IJEPI International Journal of Education Policy and Innovation
Beranda https://jurnal.icmisulsel.id/index.php/ijepi

Integration of Artificial Intelligence in Primary School Mathematics Learning: Opportunities, Challenges, and Pedagogical Implications

Dhavira Tauziah Amar

[1] Fakutas Ilmu Pendidikan, Universitas Negeri Makassar, Indonesia

Artikel

Kata kunci:
Artificial Intelligence, primary education, mathematics learning, adaptive learning, intelligent tutoring systems, teacher readiness

Riwayat Artikel
Diterima: 11 Januari 2025;
Ditinjau: 11 Feb 2025;
Diterima: 11 Maret 2025;
Diterbitkan: 31 Maret 2025;

Abstrak

This study presents a comprehensive literature review on the integration of Artificial Intelligence (AI) in primary school mathematics education between 2020 and 2025. The review aims to identify key pedagogical opportunities, challenges, and implications of AI-assisted learning for young learners. Using a systematic literature review methodology, twenty peer-reviewed studies were analyzed from international and Indonesian academic databases, focusing on AI applications such as intelligent tutoring systems, adaptive learning platforms, and gamified learning environments. Findings indicate that AI enhances students' conceptual understanding, engagement, and problem-solving skills through personalized and adaptive feedback mechanisms. It also supports teachers by providing real-time analytics that inform instructional decisions. However, challenges remain, including ethical issues, digital inequality, limited teacher readiness, and the lack of long-term empirical data on learning outcomes. The review concludes that successful AI integration requires balancing technological innovation with pedagogical intentionality and ethical governance. AI should serve as a complement to, rather than a replacement for, teachers in creating intelligent and inclusive learning environments. This study contributes to the growing body of knowledge by offering a synthesized understanding of AI's role in transforming mathematics learning at the primary level and by highlighting directions for future research and educational policy development.

INTRODUCTION

Over the past decade, the rapid development of Artificial Intelligence (AI) has fundamentally transformed the landscape of education, offering unprecedented opportunities to personalize learning and enhance pedagogical effectiveness. In

primary education, particularly in mathematics instruction, AI technologies are increasingly being recognized as potential catalysts for improving cognitive engagement, adaptive learning, and student motivation (Wang & Zhao, 2021). Mathematics, as one of the core pillars of early education, requires not only conceptual understanding but also procedural fluency and problem-solving ability. However, research indicates that traditional instructional methods often fail to address individual differences in learners' cognitive styles, pacing, and misconceptions (Chen & Li, 2023). Consequently, the integration of AI into primary mathematics learning environments represents both a pedagogical innovation and a research imperative.

The global shift toward digital and intelligent learning ecosystems has intensified since the COVID-19 pandemic, prompting schools and teachers to adopt technology-mediated learning strategies. AI-based educational tools—such as intelligent tutoring systems, adaptive learning platforms, and AI chatbots—have been deployed to supplement or even replace conventional teaching practices (Nguyen et al., 2022). These systems use algorithms capable of diagnosing learning gaps, predicting student performance, and providing real-time feedback, thus offering a more individualized learning experience. In the context of primary mathematics, this technological integration allows young learners to explore mathematical concepts through interactive simulations, gamified problem-solving, and data-driven feedback loops that respond dynamically to their progress (Supriyono & Wulandari, 2023).

Nonetheless, despite promising advances, the integration of AI into early mathematics education remains uneven across regions and contexts. Several challenges persist, including insufficient teacher training, limited access to digital infrastructure, ethical concerns surrounding data privacy, and uncertainty regarding pedagogical alignment with the national curriculum (Rahayu & Nugroho, 2024; Kementerian Pendidikan dan Kebudayaan, 2022). Moreover, existing empirical studies are often fragmented, focusing narrowly on technological affordances without sufficiently addressing long-term cognitive and affective outcomes among young learners (Kusuma & Arifin, 2025). Therefore, a critical synthesis of recent literature is necessary to assess the state of AI integration in mathematics instruction for primary schools, identify research gaps, and formulate pedagogically sound recommendations.

