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Trends, opportunities, and challenges of artificial intelligence in elementary education - A systematic literature review

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Abstract

This study aims to analyze the trends, opportunities, and challenges of implementing Artificial Intelligence (AI) in primary education based on a systematic literature review. The research method employed the Systematic Literature Review (SLR) approach with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). Data collection techniques involved searching references from reputable journal databases such as Scopus, Web of Science, ERIC, Google Scholar, IEEE Xplore, Taylor & Francis Online, and Wiley Online Library, resulting in 45 studies (2016-2024) selected based on relevance to AI in primary education. The study results indicate that (1) AI trends in primary education are dominated by Augmented Reality (AR), Virtual Reality (VR), Learning Management Systems (LMS), and Adaptive Learning Systems; (2) Opportunities for AI in primary education include the development of more effective and measurable AI technology innovations and their widespread application to improve student learning outcomes; and (3) Challenges in implementing AI in primary education include technological disparities, high costs, uneven infrastructure, lack of teacher training, and insufficient technological and budget support, and student data privacy. The study concludes that AI in primary education has the potential to enhance learning quality through AR, VR, LMS, and Adaptive Learning, yet still faces challenges related to technological disparities, costs, infrastructure, and teacher training. This study offers insights for policymakers and educators to strengthen teacher competence, improve infrastructure, and ensure equitable AI access in schools.

INTRODUCTION

The rapid development of technology has brought the world into an era of disruption, where digital innovations fundamentally transform various aspects of life (Ghavifekr & Rosdy, 2015). Advancing technology replaces conventional methods and creates new ways of conducting daily activities. Digitalization has penetrated almost all sectors, including education, by integrating technology into learning (Moltudal et al., 2022). The concept of learning is no longer confined to physical classrooms but also involves digital media, online learning platforms, and artificial intelligence-based technology. Digitalization enables broader access to information, flexibility in learning methods, and efficiency in educational administration (Yaraş & Öztürk, 2022).

Artificial Intelligence (AI) is a key technology in this digitalization era. Artificial Intelligence (AI) is a branch of computer science that enables machines to mimic human intelligence in completing specific tasks (Rathore et al., 2023). AI encompasses machine learning, natural language processing, and computer vision, allowing systems to learn from data, recognize patterns, and make decisions automatically (Walan, 2024). Various tasks previously performed by humans can now be replaced by AI, particularly repetitive tasks such as industrial production, chatbot-based customer service, and data analysis (Chamunyonga et al., 2020; Henry et al., 2021). However, the impact is not always negative. AI also creates new job opportunities, such as AI developers, data analysts, and AI ethics specialists (Delgado et al., 2020). Therefore, the biggest challenge is how humans can adapt to these changes through skills enhancement and more relevant education for the digital era.

Artificial Intelligence (AI) in education encompasses various technologies designed to enhance the effectiveness of learning and educational management, such as Augmented Reality (AR) and Virtual Reality (VR), which provide interactive and immersive learning experiences; Learning Management Systems (LMS), which assist in managing materials and learning evaluations; and Adaptive Learning (AL), which adjusts materials based on individual student needs. Additionally, Intelligent Tutoring System (ITS) enables automated learning guidance, Natural Language Processing (NLP) supports students' educational needs with chatbots and virtual assistants, while Automated Assessment Systems accelerate the evaluation process through automated analysis (Rathore et al., 2023; Walan, 2024).

The implementation of AI in education has brought significant changes in how teachers teach and students learn. This technology enables more personalized learning, provides real-time feedback, and helps teachers analyze student progress more comprehensively (Henry et al., 2021). Moreover, the primary impact of AI in education is increased accessibility and inclusivity. The application of AI at the primary school level holds great potential to improve learning quality from an early

stage (Moltudal et al., 2022). Through the use of AI, students can gain more engaging learning experiences that suit their cognitive development (Bae, 2023). AI technology also assists teachers in developing more effective teaching strategies, managing classroom administration, and providing faster and more accurate feedback to students (Alrehaili & Al Osman, 2022; Wijayama et al., 2024).

In the context of primary education, technology integration becomes essential to ensure young students develop digital literacy from an early age. AI technology offers new opportunities to improve learning processes at the elementary school level, such as through personalized learning experiences, real-time feedback, and data-driven decision-making in instructional design (Kusumaningsih et al., 2022; Shim, 2023). Several elementary schools in various countries have started using AI-powered educational applications, adaptive learning platforms, and AI-assisted formative assessments to support classroom learning (Chamunyonga et al., 2020; Henry et al., 2021). For example, applications like "DreamBox" and "Century Tech" provide adaptive mathematics learning, adjusting the difficulty level according to students' abilities. Meanwhile, AI-powered voice assistants have been introduced in some classrooms to help students practice reading and pronunciation skills (Erviana & Sepriansyah, 2024; Shaumiwaty et al., 2022). These concrete examples illustrate how AI can enrich learning experiences in primary schools.

