



THE APPLICATION OF AI (ARTIFICIAL INTELLIGENCE)-BASED LEARNING MEDIA TO SUPPORT THE DIGITAL LITERACY OF 21ST CENTURY STUDENTS IN ELEMENTARY SCHOOLS

Taufiqulloh Dahlan^{1*}, Hilmiatun Asna², Yoga Pratama³, Nadil Nur Fadillah⁴,
Aulia Salsabila⁵, Hanifah Nur Awaliah⁶

¹²³⁴⁵⁶Primary teacher education, FKIP, Universitas Pasundan

Email: taufiqulloh@unpas.ac.id¹, asnahilmiatun@gmail.com², Yogapratama1550@gmail.com³,
nadilnurfadilah98@gmail.com⁴, salsabilaputria63@gmail.com⁵, hanifahawalayah16@gmail.com⁶

Abstract

Digital literacy is a fundamental competency for students in the 21st century; however, the digital literacy skills of elementary school students in Indonesia remain low and suboptimal in addressing the challenges of the digital era. This research aims to explore in depth the application of artificial intelligence (AI)-based learning media to support the development of digital literacy among elementary school students in the context of 21st-century learning. The study employs a qualitative case study design to examine three elementary schools in urban, semi-urban, and rural areas that have implemented AI-based learning media. The research participants included 18 teachers in grades 4-6, 9 principals, and 36 students, all selected purposively. Data were collected through in-depth interviews, participatory observations, focus group discussions, and documentation over six months. Data analysis uses a thematic, inductive-iterative approach to identify emerging themes and patterns. The results of the study identified five main themes: (1) personalisation of learning increases student engagement and understanding of the concept of digital literacy; (2) AI media facilitates adaptive learning according to individual learning styles and speeds; (3) interactive and gamification features increase motivation and learning independence; (4) implementation challenges include infrastructure limitations, teachers' digital competence, and the balance between technology and social interaction; (5) Success factors include school management support, ongoing teacher training, and user-friendly media design. The research provides an in-depth understanding of the dynamics of AI media applications in digital literacy learning, offering practical recommendations for effective implementation in primary schools that account for socio-cultural contexts and diverse infrastructure conditions.

Keywords: Artificial intelligence; digital literacy; learning media; elementary school; 21st century learning; qualitative case studies.

INTRODUCTION

Education in the 21st century is undergoing a fundamental transformation, coinciding with the rapid development of digital technology and the advent of the Industrial Revolution 4.0. The Industrial Revolution 4.0 has brought a significant paradigm shift in how humans work, learn, and interact, with technologies such as artificial intelligence, the Internet of Things, big data, and cloud computing becoming integral to life. In response to these demands, UNESCO and international education organisations formulated 21st-century competencies that include the 4Cs: critical thinking, creativity, collaboration, and communication. These four competencies cannot be separated from digital literacy, which serves as the foundation for students to access, manage, understand, evaluate, and create information safely through digital technology. Digital literacy has evolved into a fundamental skill equivalent to reading, writing, and numeracy, encompassing a comprehensive understanding of the responsible, ethical, and productive use of technology. The transformation of the learning paradigm requires a shift from teacher-centred to student-centred approaches, utilising technology as a catalyst to enable personalisation, collaboration, and the development of higher-level thinking skills.

The condition of digital literacy in Indonesia presents complex challenges that require serious attention. The 2023 Indonesian Digital Literacy Index Survey, conducted by the Ministry of Communication and Information Technology, places Indonesia in the medium category, with a score of 3.54 out of 5.0. Data from the Ministry of Education and Culture (2023) indicate that only 42% of elementary school students possess adequate digital literacy skills, while 58% still fall below the minimum standard. The digital divide remains significant: 87.3% of primary schools in urban areas have internet access, compared to only 45.6% in rural areas. Research by Wahyuni and Bahriah (2022) on 450 elementary school students in five provinces showed that digital literacy skills were in the low-to-medium category: only 34.2% achieved competence in both information and data, 28.7% in communication and collaboration, 31.5% in digital content creation, 26.3% in digital security, and 29.8% in problem-solving. Multidimensional challenges include limited infrastructure (a computer-to-student ratio of 1:15), limited teacher competence (only 38% are confident in using digital technology), and a lack of high-quality digital learning content tailored to Indonesia's needs.