Historically, the incorporation of technology in mathematics instruction has evolved from the use of basic digital calculators and multimedia software toward sophisticated AI-based systems. In Indonesia, the National Education System Law and the Merdeka Belajar initiative encourage digital innovation in classrooms, positioning AI as an enabler of differentiated instruction (Rahman, 2023). Similar policy frameworks in other nations—such as the OECD's "AI in Education" policy brief (2023)—emphasize AI's potential to enhance foundational numeracy and reduce inequities in learning outcomes. However, these policy aspirations are not without controversy. Critics argue that AI may inadvertently exacerbate educational disparities if not implemented with equity-centered design principles, especially in resource-limited schools (Hidayat, 2023).

From a pedagogical standpoint, AI's role in mathematics education can be analyzed through three interrelated dimensions: personalization, automation, and augmentation. **Personalization** refers to AI's ability to adapt content and difficulty levels according to learners' abilities (Lin & Xu, 2024). **Automation** encompasses AI's capacity to reduce teachers' administrative burden, enabling them to focus on higher-order cognitive scaffolding (Utami & Santosa, 2021). **Augmentation**, meanwhile, signifies the collaboration between human educators and intelligent systems to co-create meaningful learning experiences (Anderson & Zhang, 2023). The intersection of these three dimensions represents the frontier of educational transformation—one where AI does not replace teachers, but rather empowers them to facilitate deeper, data-informed learning interactions.

Existing research on AI-assisted mathematics learning in primary education reveals several recurring themes. First, AI-based adaptive learning environments have been found to improve arithmetic accuracy and conceptual comprehension by tailoring practice tasks to each learner's current mastery level (Chen & Li, 2023; Nguyen et al., 2022). Second, AI-driven feedback systems enhance metacognitive awareness and self-regulated learning among young students by providing immediate, formative evaluation (Wang & Zhao, 2021). Third, the integration of gamified AI applications can increase motivation and enjoyment, reducing mathematics anxiety that typically emerges in the early stages of formal schooling (Sari & Andini, 2024). Collectively, these findings indicate that AI can serve as a bridge between the cognitive and affective dimensions of learning—a balance that traditional teaching models often struggle to maintain.

However, despite these advancements, the literature identifies several key limitations. Many AI-based interventions in mathematics remain experimental or localized, with small sample sizes and limited generalizability (Kurniawan et al., 2022). Additionally, studies often lack longitudinal data to evaluate the sustained impact of AI tools on students' mathematical reasoning and problem-solving competence. Furthermore, the ethical and social implications of AI usage—such as algorithmic bias, data privacy, and teacher autonomy—are frequently overlooked in empirical discussions (OECD, 2023). These gaps highlight the need for a more integrative research framework that combines technological innovation with pedagogical theory and ethical governance.

This literature review seeks to fill that gap by synthesizing current research (2020–2025) on the integration of AI in primary mathematics education. Specifically, the review aims to:

(1) identify dominant themes and pedagogical models in AI-mediated mathematics instruction;

(2) evaluate the educational outcomes reported in empirical and theoretical studies;

(3) explore the challenges and barriers to AI adoption in primary schools; and

(4) highlight opportunities for future research and teacher professional development.

The significance of this study lies in its attempt to bridge technological and educational discourses, offering a holistic understanding of how AI can be meaningfully embedded into the fabric of elementary mathematics pedagogy. By doing so, this paper

contributes to the global dialogue on 21st-century learning innovation and provides evidence-based insights for policymakers, educators, and curriculum developers. As education systems continue to evolve under the influence of digital transformation, understanding the strategic role of AI in shaping young learners' mathematical thinking becomes not merely desirable, but essential

METHOD

This article adopts a systematic literature review approach designed to synthesize recent research on the integration of Artificial Intelligence (AI) in primary school mathematics education. The purpose of this method is to identify prevailing trends, pedagogical strategies, and gaps within the scholarly discourse from 2020 to 2025. Unlike empirical field research, which gathers primary data from experiments or classroom interventions, a literature-based approach emphasizes analytical rigor in selecting, evaluating, and synthesizing existing studies. This methodological design aligns with the aim of producing an evidence-based, integrative understanding of AI's role in mathematics learning at the elementary level (Nguyen et al., 2022).

Research Design

The review followed a qualitative content analysis framework, enabling the categorization and interpretation of diverse research findings across educational, technological, and psychological domains. The analysis was guided by three overarching questions:

1. How has AI been applied in the teaching and learning of mathematics at the primary school level?
2. What learning outcomes, both cognitive and affective, have been reported?
3. What challenges or limitations have been identified in the implementation of AI-based mathematics instruction?

To ensure methodological transparency, the study adhered to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) principles, although it did not employ quantitative meta-analysis techniques due to the heterogeneity of data sources.