While the advantages of AI are widely acknowledged, there remains a notable need for more thorough research focused on its application in primary education. Current studies predominantly emphasize higher education and professional training, which means that the exploration of AI's impact on primary school learning is an area that warrants further investigation (Chamunyonga et al., 2020; Delgado et al., 2020; Walan, 2024). Consequently, it's clear that a deeper investigation is necessary to fully grasp AI's effectiveness, the challenges it poses, and the opportunities it can provide within the realm of primary education.

This research contributes as a comprehensive study that analyzes trends, opportunities, and challenges of AI implementation in primary education. These three aspects are emphasized because understanding trends helps capture the current state and direction of AI adoption in elementary education, serving as a foundation for future development. Meanwhile, identifying opportunities reveals AI's potential benefits to enhance teaching quality and student learning while exploring challenges, highlighting the critical technical and pedagogical barriers that must be addressed to ensure effective and equitable AI integration in primary schools. Few studies comprehensively overview how AI can be optimized in primary school environments. Therefore, this study aims to analyze trends in AI applications in primary education, identify opportunities to improve student learning outcomes and examine the challenges that must be addressed for optimal AI implementation.

METHODS

Research Design

This study employs the Systematic Literature Review (SLR) method, and the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) reporting guideline is used to enhance transparency in the article selection process. PRISMA functions as a reporting guideline to transparently describe the process of identifying, screening, and selecting articles, ensuring traceability of the review process. PRISMA ensures that with appropriate selection rigor and quality assessment criteria, only high-quality academic articles are included, thereby enhancing the validity and reliability of the research findings. Additionally, PRISMA-based SLR provides transparency in the study selection process, making the research outcomes more replicable and useful as references for developing AI-based education policies.

This study follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) procedure. The primary objective of PRISMA is to improve the transparency and scientific value of systematic reviews or meta-analyses. The following PRISMA flow diagram visually represents the stages of this systematic literature review process.