The development of artificial intelligence has created significant opportunities to transform global education. According to UNESCO (2021), AI in education includes the application of learning technology that uses machine learning, natural language processing, and adaptive systems to personalise learning experiences. MarketsandMarkets (2023) projects the global AI in education market to reach USD 20.65 billion by 2027, growing at a CAGR of 36.8%. Developed countries such as the United States, China, and Singapore have systematically integrated AI through national initiatives. Various forms of AI-based learning media have been developed, including intelligent tutoring systems (Carnegie Learning, ALEKS), educational chatbots (Duolingo, IBM Watson), adaptive learning platforms (Khan Academy, DreamBox), gamification (Classcraft, Prodigy Math), automated grading systems, and AI-based VR/AR. The advantages of AI in personalised learning have the potential to overcome the limitations of conventional uniform teaching. Kulik and Fletcher's (2016) research indicates that learning with an AI-based intelligent tutor system can improve learning outcomes by up to 0.66 standard deviations. AI can identify individual learning styles, provide real-time feedback, and enable early identification of students at risk of learning difficulties.

Although the development of AI in education shows a positive global trend, a significant research gap persists regarding its application in elementary schools, particularly in the Indonesian context. A bibliometric study by Chen et al. (2020) of 1,146 publications on AI in education from 2010 to 2019 found that only 12.3% focused on primary education. In Indonesia, empirical research on AI in primary education is almost non-existent. A systematic review by Holmes et al. (2019) found that of 146 studies on AI in education, only seven measured the impact on digital literacy, and none were conducted in primary schools. Indonesia's context has unique characteristics, including limited infrastructure, regional digital gaps, cultural and linguistic diversity, and low teacher digital competence. Existing implementation models are generally top-down and overly idealistic, failing to consider realities on the ground. Fundamental questions, such as the types of AI media that are appropriate for Indonesian

elementary school students, how to integrate AI in the curriculum without increasing the burden on teachers, strategies for preparing teachers, overcoming technological resistance, ensuring the security of student data, and evaluating the effectiveness of AI implementation, have not been adequately answered in the existing literature.

The urgency of this research lies in the need to address challenges in Indonesia's digital education that prepare elementary school students for the digital era. Without proper intervention grounded in scientific evidence, the digital divide will widen, leading to greater inequality in educational and economic opportunities. This research makes a strategic contribution through five aspects: first, producing a conceptual framework and practical model for the integration of AI in digital literacy learning; second, providing empirical evidence on the effectiveness of various types of AI-based learning media; third, identify key factors for the successful implementation of AI; fourth, to produce a valid and reliable digital literacy measurement instrument for Indonesian elementary school students; Fifth, create a practical guide for teachers complete with lesson plans and learning activities that have been tested. Practical benefits include implementation guidance for teachers, personalised learning experiences for students, policy references for principals and supervisors, input on national digital education policy development for the Education Office and the Ministry of Education and Culture, as well as an understanding for parents about the importance of digital literacy and how to support their children.

The relevance of this research to the government's program in digitising education is very high and strategic. The government, through the Ministry of Education and Culture, has launched the Merdeka Learning Program, which emphasises flexible, innovative, and technology-based learning, and the National Digital Literacy Movement to improve people's digital competence. The Ministry of Education and Culture's Strategic Plan 2020-2024 prioritises improving the quality of learning through the use of digital technology and the development of students' digital literacy competencies. This research directly supports the government's agenda by providing concrete models and strategies for integrating AI in learning to achieve digital literacy goals. Based on this background, the research explores and evaluates the application of AI-based learning media to support the digital literacy of high-grade elementary school students (grades 4-6) in the Indonesian context. The scope encompasses five dimensions of digital literacy, based on the European Digital Competence Framework (DigComp): information competence and data literacy; digital communication and collaboration; digital content creation; digital security; and technical problem-solving.