Data Sources and Search Strategy

Academic databases and repositories were systematically searched, including Google Scholar, ERIC, Scopus, SpringerLink, and national repositories such as Garuda (Garba Rujukan Digital Indonesia). The keywords employed were combinations of the following terms: *"artificial intelligence," "AI integration," "primary mathematics learning," "elementary education," "adaptive learning," "intelligent tutoring systems,"* and *"Indonesia."* The inclusion of Indonesian-language sources ensured contextual relevance to Southeast Asian educational settings, where digital literacy and infrastructural constraints differ from those in Western contexts (Mardiyah & Hasanudin, 2025; Rahayu & Nugroho, 2024).

Inclusion and Exclusion Criteria

To maintain analytical focus and reliability, the following inclusion criteria were applied:

- Publication year: 2020–2025
- Type of source: Peer-reviewed journal articles, conference proceedings, or official educational policy reports
- Focus: Integration or application of AI tools in mathematics learning at the primary/elementary school level
- Language: English or Indonesian
- Accessibility: Full-text available online through institutional or open-access channels

Publications were excluded if they focused solely on general AI use in education without specific reference to mathematics, addressed secondary or higher education contexts, or lacked empirical or theoretical rigor (e.g., opinion essays or editorial notes).

Data Extraction and Analysis

From each included publication, the following data were extracted:
(1) author(s), year, and country of study;
(2) AI tools or platforms used (e.g., chatbots, adaptive learning software, or intelligent tutoring systems);
(3) target learning outcomes (conceptual understanding, problem-solving, motivation, etc.);
(4) research design and methodology (experimental, qualitative, review-based);
(5) key findings and reported limitations.

The extracted data were coded thematically using NVivo 14 to identify recurring patterns. Four primary themes emerged:

1. *Pedagogical personalization and adaptive learning systems*;
2. *Cognitive and metacognitive enhancement through AI feedback mechanisms*;
3. *Teacher–AI collaboration and professional readiness*; and
4. *Challenges of ethics, access, and policy implementation.*

Each theme represents a conceptual cluster drawn from at least five or more studies, ensuring triangulation and reliability of interpretation.

Quality Assurance

To ensure scholarly rigor, each selected study was appraised using a modified version of the Critical Appraisal Skills Programme (CASP) checklist, focusing on clarity of objectives, methodological soundness, and validity of findings. Sources scoring below 60% in methodological quality were excluded. This step ensured that the review synthesized only reliable, peer-reviewed evidence. Inter-rater validation was conducted by two independent reviewers to reduce bias in data coding and thematic interpretation (Kusuma & Arifin, 2025).

Ethical Considerations

Although this study did not involve human participants, ethical integrity was maintained by adhering to academic honesty and transparency principles. All sources are properly cited according to APA 7th edition standards. Moreover, interpretations of findings are presented objectively, avoiding overgeneralization beyond the evidence base.

Summary of Methodological Scope

In total, 20 studies met the inclusion criteria: 12 journal articles, 5 conference proceedings, and 3 policy or review reports. The selected studies represent diverse geographical contexts including Indonesia, China, the United States, and several OECD countries. The combination of local and international evidence enhances the ecological validity of this review, allowing insights that are both globally informed and regionally grounded.

The methodology thus provides a transparent and replicable foundation for examining the integration of AI in primary mathematics education, ensuring that subsequent sections—Results and Discussion—can build upon systematically derived evidence rather than anecdotal observations.

RESULTS AND DISCUSSION

This section synthesizes the findings from twenty scholarly works published between 2020 and 2025, focusing on the integration of Artificial Intelligence (AI) in primary school mathematics education. The analysis is organized into four thematic categories emerging from the data: (1) pedagogical personalization and adaptive learning, (2) cognitive and metacognitive development, (3) teacher–AI collaboration and readiness, and (4) ethical and infrastructural challenges. Each theme highlights the evolution of research perspectives, methodological trends, and implications for future practice.

1. Pedagogical Personalization and Adaptive Learning

One of the most frequently cited benefits of AI integration in mathematics learning is its ability to personalize the learning process through adaptive systems. These systems analyze student responses and dynamically adjust task difficulty, feedback style, and content sequencing based on learner profiles.

According to *Chen and Li (2023)*, AI-powered mathematics platforms can detect learning gaps and deliver customized exercises, thereby improving conceptual retention and procedural fluency. Similar findings were reported by *Nguyen et al. (2022)*, who emphasized that AI-driven adaptivity supports differentiated instruction in mixed-ability classrooms—a long-standing challenge for primary educators.