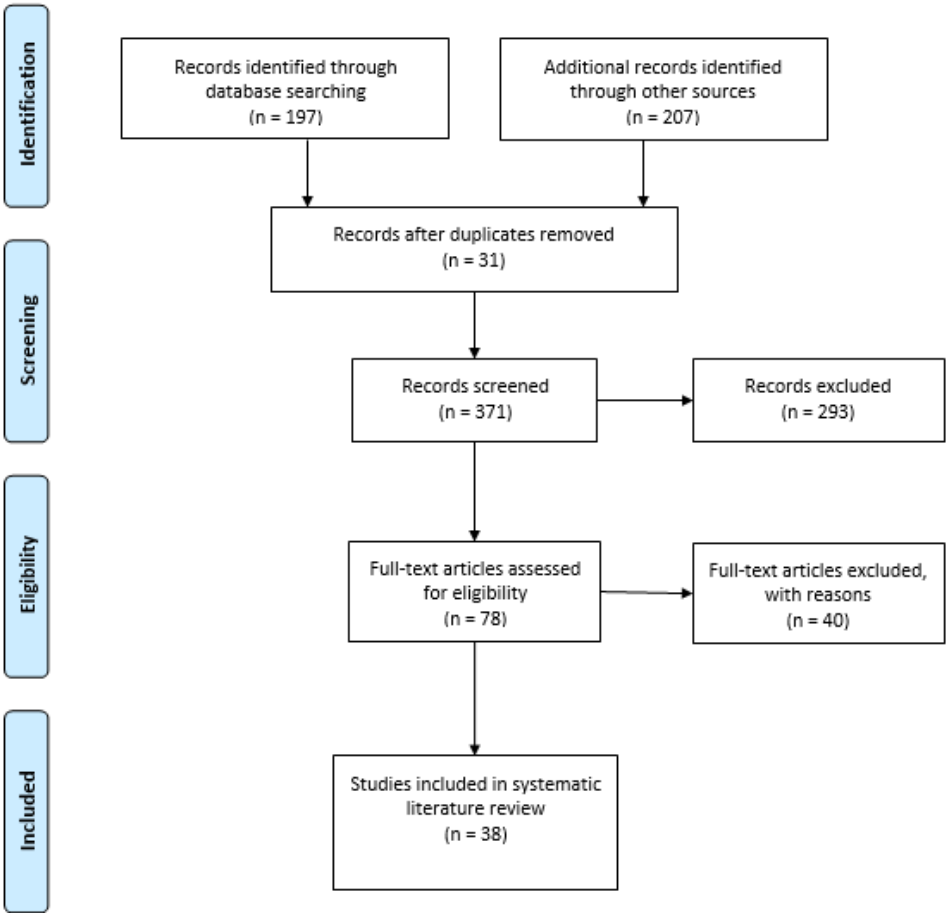

Figure 1. PRISMA Diagram Flow

Eligibility Criteria

In this systematic literature review, inclusion and exclusion criteria are applied to ensure that the reviewed articles are relevant and of appropriate quality to achieve the research objectives. The inclusion criteria are as follows: (1) Articles published between 2016 and 2024 to ensure up-to-date data; (2) Accepted publication types include peer-reviewed journals indexed by Google Scholar at a minimum and Scopus at a maximum, as well as reputable conference proceedings; (3) The research topic must discuss the application of Artificial Intelligence (AI) in primary education; (4) Articles must have a clear scientific research method, such as quantitative, qualitative, mixed method, or research and development; and (5) Articles must be written in internationally recognized languages. Furthermore, the exclusion criteria are applied to filter out less relevant or low-quality articles, which include (1) Articles published outside the specified time frame; (2) Articles from unverifiable sources, such as blogs, opinions, and unpublished reports; (3) Articles irrelevant to the topic; (4) Conceptual articles, such as systematic literature reviews, bibliometric studies, meta-analyses, narrative reviews, theoretical frameworks, or editorials; (5) Articles written in languages not internationally recognized.

Research Collection Data

Data was collected by searching references from reputable journal databases, such as Scopus, Web of Science, ERIC, and Google Scholar. However, Google Scholar was used only as a supplementary tool to cross-check article availability, not as a primary quality filter. Keywords used in the literature search included "Artificial Intelligence in Primary Education," "AI-Based Learning Tools," "Machine Learning for Elementary Students," "AI in Education," and "Adaptive Learning Technologies." Additional search platforms such as IEEE Xplore, Taylor & Francis Online, and Wiley Online Library were also utilized to broaden the scope of relevant references. To ensure consistency across databases, Boolean operators (AND, OR, NOT) were applied, along with truncation (e.g., AI to capture Artificial Intelligence, AI-based, AIEd, etc.) and search restrictions limited to titles, abstracts, and keywords.

RESULTS

The use of Artificial Intelligence (AI) in elementary education continues to grow, offering various innovations for more interactive and adaptive learning. This systematic review aims to identify trends, opportunities, and challenges in implementing AI in elementary school settings based on the analysis of 38 research articles published in various reputable journals and proceedings. Below is the descriptive data analysis based on the 38 reviewed articles.

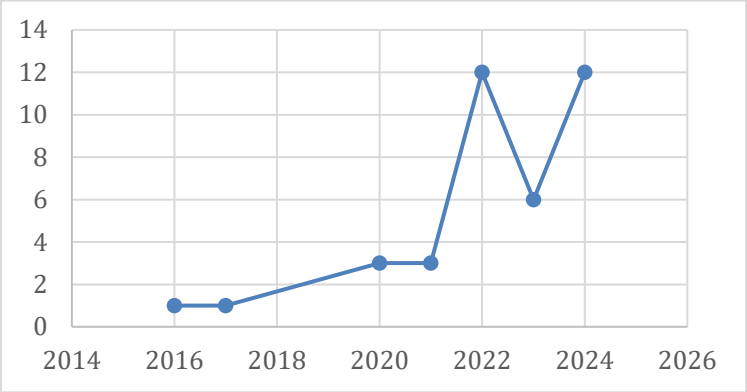

Figure 2. Trends in Article Publications from 2016-2024

The graph shows the distribution of research articles based on publication year from 2016 to 2024. Between 2016 and 2018, the number of articles was very low, with only one article per year. The number of articles gradually increased from 2019 to 2021, with a steady rise from two to three articles. In 2022, there was a significant surge, reaching its peak at approximately 12 publications. However, in 2023, the number of articles dropped sharply to around six. This trend rebounded in 2024, matching the highest publication count from 2022. Overall, publication trends have shown an upward trajectory over the years, especially after 2020. The increase in the number of publications in 2022 was driven by the accelerated adoption of digital learning technologies after the global pandemic, in line with the implementation of UNESCO's policy on *Artificial Intelligence in Education: Guidance for Policy Makers*, released in 2021, which encouraged many countries to begin directing educational research toward the inclusive and ethical use of AI.