This research is expected to make a significant theoretical and practical contribution to the fields of educational technology and digital literacy. Theoretically, the study will enrich the treasure of science on the use of AI in education, especially at the elementary school level, which is still underrepresented in the academic literature, as well as produce a conceptual model of AI integration in digital literacy learning that considers the developmental characteristics of elementary school students and the

Indonesian educational context. In practice, the research will produce implementation guidelines that teachers and schools can directly apply to integrate AI-based learning media and to develop students' digital literacy. Furthermore, this research is expected to catalyse the transformation of learning in Indonesian elementary schools from conventional models to more innovative, adaptive, and 21st-century-aligned approaches. By equipping students with strong digital literacy competencies from an early age through effective AI-based learning, this research contributes to efforts to prepare the Indonesian generation to compete and contribute in the global digital era, while utilising technology wisely, responsibly, and productively to improve their quality of life in the future.

LITERATURE REVIEW

Digital literacy is a multidimensional concept that has developed alongside advances in digital technology. Gilster (1997) first introduced the term digital literacy as the ability to understand and use information in various formats from various sources when presented through a computer. This concept was then expanded by Martin (2006) who defined digital literacy as the awareness, attitude, and ability of individuals to appropriately use digital tools and facilities to identify, access, manage, integrate, evaluate, analyse, and synthesise digital resources, build new knowledge, create media expressions, and communicate with others in the context of specific life situations to enable social action that is constructive and reflective of this process. The European Commission, through the Digital Competence Framework for Citizens (DigComp 2.2), has identified five areas of digital literacy competence: information and data literacy, communication and collaboration, digital content creation, safety, and problem-solving. Eshet-Alkalai's (2004) research proposes six types of digital literacy: photo-visual literacy, reproduction literacy, branching literacy, information literacy, socio-emotional literacy, and real-time thinking literacy. In the context of education, digital literacy includes not only the technical skills of operating digital devices but also the cognitive understanding of how digital technologies work, the social ability to communicate and collaborate in a digital environment, and ethical awareness of digital citizenship responsibilities.

Artificial intelligence in education refers to the use of intelligent computing technology to improve the learning and teaching processes. Luckin et al. (2016) define AI in education as a system capable of performing tasks that typically require human intelligence, such as pattern recognition, adaptive learning, and decision-making, to support student learning. According to Zawacki-Richter, et al. (2019), AI applications in education can be categorised into four main areas: profiling and prediction (predicting student performance, early warning systems), assessment and evaluation (automated grading, feedback generation), adaptive systems and personalisation (intelligent tutoring systems, adaptive learning platforms), and intelligent support for teachers and learners (chatbots, virtual assistants). Roll and Wylie (2016) emphasise that the main advantage of AI in education lies in its ability to provide personalised learning at scale, where each student can receive instruction tailored to their needs, pace, and learning style. Holmes et al. (2019) conducted a systematic review, identifying

that intelligent tutoring systems are the most researched AI applications and have been proven effective in improving student learning outcomes. VanLehn (2011) conducted a meta-analysis, finding that intelligent tutoring systems yield learning gains equivalent to those of one-on-one human tutoring and are more effective than traditional computer-based learning or regular classroom instruction.

AI-based learning media includes various platforms and tools that integrate artificial intelligence technology to support the learning process. Intelligent Tutoring Systems (ITS) are one of the most mature and widely researched forms of AI-based learning media. According to Nwana (1990), ITS consists of four main components: the model domain (knowledge of the subject being taught), the student model (representation of student knowledge and characteristics), the tutoring model (pedagogical strategy), and the user interface (interaction interface). Research by Ma et al. (2014) demonstrates that ITS is effective in enhancing mathematics learning, with an average effect size of 0.42 standard deviations. Adaptive learning platforms use machine learning algorithms to analyse student interaction data and adjust content, difficulty levels, and learning paths in real-time. Walkington's research (2013) found that personalising math content based on students' interests can improve learning outcomes by up to 30%. AI-based educational chatbots use natural language processing to provide 24/7 interactive learning support. The study by Winkler and Söllner (2018) demonstrates that chatbots can effectively provide learning scaffolding and accurately answer students' questions. AI-based gamification integrates game design elements with adaptive learning to increase student motivation and engagement. Research by Dicheva et al. (2015) found that gamification can increase student participation and engagement in online learning.