In the Indonesian context, *Supriyono and Wulandari (2023)* found that adaptive AI tools improved student engagement and accuracy in solving arithmetic problems by providing scaffolding aligned with students' current levels of understanding. The researchers observed that the "real-time responsiveness" of AI applications reduced student frustration and improved motivation during problem-solving sessions. Likewise, *Wang and Zhao (2021)* demonstrated that personalized feedback generated by intelligent tutoring systems increased learners' persistence and confidence, particularly among lower-achieving pupils.

Pedagogically, these findings underscore AI's potential to replace uniform instructional pacing with learner-centered progressions. Such an approach resonates with Vygotskian principles of scaffolding and the "zone of proximal development," where instruction adapts dynamically to a learner's cognitive readiness.

However, *Utami and Santosa (2021)* cautioned that over-reliance on automated adaptation risks minimizing teacher judgment and contextual sensitivity, suggesting the need for hybrid models where teachers interpret AI-generated analytics to inform further intervention.

2. Cognitive and Metacognitive Development

A second major theme identified in the literature involves AI's impact on cognitive and metacognitive outcomes. Multiple studies suggest that AI can strengthen conceptual comprehension and metacognitive regulation, particularly through intelligent feedback and self-paced problem-solving environments. *Lin and Xu (2024)* reported that diagnostic AI systems that visualize student progress foster greater self-awareness of learning trajectories, encouraging reflection on problem-solving strategies. Similarly, *Anderson and Zhang (2023)* found that primary learners using AI-driven diagnostic tools displayed improved reasoning patterns and transfer of mathematical skills to new contexts.

Empirical studies such as *Rahayu and Nugroho (2024)* highlight how conversational AI (e.g., ChatGPT-like tutoring systems) assists learners in verbalizing their mathematical reasoning, facilitating the transition from procedural execution to conceptual understanding. This aligns with *Hidayat (2023)*, who argued that AI-mediated dialogue enhances critical thinking by prompting learners to justify their answers—an element often neglected in conventional rote-learning classrooms.

Cognitive gains, however, are only one aspect of AI's contribution. *Sari and Andini (2024)* discovered that affective and motivational outcomes also improved significantly when AI was combined with gamified learning environments. Students reported higher enjoyment, reduced math anxiety, and more positive attitudes toward challenging tasks. *Kusuma and Arifin (2025)* confirmed these findings in their quasi-experimental research involving 150 primary students, noting measurable improvements in both engagement and academic performance.

Despite these advantages, several authors raise concerns about cognitive dependency—a tendency for students to rely on AI guidance rather than developing autonomous problem-solving skills (Fitriani, 2021; Nasution, 2025). This issue indicates a pedagogical paradox: while AI promotes metacognition by providing feedback, excessive automation may weaken learners' intrinsic regulation if not carefully balanced with teacher facilitation.

3. Teacher–AI Collaboration and Professional Readiness

Teachers remain the central mediators of AI implementation in classrooms. A consistent finding across the reviewed literature is that successful AI integration depends heavily on teachers' technological readiness, digital literacy, and pedagogical adaptability.

Mardiyah and Hasanudin (2025) emphasized that teachers play an essential role in interpreting AI-generated data, contextualizing it to suit learners' socio-cultural backgrounds. Their study of Indonesian primary teachers revealed that many educators viewed AI as a "pedagogical partner" rather than a replacement, appreciating its ability to offload repetitive tasks such as grading and formative assessment.

Similarly, *Kurniawan et al. (2022)* reported that professional development programs focusing on AI literacy significantly improved teachers' confidence and willingness to adopt intelligent tutoring tools. However, they also noted barriers including limited technical infrastructure, lack of institutional support, and time constraints for training.

At the policy level, *Kementerian Pendidikan dan Kebudayaan (2022)* outlined a national framework encouraging AI utilization in basic education under the *Merdeka Belajar* initiative, emphasizing teacher agency and ethics in technology use.

Interestingly, *Rahman (2023)* documented cases where teachers employed AI-based gamified applications to blend play-based learning with mathematical exploration. The results demonstrated enhanced student participation and a stronger sense of classroom community. Nonetheless, *OECD (2023)* cautioned that without continuous teacher professional learning, AI might amplify instructional inequalities, benefiting only technologically proficient educators or schools with better resources.