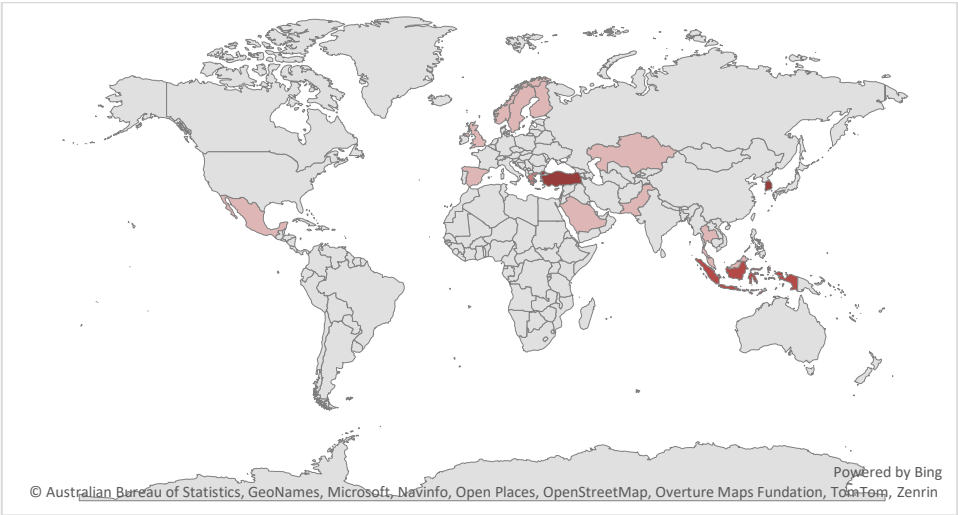

Figure 3. Trends in Article Publications Based on Research Locations

Based on the distribution of articles by research location, Indonesia stands out as the country with the highest number of publications, reflecting a strong interest

and research in this field. In addition to Indonesia, European countries such as Finland, Greece, Norway, Spain, Sweden, and Turkey have contributed significantly to academic publications. Asian countries like South Korea, Pakistan, Thailand, and Saudi Arabia also have substantial representation in the research. Furthermore, publications originating from North America (Mexico) and Central Asia (Kazakhstan) indicate that research in this field is widespread worldwide.

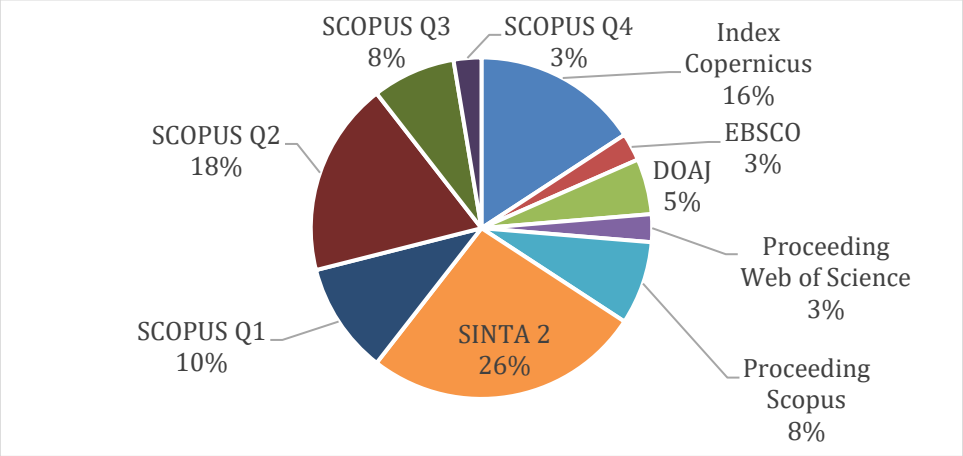

Figure 4. Trends in Article Publications Based on Journal Indexing

The distribution of articles based on journal indexing reveals that most publications are indexed in SINTA 2, with 10 articles (26% of the total). Index Copernicus ranks second with six articles (16%). SCOPUS Q2 has a significant share of seven articles (18%), followed by SCOPUS Q1 with four articles (10%). SCOPUS Q3 and SCOPUS Proceedings each account for three articles (8%). DOAJ includes two articles (5%), while EBSCO, SCOPUS Q4, and Web of Science Proceedings each have only one article (3%). This distribution indicates that most articles are published in reputable national and international indexing platforms, with SINTA 2 and SCOPUS dominating as the main publication platforms. Indexing articles in reputable journals such as SINTA and SCOPUS ensures research quality through rigorous review processes, encourages researchers to present relevant and applicable findings, and expands access for academics, teachers, and policymakers, thereby increasing the chances of research findings being implemented in elementary education practices.

The distribution of articles by research method shows that Research and Development (R&D) is the most frequently used method, with nine articles out of 38. Quasi-experimental quantitative methods rank second with seven articles, reflecting a focus on testing interventions under near-experimental conditions. Descriptive Qualitative methods are also dominant, with six articles highlighting a strong interest in in-depth exploration of specific phenomena. Mixed Methods and Quantitative Surveys are used in four articles each, indicating a common use of both qualitative and quantitative approaches and surveys for data collection.

Phenomenological Qualitative methods are employed in two articles. In contrast, Action Research, Case Study Qualitative, Comparative Quantitative, Correlational Quantitative, Descriptive Quantitative, and Ethnographic Qualitative methods are each used in only one article. This distribution reflects a research tendency toward development, experimentation, and descriptive exploration in the studied field.