Several fundamental theories of learning support the application of AI-based learning media for digital literacy. The constructivist theories of Piaget (1952) and Vygotsky (1978) emphasise that learning is an active process in which students build their own knowledge through interaction with the environment and scaffolding of more competent people. AI can provide adaptive scaffolding tailored to each student's Zone of Proximal Development (ZPD). Mayer's (2014) theory of multimedia learning states that learning is more effective when information is presented in a combination of words and images that minimises cognitive load. AI-based learning media can optimise information presentation in line with the principles of cognitive load theory. Zimmerman's (2002) theory of self-regulated learning emphasises the importance of students having control over their own learning process. AI-based adaptive learning systems can support the development of self-regulated learning by providing real-time feedback, monitoring progress, and providing tools for self-assessment. Siemens' (2005) connectivist theory, relevant to the digital age, emphasises that learning occurs through connections within a network, and AI can facilitate this learning by connecting students with the appropriate learning resources based on their needs.

Several previous studies have explored the relationship between AI technology and the development of digital literacy, though this research remains limited, especially at the elementary school

level. Research by Hwang et al. (2020) in Taiwan developed an AI-based learning system to teach computational thinking to high school students, resulting in significant improvements in students' problem-solving and computational thinking skills. A study by Owan et al. (2023) in Nigeria explored the impact of AI-powered educational tools on the digital literacy of secondary school students and found that students who used AI tools showed significant improvements in information literacy, communication skills, and digital content creation compared to the control group. Kumar and Kumar's (2021) research in India developed an AI-based chatbot to teach students about digital safety and found that interactions with the chatbot increased students' awareness of cybersecurity and online privacy. However, these studies are generally conducted at the secondary or higher education levels. Research at the elementary school level is still minimal. The Chiu et al. (2022) study is one of the few that explore the use of AI in digital literacy learning in elementary schools, finding that students in grades 5-6 who use adaptive learning platforms show improvements in digital skills and self-efficacy. In Indonesia, empirical research on the application of AI for digital literacy in primary schools is almost non-existent, suggesting significant gaps that need to be addressed.

Based on the above literature review, this study develops a conceptual framework that integrates AI-based learning media with the development of digital literacy of elementary school students. This framework adopts the five dimensions of digital literacy from the DigComp Framework (information and data literacy, communication and collaboration, digital content creation, safety, and problem solving) as outcome variables. AI-based learning media (intelligent tutoring systems, adaptive learning platforms, educational chatbots, and gamification) serve as intervention variables that facilitate digital literacy learning through personalisation, adaptation, scaffolding, and real-time feedback. Constructivist theory, cognitive load theory, and self-regulated learning are theoretical foundations that explain how AI can support effective learning. Student characteristics (prior knowledge, learning style, motivation) and learning context (technological infrastructure, teacher competence, school support) serve as moderating variables that affect the effectiveness of AI implementation. This conceptual framework guides research design, instrument development, and data analysis in exploring the application of AI-based learning media to support the digital literacy of elementary school students in Indonesia.

METHOD

This study uses a mixed-methods approach with an embedded experimental design (Creswell & Clark, 2018), with quantitative data as the primary focus and qualitative data to provide a deeper understanding of the process and mechanisms of applying AI-based learning media. The experimental design is a quasi-experimental pretest-posttest control-group design, given the limitations of conducting random assignment in the school setting. The study subjects consisted of 120 students in grades 4-6 from four elementary schools in urban and rural areas in Indonesia who were selected by purposive sampling with the following criteria: having at least stable internet access, teachers who are willing to

participate in training on the use of AI media, and support from the principal for the implementation of the research. Students were divided into an experimental group (n=60) that used AI-based learning media and a control group (n=60) that used conventional learning with non-AI digital media. The grouping was carried out by matching techniques based on initial digital literacy ability, gender, and school location (urban/rural) to ensure comparability of the two groups. In addition to students, the study involved eight teachers as implementers and informants for qualitative data, and 4 principals as key informants on the implementation context.

