). However, they often face challenges related to technological infrastructure, teacher readiness, and access to training. Integrating deep learning in such settings requires both technical adaptation and cultural alignment ensuring that AI applications respect Islamic pedagogical principles while promoting cognitive growth. Therefore, advancing the application of deep learning within Islamic primary schools necessitates a contextually sensitive approach that harmonises technological innovation with Islamic pedagogical values, ensuring that cognitive enhancement is achieved without compromising cultural and moral integrity

The current study addresses this research gap by investigating how deep learning can be applied to support early cognitive development in a local Islamic primary school setting. Specifically, the study was conducted at MIS Terpadu Alhijrah Bintuju**,** an Indonesian Islamic school integrating general and religious curricula. A hybrid CNN–LSTM model was developed to monitor and interpret students' attention, memory, and problem-solving patterns during classroom learning activities. The system generated adaptive feedback that helped teachers adjust instruction according to learners' individual cognitive profiles.

This research contributes to both theory and practice. Theoretically, it aligns with constructivist and sociocultural learning perspectives that view cognitive growth as a dynamic, interactive process supported by meaningful feedback and scaffolding (Bruner, 1983; Vygotsky, 1978). Practically, it extends the application of deep learning into faith-based educational environments in the Global South, an area that remains underrepresented in current AI education research. By contextualizing AI integration within an Indonesian Islamic school, this study seeks to demonstrate how technological innovation and cultural sensitivity can coexist to enhance educational equity and cognitive development among primary learners.

Unlike most previous studies that focus on secular or technologically advanced contexts, this study introduces a culturally aligned AI framework that integrates deep learning with Islamic pedagogical values to enhance early cognitive development. This represents a novel contribution to the literature by demonstrating how deep learning can be

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ethically and contextually harmonized with faith-based education, offering new insights into culturally responsive artificial intelligence in primary schooling.

2. RESEARCH METHOD

This study adopted a mixed-methods design, integrating quantitative and qualitative approaches to gain a comprehensive understanding of how deep learning systems can enhance early cognitive development in primary education. Conducted at *MIS Terpadu Alhijrah Bintuju*, an Islamic primary school in Indonesia combining religious and general education, the research involved 60 students aged 8–10 years (32 boys and 28 girls) selected through purposive sampling. Ethical approval and parental consent were obtained prior to implementation.

The intervention utilized a deep learning–based adaptive model built on a hybrid *Convolutional Neural Network (CNN)* and *Long Short-Term Memory (LSTM)* architecture. Trained on multimodal classroom data including visual cues (gaze, posture, expression) and textual input from digital exercises the model aimed to identify patterns in attention, memory, and problem-solving ability. It then generated adaptive feedback for teachers and personalized learning pathways for students over an eight-week intervention integrating AI-assisted and conventional lessons.

Data were gathered using three instruments: cognitive performance tests, behavioral observation checklists, and semi-structured interviews with teachers and students. Quantitative data were analyzed through paired-sample t-tests to measure cognitive gains, while qualitative data underwent thematic analysis to interpret engagement and motivation patterns. The model achieved an average accuracy of 91.4% in attention classification and 88.7% in memory recognition. Triangulation of statistical and qualitative findings ensured data validity, positioning deep learning as a reliable and pedagogically meaningful approach to supporting young learners' cognitive development within culturally grounded educational contexts.

3. RESULTS AND DISCUSSION

The integration of the deep learning–based adaptive learning model produced substantial improvements in the cognitive performance and classroom engagement of students at *MIS Terpadu Alhijrah Bintuju*. The results are presented in three dimensions: cognitive performance outcomes, behavioral engagement indicators, and qualitative perceptions from teachers and students.

Cognitive Performance Outcomes

The quantitative analysis revealed a statistically significant improvement in students' early cognitive development following the eight-week intervention. As shown in Table 1, post-test scores in attention span, memory recall, and problem-solving ability were considerably higher than those in the pre-test condition.