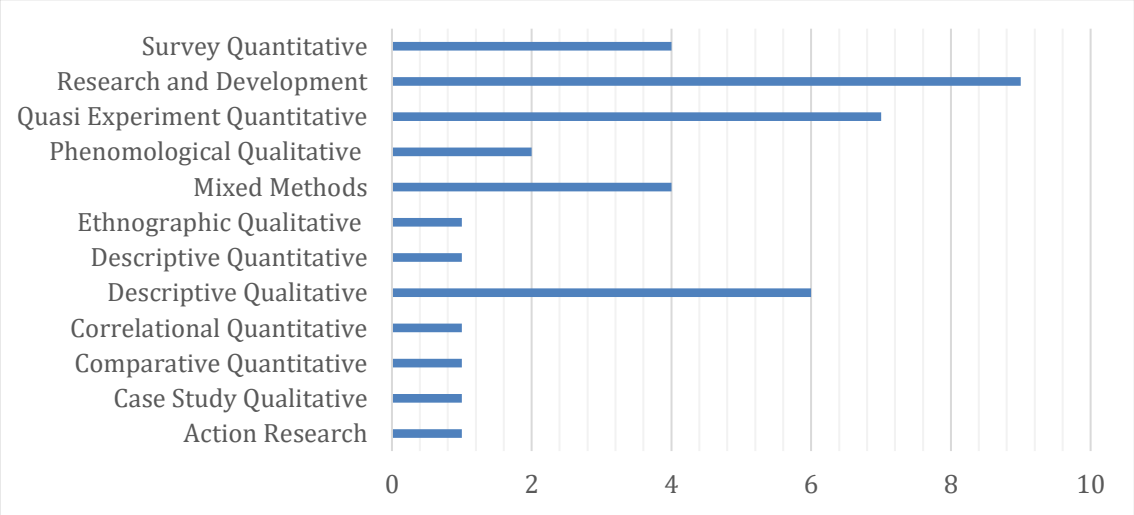

Figure 5. Trends in Article Publications Based on Research Methods

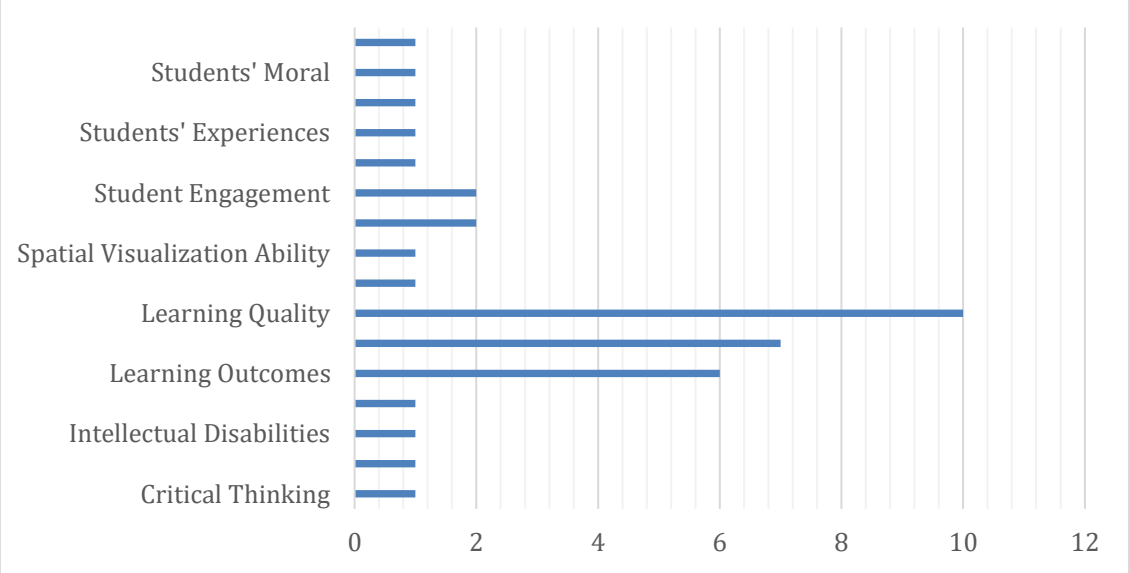

Figure 6. Trends in Article Publications Based on Related Research Variables

The distribution of articles based on research variables related to Artificial Intelligence (AI) shows that Learning Quality is the most studied aspect, with 10 articles out of 38. This indicates that much research focuses on how AI can improve overall learning quality. Additionally, Learning Performance is a key focus, with seven articles, followed by Learning Outcomes with six articles, showing interest in the impact of AI on students' performance and learning outcomes. Student Achievement and Student Engagement are each studied in two articles, reflecting

attention to academic achievement and student involvement in AI-based learning. Other, more specific variables such as Critical Thinking, Digital Literacy, Intellectual Disabilities, Learning Interest, Prospect Curriculum, Spatial Visualization Ability, Students' Autonomy, Students' Experiences, Students' Mastery of Concepts, Students' Morals, and Students' Safety Awareness are each addressed in only one article. This indicates that while there is variety in the research topics, the main focus remains on learning quality, performance, and outcomes in AI implementation in education.