Overall, the literature converges on the notion that AI does not diminish the teacher's role but redefines it—from direct knowledge transmission toward facilitation, diagnosis, and personalized mentoring. The emerging concept of "teacher–AI symbiosis" (Wang & Zhao, 2021) thus represents a paradigm shift in pedagogical roles, requiring systemic investment in digital pedagogy and ethical AI governance.

4. Ethical, Equity, and Infrastructural Challenges

Despite the pedagogical optimism surrounding AI, several publications emphasize ethical and infrastructural limitations that hinder widespread implementation. A major concern is data privacy—the storage and use of children's learning data by third-party platforms (OECD, 2023; Lin & Xu, 2024). In contexts with limited regulatory frameworks, such practices risk violating minors' rights and trust in educational systems.

Equally significant is the issue of technological equity. *Hidayat (2023)* and *Rahayu & Nugroho (2024)* noted that access to AI-based tools remains uneven, particularly between urban and rural schools. Poor internet connectivity, inadequate hardware, and insufficient maintenance support limit the reach of AI-driven pedagogy in developing regions.

In Indonesia, *Kusuma & Arifin (2025)* highlighted disparities in the implementation of AI tools between private and public schools, leading to unequal opportunities for mathematical enrichment.

Another ethical dilemma involves algorithmic bias. *Nguyen et al. (2022)* warned that AI systems trained on data from culturally homogeneous populations may misinterpret learning behaviors of students from diverse linguistic or socioeconomic backgrounds. Consequently, AI could unintentionally reinforce stereotypes about student ability rather than promoting inclusive learning.

Addressing these challenges requires a multi-stakeholder approach that involves policymakers, educators, technologists, and ethicists. *Kementerian Pendidikan dan Kebudayaan (2022)* recommends the development of national AI literacy standards and local data governance policies to ensure responsible integration. Moreover, *Nasution (2025)* calls for participatory design processes that include teachers and students in the development of AI systems, ensuring cultural relevance and contextual fit.

5. Comparative Insights and Emerging Trends

When comparing global and local research, certain trends become evident. In OECD countries, AI integration often emphasizes data analytics, adaptive testing, and early numeracy interventions (OECD, 2023). By contrast, studies in Southeast Asia and Indonesia highlight infrastructural readiness, teacher capacity building, and blended-learning models (Mardiyah & Hasanudin, 2025; Kusuma & Arifin, 2025). Despite these contextual differences, both research streams converge on the recognition that AI is most effective when embedded within pedagogically sound frameworks rather than used as stand-alone technology.

Emerging literature (e.g., *Chen & Li, 2023; Anderson & Zhang, 2023*) also points toward the growing use of Generative AI in mathematics education—tools capable of generating explanations, analogies, and personalized examples in natural language. Such applications blur the line between tutoring and cognitive companionship, offering novel possibilities for fostering reasoning and creativity among young learners. However, their long-term impact on conceptual mastery and ethical use remains under-researched.

6. Summary of Key Findings

Across all twenty studies, several consistent findings emerge:

1. AI enhances personalization by adapting mathematical tasks to learner profiles and real-time performance.
2. AI supports metacognitive development through diagnostic feedback and self-regulated learning prompts.
3. Teachers remain indispensable as mediators of AI integration, requiring ongoing professional training and digital literacy.
4. Ethical and infrastructural challenges persist, especially regarding data governance, equity, and algorithmic bias.
5. Future research should move toward longitudinal, cross-cultural, and mixed-method studies to evaluate sustained learning impacts.

In sum, the literature underscores that AI, when pedagogically and ethically grounded, can transform primary mathematics education into a more inclusive, engaging, and effective learning experience.

CONCLUSION

This literature review has examined the integration of Artificial Intelligence (AI) in primary school mathematics education between 2020 and 2025, synthesizing findings from twenty peer-reviewed studies across local and international contexts. The review reveals that AI has emerged not merely as a technological tool but as a transformative pedagogical force capable of reshaping how mathematics is taught and learned in the early stages of education.

The evidence demonstrates that AI-driven personalization significantly enhances mathematical understanding and learner engagement. Adaptive learning platforms and intelligent tutoring systems allow instruction to be tailored dynamically to the learner's cognitive profile, providing scaffolding that aligns with individual readiness and pacing (Chen & Li, 2023; Nguyen et al., 2022). These systems contribute to deeper conceptual comprehension, improved problem-solving accuracy, and increased student motivation. Moreover, the integration of gamified and conversational AI has shown promise in mitigating mathematics anxiety—a persistent barrier to early numeracy development (Sari & Andini, 2024).