Cognitive Indicator	Pre-test Mean	Post-test Mean	Improvement (%)	*p*-value
Attention Span	68.4	80.7	+18.0%	0.001
Memory Recall	65.9	80.5	+22.1%	0.000
Problem Solving	62.7	78.6	+25.4%	0.002

(*Note: N = 60; Paired-sample t-test significance at p < 0.05*)

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The findings indicate that the hybrid CNN–LSTM model effectively identified and responded to students' cognitive needs through adaptive feedback mechanisms. This outcome aligns with the findings of Wang and Chen (2022), who demonstrated that LSTM-based systems could predict and enhance learners' performance trajectories through real-time pattern recognition. In this study, the adaptive feedback loop where teachers received suggestions for differentiated instruction proved crucial in maintaining student attention and improving retention.

Furthermore, the AI system's diagnostic capacity allowed teachers to detect early signs of cognitive fatigue or disengagement. For example, when the CNN detected declining facial focus or inattentive posture, the system automatically prompted interactive visual cues or encouraged short reflective breaks. This dynamic adaptation likely contributed to the observed gains in attention and memory performance.

Behavioral Engagement and Motivation

Behavioral observations supported the quantitative findings. During AI-assisted sessions, students displayed greater enthusiasm, longer sustained focus, and increased willingness to participate in classroom discussions. Engagement levels measured through on-task behavior and response participation rose from an average of 63% in traditional sessions to 84% during AI-supported learning. Teachers also reported fewer incidents of distraction and fatigue, particularly among students who previously struggled with sustained concentration.

These behavioral improvements align with Holmes et al. (2022), who found that AI-mediated adaptive environments can stimulate learners' intrinsic motivation by providing instant, personalized feedback. Moreover, the deep learning model in this study appeared to foster a sense of autonomy among learners; students frequently mentioned that "the computer knows what I need to learn next," reflecting a shift toward self-regulated learning behavior.

Teachers' and Students' Perceptions

The qualitative interviews revealed strong positive attitudes toward the implementation of the deep learning system. Most teachers perceived the model as a "helpful teaching assistant" that reduced the cognitive load of continuous monitoring, allowing them to focus on conceptual explanations and moral guidance. Teachers appreciated that the AI system visualized cognitive data in an accessible format, presenting each student's learning profile through attention and memory graphs.

Students likewise expressed excitement and curiosity about the AI-supported lessons. Many described the activities as "more fun" and "less boring," and appreciated the immediate feedback when solving digital exercises. One student commented, *"When I forget something, the system helps me remember with pictures and hints."* Such findings corroborate Su et al. (2021) and Nugroho et al. (2023), who highlighted that AI-based adaptive systems can increase learner engagement and reduce anxiety by providing responsive feedback loops.

Integration in the Islamic Education Context

A key contribution of this study lies in demonstrating that deep learning can be contextually and ethically integrated into Islamic primary education. Teachers reported

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that the AI system did not disrupt the school's moral and religious framework; rather, it complemented it by promoting self-discipline and reflection—values consistent with Islamic educational philosophy (Nata, 2019). Importantly, the integration process respected institutional ethics and parental expectations, ensuring that student data remained private and anonymized.

This suggests that AI technologies can be harmonized with faith-based learning environments, provided they are designed with cultural sensitivity and pedagogical alignment. The combination of deep learning and Islamic values may thus serve as a new paradigm for culturally responsive AI education in developing nations.

Discussion

Overall, the findings confirm that applying deep learning approaches in primary education significantly enhances early cognitive development, engagement, and motivation. The results substantiate previous studies (Wang & Chen, 2022; Holmes et al., 2022) while extending them into a faith-based Indonesian context. The CNN–LSTM hybrid model demonstrated strong predictive reliability, with accuracy rates above 88% for memory and 91% for attention detection. This high level of precision contributed to more effective adaptive instruction and improved cognitive outcomes.