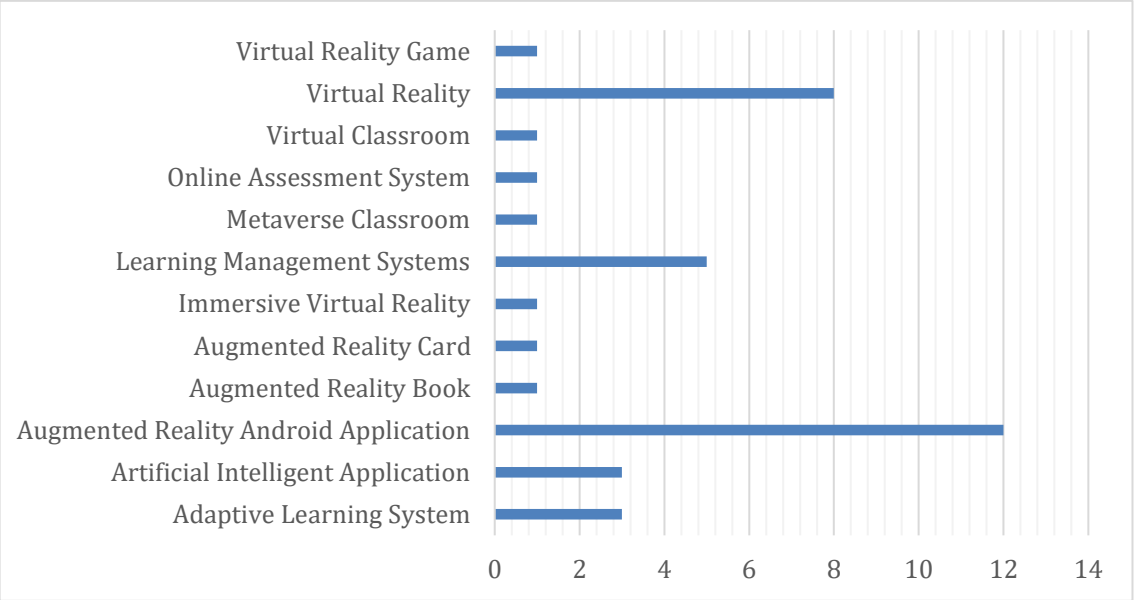

Figure 7. Article Distribution Based on AI Products

The distribution of articles based on AI products in research shows that Augmented Reality (AR) Android Applications are the most dominant topic, with 12 articles out of 38. This demonstrates significant attention to the application of Android-based AR in learning. Additionally, Virtual Reality (VR) is widely studied, with eight articles discussing VR applications in education. Learning Management Systems (LMS) rank next with five articles, highlighting the importance of digital platforms in AI-based learning management. Adaptive Learning Systems and Artificial Intelligence Applications are each examined in three articles, indicating interest in learning systems that can adapt to user needs. Virtual Reality Games, Virtual Classrooms, Metaverse Classrooms, Online Assessment Systems, Immersive Virtual Reality, Augmented Reality Books, and Augmented Reality Cards are each studied in only one article, reflecting the early exploration of various other AI products in education. Overall, research predominantly focuses on implementing AR and VR, indicating a trend toward utilizing immersive technology in education.

DISCUSSIONS

1. Trends in Artificial Intelligence In Elementary Education

Based on the 38 reviewed articles, the trends in Artificial Intelligence (AI) in elementary education show a dominance in the use of Augmented Reality (AR) and Virtual Reality (VR), particularly in the form of Android applications and VR-based systems. This dominance occurs because these technologies can create more interactive and immersive learning environments, which are well-suited to the characteristics of elementary-aged children (Contrino et al., 2024; Mystakidis et al., 2022). At this stage, children tend to understand concepts more easily through direct experience rather than text-based or lecture-based learning (Fernández-Batanero et al., 2024; Laine et al., 2023). The growing affordability of technological devices supports the shift toward AR- and VR-based learning (Bae, 2023). Many schools have access to Android-based devices and VR headsets, facilitating the adoption of these technologies in learning (Rusli et al., 2022). Moreover, AR and VR enhance students' motivation and engagement (Kusumaningsih et al., 2022; Shim, 2023). These technologies allow them to explore abstract concepts, such as science or mathematics, in more tangible ways (Pratama et al., 2022).