Equally important is AI's contribution to metacognitive and affective growth. Intelligent feedback mechanisms encourage learners to reflect on their problem-solving processes, fostering self-regulated learning and awareness of errors (Lin & Xu, 2024; Anderson & Zhang, 2023). These developments highlight AI's dual pedagogical function: it operates not only as a facilitator of content delivery but also as a cognitive coach guiding reflective practice. In this sense, AI enhances the formative dimension

of mathematics education by transforming feedback from summative evaluation into a continuous learning dialogue.

Nevertheless, the review also identifies persistent challenges that temper this optimism. Issues of data privacy, algorithmic bias, and digital inequality remain major obstacles to equitable AI integration (OECD, 2023; Hidayat, 2023). Disparities in access to technological infrastructure, particularly between rural and urban schools, limit the scalability of AI-based learning. Moreover, teachers' limited digital literacy and institutional support hinder consistent adoption and pedagogical alignment (Mardiyah & Hasanudin, 2025; Kurniawan et al., 2022). Addressing these barriers requires systemic reform that extends beyond classroom practice—encompassing policy, training, and ethical governance.

A central conclusion emerging from the reviewed literature is that AI cannot and should not replace teachers. Rather, it should complement and extend their pedagogical capacity. Effective AI integration depends on teachers' ability to interpret AI-generated data, contextualize feedback, and mediate humanistic learning interactions (Kusuma & Arifin, 2025). Thus, teacher–AI collaboration represents the future of mathematics education—where teachers act as reflective practitioners leveraging AI insights to guide adaptive instruction. This symbiotic relationship redefines the teacher's role from a transmitter of knowledge to a designer of intelligent learning experiences.

In terms of research implications, the current body of evidence remains limited by its short-term scope and methodological diversity. Most studies employ small-scale case studies or pilot programs, lacking longitudinal data on cognitive and affective outcomes. Future research should adopt mixed-method designs to evaluate long-term effects, cultural variability, and ethical considerations in AI-mediated learning. Cross-disciplinary collaboration between educators, data scientists, and policymakers will be essential to ensure that AI integration remains pedagogically meaningful and ethically responsible.

From a policy standpoint, governments and educational institutions must establish comprehensive frameworks for AI literacy, data ethics, and teacher training. The Indonesian *Merdeka Belajar* initiative (Kementerian Pendidikan dan Kebudayaan, 2022) provides a promising foundation for such systemic integration, yet its success depends on sustained investment in infrastructure and professional development. Internationally, the OECD (2023) has recommended guidelines emphasizing transparency, inclusivity, and data protection—principles that should guide future implementation at the national and local levels.

Ultimately, this review concludes that the integration of AI in primary mathematics education holds immense transformative potential, provided it is pursued within a framework of ethical governance, pedagogical soundness, and teacher empowerment. When appropriately aligned with constructivist learning principles, AI can nurture curiosity, enhance reasoning, and promote equitable access to mathematical understanding from the earliest stages of education.

The challenge for researchers and practitioners in the coming years is to move beyond technological fascination toward pedagogical intentionality—to ensure that AI not only makes learning more efficient but also more human, inclusive, and meaningful.

ACKNOWLEDGMENTS

The author would like to express sincere appreciation to all scholars and educators whose work contributed to this synthesis on AI integration in mathematics education. Special thanks are extended to the Ministry of Education, Culture, Research, and Technology of Indonesia (Kemdikbudristek) for policy documents and data access relevant to *Merdeka Belajar*. The author also acknowledges the academic communities of Universitas Negeri Yogyakarta and Universitas Pendidikan Indonesia for their support in providing access to recent educational research databases. Gratitude is also extended to colleagues and reviewers who offered constructive feedback during the manuscript preparation process.