The study's success can be attributed to three synergistic factors: (1) the use of deep learning models that personalize feedback based on individual cognitive signals, (2) the active participation of teachers in interpreting AI outputs, and (3) the integration of moral and cultural dimensions that sustained motivation and discipline. These results underscore the feasibility and value of using deep learning as a pedagogical augmentation tool, rather than a replacement for human instruction.

The findings of this study provide compelling evidence that the integration of a deep learning based adaptive model can significantly enhance students' cognitive performance, behavioural engagement, and motivation in Islamic primary education. The CNN–LSTM hybrid system effectively identified learners' attention, memory, and problem-solving patterns, enabling adaptive feedback that improved learning outcomes by more than 20% across cognitive domains. Teachers and students alike expressed positive perceptions, viewing the AI system as both a supportive instructional tool and an engaging learning medium. Importantly, the model's alignment with Islamic educational values demonstrated that artificial intelligence can be ethically and culturally harmonised within faith-based contexts. Collectively, these results affirm that deep learning offers a transformative and context-sensitive framework for fostering early cognitive development and promoting personalised, value-driven learning in primary education.

From a conceptual perspective, the integration of deep learning systems in Islamic primary education reflects a dynamic intersection between artificial intelligence and constructivist learning theory. In constructivism, learning is viewed as an active process in which learners build knowledge through exploration, interaction, and reflection (Bruner, 1983; Vygotsky, 1978). Deep learning, as applied in this study, mirrors this epistemological stance by allowing the AI model to "learn" from patterns in multimodal data and subsequently generate adaptive feedback that supports students' individual meaning-making processes. The system's ability to analyze students' cognitive states and respond with differentiated tasks represents a digital enactment of *scaffolding*, where technology

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functions as a responsive mediator that guides learners within their *zone of proximal development*.

In an Islamic pedagogical context, this synergy becomes particularly meaningful. Islamic education emphasizes *ta'dib* (holistic formation of intellect, emotion, and morality) and encourages *active reflection* (*tafakkur*) as a means of understanding both divine knowledge and worldly phenomena. The adaptive feedback generated by AI aligns with this principle by fostering self-awareness, self-regulation, and responsibility in learning—qualities that resonate with the Islamic view of humans as active seekers of knowledge (*thalib al-'ilm*). Thus, the constructivist foundation of AI-assisted learning supports the spiritual and moral objectives of Islamic education, transforming technology from a mere instructional aid into a medium for reflective and value-oriented cognitive growth.

This conceptual alignment suggests that culturally responsive AI systems can act as *intelligent scaffolds* that bridge modern technological innovation with traditional moral pedagogy. By merging data-driven adaptivity with the Islamic emphasis on guided self-development, deep learning technologies may foster both intellectual autonomy and ethical consciousness—offering a holistic model of 21st-century Islamic education grounded in constructivist principles.

4. CONCLUSION

The study demonstrates that integrating deep learning technology into primary education can substantially enhance early cognitive development among young learners. The implementation of a CNN–LSTM hybrid model in MIS Terpadu Alhijrah Bintuju effectively strengthened key cognitive abilities attention, memory, and reasoning while fostering higher engagement and motivation in classroom learning. The adaptive feedback provided by the model enabled personalized instruction and created a more inclusive learning environment, aligning *with* current pedagogical trends that emphasize differentiation and learner autonomy in digital education. Both teachers and students perceived the AI-based system positively, recognizing it as a valuable tool for enhancing learning experiences and improving academic performance.

Nevertheless, the study also identified several challenges that warrant attention. Limited technological infrastructure, inconsistent internet access, and insufficient teacher training occasionally hindered the smooth implementation of AI-assisted learning. Addressing these limitations through sustained professional development and infrastructure investment is essential for wider adoption. Overall, this research affirms that culturally aligned deep learning applications can serve as intelligent pedagogical partners in Islamic primary schools supporting cognitive growth, motivation, and equity in learning while preserving moral and cultural values.

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