Furthermore, Learning Management Systems (LMS) and Adaptive Learning Systems have also gained significant attention, indicating an increasing use of AI for personalized and data-driven learning. In today's digital era, the one-size-fits-all approach is becoming obsolete, as each student has different needs, learning styles, and learning speeds (Moltudal et al., 2022; Standen et al., 2020). LMS plays a critical role in organizing, managing, and monitoring student learning systematically. With advanced features such as automatic scheduling, performance analysis, and multimedia integration, LMS provides flexibility for teachers and students to access materials anytime (Hariyanta et al., 2022; Moltudal et al., 2022). This significantly helps create a more adaptive learning environment tailored to individual needs (Zaitun et al., 2021). Meanwhile, Adaptive Learning Systems use artificial intelligence to tailor learning experiences based on student responses. These systems can identify students' strengths and weaknesses in understanding the material and automatically adjust the difficulty level and content type provided (Rathore et al., 2023). This approach increases learning efficiency as students do not need to repeat material they have already mastered and can focus more on areas requiring greater attention (Uli Lumbanraja & Purwanto, 2021; Wardhani, 2020).

2. Opportunities for Artificial Intelligence In Elementary Education

Of the 38 reviewed articles, the majority employed research and development (R&D) and quasi-experiment methods, indicating a focus on AI product innovation and measuring its impact on student learning outcomes. The first opportunity for AI implementation in elementary education is the global emphasis on developing innovative technologies to support interactive and adaptive learning. The

dominance of the R&D method implies that many studies are oriented toward the creation and refinement of AI-based products, such as Augmented Reality (AR) applications, Virtual Reality (VR), Learning Management Systems (LMS), Adaptive Learning Systems, and Virtual Classrooms (Özkal, 2022; Persefoni & Tsinakos, 2016; Rakhimzhanova et al., 2025; Riniati et al., 2024).

The development of AI-based products in elementary education opens opportunities for collaboration among researchers, technology developers, and educational practitioners to create more interactive, engaging, and student-oriented solutions. Specifically, AR and VR technologies allow for more realistic learning experiences, enabling students to better understand abstract concepts (Kadafi et al., 2021; Nadzeri et al., 2024; Safitri et al., 2023). Moreover, the increasing popularity of Adaptive Learning Systems signifies a shift toward learning tailored to individual student needs (Suh & Ahn, 2022).

The second opportunity is the growing interest in measuring the impact of AI on various learning aspects, as evidenced by the prevalence of Quasi-Experiment methods in research (Rugaiyah et al., 2024; Sarioğlu & GIrgIn, 2020; Sukasih et al., 2022; Urhan & Akpinar, 2024). Most studies aim to assess the effectiveness of AI in enhancing learning outcomes, student engagement, learning quality, and other developmental aspects. Research on AI in elementary education focuses on academic results and non-academic aspects, such as student engagement, independent learning, and social skills development. Future opportunities lie in deeper exploration of AI's impact on academic and non-academic aspects, as AI holds immense potential to enrich the learning experience.

Further research could investigate how AI helps improve academic aspects, such as understanding complex concepts, boosting exam performance, and fostering critical thinking and problem-solving skills. Additionally, there is a need to explore how AI can support differentiated learning, particularly for students with diverse educational needs, including gifted students and those with learning difficulties (Erviana & Sepriansyah, 2024; Shaumiwaty et al., 2022). Further studies could examine how AI influences learning motivation, self-confidence, and social interactions in the non-academic realm. Exploring AI's impact on emotional management and character development, such as enhancing learning discipline, safety awareness, and fostering digital ethics, is also crucial. This aligns with the constructivist emphasis on learning as a social and reflective process, where technology-supported collaboration and problem-solving contribute to developing cognitive and socio-emotional competencies (Lawlor & Tangney, 2016; Suh & Ahn, 2022).

3. Challenges Artificial Intelligence In Elementary Education

Based on publication trends, AI in elementary education is still developing, with an increasing number of publications in recent years. However, there is a gap between the rapid development of AI technology and research examining its effectiveness in education. Many AI innovations advance rapidly in the industrial and higher education sectors but are still limited in direct application within elementary education environments. This results in delays in implementing the latest technologies suited to the needs of students and teachers (Adenan, 2022).

Furthermore, the research location presents its own challenges. Many studies are conducted in countries with more advanced technological access, while schools in areas with limited infrastructure and internet access struggle to adopt AI in learning. This highlights disparities in technological distribution across different regions, particularly in developing countries, limiting AI utilization in elementary schools to those with adequate technological support (Suryaning et al., 2022).