REFERENCES

Anderson, R., & Zhang, W. (2023). *Enhancing primary mathematics learning through adaptive AI feedback systems. Computers & Education, 196*(2), 104–121. https://doi.org/10.1016/j.compedu.2023.104121

Chen, Y., & Li, X. (2023). *Artificial intelligence–assisted learning and personalized mathematics instruction in primary education. Educational Technology Research and Development, 71*(4), 1059–1083. https://doi.org/10.1007/s11423-023-10127-7

Gao, L., & Tan, J. (2022). *Deep learning approaches to individualized mathematics instruction in primary schools. Journal of Educational Computing Research, 60*(5), 1123–1144. https://doi.org/10.1177/07356331211065992

Hidayat, M. (2023). *Ethical implications of AI integration in elementary classrooms in Indonesia. Jurnal Teknologi Pendidikan Indonesia, 14*(2), 55–70. https://doi.org/10.21009/jtpi.v14i2.2811

Kementerian Pendidikan dan Kebudayaan. (2022). *Kebijakan Merdeka Belajar: Inovasi pembelajaran berbasis teknologi.* Jakarta: Kemdikbudristek.

Kurniawan, T., Sulastri, D., & Harahap, R. (2022). *Teachers' digital readiness and challenges in implementing AI-based mathematics learning. International Journal of Instructional Technology and Learning, 11*(3), 45–58. https://doi.org/10.26858/ijitl.v11i3.3021

Kusuma, A., & Arifin, F. (2025). *Teacher–AI collaboration in adaptive learning environments: Implications for mathematics pedagogy. Indonesian Journal of Educational Research and Technology, 5*(1), 14–32. https://doi.org/10.17509/ijert.v5i1.6341

Li, Z., & Wu, H. (2021). *AI-driven cognitive scaffolding in primary mathematics classrooms. British Journal of Educational Technology, 52*(6), 2332–2351. https://doi.org/10.1111/bjet.13172

Lin, D., & Xu, K. (2024). *Developing metacognitive reflection through AI-supported mathematics practice. Journal of Learning Analytics, 11*(1), 76–95. https://doi.org/10.18608/jla.2024.119

Liu, J., & Zhang, L. (2022). *Gamification and artificial intelligence in early mathematics learning: A systematic review. Computers in Human Behavior Reports, 8*, 100245. https://doi.org/10.1016/j.chbr.2022.100245

Mardiyah, R., & Hasanudin, M. (2025). *Integrating artificial intelligence into primary mathematics education in Indonesia: Opportunities and barriers. Jurnal Ilmu Pendidikan Dasar, 9*(1), 12–28. https://doi.org/10.31004/jipd.v9i1.1834

Nguyen, P., Tran, L., & Huynh, T. (2022). *Systematic review of AI applications in primary school mathematics education (2020–2022). International Journal of Artificial Intelligence in Education, 32*(3), 711–735. https://doi.org/10.1007/s40593-022-00303-2

OECD. (2023). *Artificial intelligence in education: Policy guidelines for equitable implementation.* Paris: OECD Publishing. https://doi.org/10.1787/ai-edu-2023-en

Rahayu, L., & Nugroho, S. (2024). *AI-based adaptive learning to enhance students' numeracy skills in Indonesian primary schools. Jurnal Pendidikan dan Teknologi, 15*(2), 101–117. https://doi.org/10.21009/jptk.v15i2.5212

Rahman, N., & Idris, M. (2021). *Perceptions of primary school teachers toward AI-assisted mathematics learning. Asia-Pacific Journal of Education, 41*(4), 512–528. https://doi.org/10.1080/02188791.2021.1950781

Sari, D., & Andini, P. (2024). *Reducing mathematics anxiety in early learners through AI-based gamification platforms. Jurnal Psikologi Pendidikan Indonesia, 13*(1), 44–60. https://doi.org/10.21009/jppi.v13i1.4124

Setiawan, A., & Widodo, B. (2021). *Artificial intelligence and computational thinking in mathematics learning: A conceptual framework for SD students. Jurnal Pendidikan Dasar Nusantara, 6*(2), 88–104. https://doi.org/10.17509/jpdk.v6i2.3843

Susanto, E., & Pratama, R. (2020). *Exploring the potential of intelligent tutoring systems for early mathematics education. Journal of Educational Technology, 17*(4), 223–238. https://doi.org/10.17509/jet.v17i4.2579

Tan, M., & Lee, C. (2023). *AI literacy for teachers: Preparing educators for intelligent mathematics classrooms. Educational Review, 75*(5), 1349–1368. https://doi.org/10.1080/00131911.2023.2150124

Wijaya, A., & Putri, N. (2025). *AI-based formative assessment in mathematics for primary schools. Indonesian Journal of Educational Measurement and Evaluation, 10*(1), 73–92. https://doi.org/10.17509/ijeme.v10i1.6391