One of the major challenges in implementing AI, especially AR and VR, is the high cost. Elementary schools, particularly in developing regions, often face budget constraints for acquiring equipment such as VR headsets, AR devices, and compatible computers or tablets (Fakhrudin & Yamtinah, 2017; Rohman et al., 2024). In addition to hardware, the costs of developing and licensing AI software are also barriers. Major companies develop many high-quality AR and VR applications, and significant investments are required to implement them in schools. Moreover, maintenance costs and the need for supporting technologies, such as data storage servers and stable internet connections, must also be considered (Rachmadtullah et al., 2022). Consequently, many schools cannot adopt AI optimally due to budget limitations, restricting its use to financially capable schools and creating technological educational disparities.

Beyond financial challenges, the lack of teacher training in integrating AI into curricula is a significant issue. AI is not merely a tool but requires appropriate pedagogical understanding to be effectively utilized. Many elementary school teachers have no experience using AI in learning (Rathore et al., 2023). Most teacher training still focuses on conventional teaching methods and does not include AI technology as part of comprehensive learning strategies. Without adequate training, teachers tend to struggle to design AI-based teaching materials, optimize their use in learning, and evaluate their effectiveness in enhancing student outcomes. As a result, even when technology is available, its use in classrooms becomes limited or does not align with expected learning objectives (Walan, 2024).

Another challenge in implementing AI in elementary education is the unequal distribution of technological infrastructure. Many schools, especially in rural areas or regions with limited resources, face unstable internet access, limited electricity, and inadequate technological facilities (Rashed & Almohesh, 2024; Sukasih et al.,

2022). Most AI products, especially cloud-based ones like Learning Management Systems (LMS) and Adaptive Learning Systems, require fast and stable internet connections to function optimally (Suh & Ahn, 2022). However, internet connectivity remains limited in many regions, hindering the full utilization of AI-based learning systems.

In addition to infrastructure barriers, AI implementation also poses risks related to algorithmic bias, where AI systems may produce unequal learning recommendations for students from different socio-economic or cultural backgrounds, potentially reinforcing educational inequality (Rachmadtullah et al., 2024). Privacy concerns also emerge as student data, including learning patterns, emotional responses, and personal information, are collected and analyzed by AI systems, raising ethical questions about data security and consent (Alam & Alam, 2023; Henry et al., 2021). Furthermore, excessive reliance on AI-based interactions may reduce opportunities for students to develop essential social skills such as empathy, communication, and teamwork, which are crucial for holistic development at the elementary level (Altiok & Yükseltürk, 2018).

The findings of this study imply that educational policymakers and institutions should prioritize investment in AI-based learning technologies, particularly AR, VR, LMS, and Adaptive Learning, to enhance elementary education quality. Additionally, teacher training programs must be strengthened to ensure educators can effectively integrate AI tools into their teaching practices. Lastly, addressing infrastructure gaps, cost barriers, and data privacy concerns is crucial to ensuring equitable and sustainable AI implementation in elementary education.

The limitations of this study are not only in the number of articles analyzed but also in the limited variation of research methodologies applied in the selected studies. Most articles rely heavily on qualitative descriptive approaches, while experimental or longitudinal studies are still minimal. In addition, the geographical distribution of the articles is concentrated in a few countries, particularly in Southeast Asia, resulting in findings that may not fully represent global trends in AI implementation in elementary education.

Therefore, recommendations for future research include expanding the number and variety of analyzed articles, conducting empirical studies on the effectiveness of AI in improving the quality of learning in various elementary school contexts, and developing teacher training strategies to ensure more optimal and sustainable AI implementation. One important step is developing a structured and sustainable AI-based teacher training model, ensuring teachers possess pedagogical and technological competencies to effectively integrate AI into their teaching practices. In addition, future studies should establish a comprehensive evaluation framework to measure the long-term impact of AI adoption on student learning outcomes and the overall quality of education. Further research should also propose

practical approaches to address technological access gaps between urban and rural schools, such as education technology subsidies, partnerships with the private sector, or ongoing technology mentoring programs.

CONCLUSION

Based on the results and discussion of the research above, it can be concluded that (1) AI trends in elementary education are dominated by Augmented Reality (AR), Virtual Reality (VR), Learning Management Systems (LMS), and Adaptive Learning Systems; (2) Opportunities for AI in elementary education include the development of more effective and measurable AI technology innovations and their widespread application to improve student learning outcomes; and (3) Challenges in the implementation of AI in elementary education involve technological gaps, high costs, uneven infrastructure, lack of teacher training, as well as insufficient technological, budgetary support, and student data privacy. This study concludes that AI in elementary education can potentially improve the quality of learning through AR, VR, LMS, and Adaptive Learning. Beyond summarizing trends, opportunities, and challenges, this conclusion needs to highlight deeper systemic issues, such as how AI adoption aligns with actual teaching practices, curriculum standards, and educational policies in elementary schools. Addressing this gap will allow future research to generate more concrete, context-sensitive recommendations for sustainable AI implementation.

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