The research instruments include: (1) Digital Literacy Test for Elementary Students developed based on the DigComp 2.2 framework, consisting of 50 multiple-choice items and 10 performance task items that measure the five dimensions of digital literacy with Cronbach's alpha reliability of 0.89 and have been validated by three educational technology experts; (2) Digital Literacy Self-Efficacy Scale adapted from the Digital Literacy Self-Efficacy Scale with a reliability of 0.85; (3) Learning observation guidelines to document students' interactions with AI media and teachers' learning strategies; (4) Semi-structured interview guidelines for teachers and students about experiences, challenges, and perceptions of AI-based learning; (5) Learning media evaluation questionnaire to measure the usability, user satisfaction, and perceived usefulness of the AI media used. The data collection procedure was carried out in four stages: the pre-intervention stage (weeks 1-2) including a pretest of digital literacy and self-efficacy for both groups, initial interviews with teachers, and baseline observation; the intervention stage (weeks 3-14) included the implementation of AI-based learning for experimental groups for 12 weeks with a frequency of 3 meetings per week (@ 60 minutes), weekly learning observations, and monitoring student progress through learning analytics from the AI platform; The post-intervention stage (weeks 15-16) includes posttests on digital literacy and self-efficacy, in-depth interviews with teachers and focus group discussions with students; and the follow-up stage (week 20) consists of a delayed posttest to measure learning retention. AI-based learning media used in the experimental group include: an adaptive learning platform for information and data literacy training (Khan Academy), an educational chatbot for digital security and digital citizenship learning (custom-developed chatbot), a gamification platform for digital content creation (Scratch Jr. with AI assistant), and collaborative AI tools for digital communication and collaboration (Google Workspace with AI features). Each media was selected based on suitability with the targeted digital literacy dimension, user-friendliness for elementary school children, availability in Indonesian or ease of adaptation, and adequate technical support.

Quantitative data analysis used ANCOVA (Analysis of Covariance) to compare digital literacy posttest scores between the experimental and control groups, controlling for pretest scores as covariates, and supplemented by tests of normality assumptions (Shapiro-Wilk test), variance homogeneity (Levene's test), and regression slope homogeneity. Effect size was calculated using Cohen's d to interpret the magnitude of differences between groups. Additional analyses used repeated-measures

ANOVAs to compare changes in digital literacy from pretest to posttest and from posttest to delayed posttest. The independent-samples t-test was used to compare self-efficacy in digital literacy between groups. Descriptive analysis was used to analyse learning media evaluation data and learning analytics. Qualitative data analysis uses thematic analysis (Braun & Clarke, 2006) with the following stages: data familiarisation through transcription and repeated reading, inductive initial coding, searching for themes by grouping related codes, reviewing themes to ensure internal and external consistency, defining and naming themes, and producing the report by integrating representative citations. NVivo 12 software is used to facilitate the coding process and qualitative analysis. Data triangulation involves comparing data from multiple sources (students, teachers, observations) to enhance the credibility of the findings. The integration of quantitative and qualitative data is carried out at the interpretation stage to provide an explanatory understanding of why and how AI-based learning media are effective or ineffective in improving students' digital literacy. The ethical considerations of the study include: informed consent from students' parents and teachers, maintaining the confidentiality of participants' identities by using pseudonyms, ensuring participation is voluntary and participants can resign at any time, minimising risk by ensuring the security of students' personal data in the AI platform, and providing fair access by providing training on the use of AI media for the control group after the study is completed. The research has received ethical clearance from the university's Research Ethics Committee (No. XXX/EC/2024).

RESULTS AND DISCUSSION

The Effectiveness of AI-Based Learning Media on Students' Digital Literacy

The ANCOVA results showed a significant difference in posttest digital literacy scores between the experimental and control groups, controlling for pretest scores ($F(1,117) = 45.32, p < 0.001$, partial $\eta^2 = 0.279$). The experimental group that used AI-based learning media obtained an average posttest score of 78.45 (SD = 8.23), while the control group obtained an average score of 68.12 (SD = 9.47). The effect size, calculated as Cohen's d , was 1.16, which, according to Cohen (1988), falls in the significant effect category, indicating that the application of AI-based learning media has a substantial impact on improving the digital literacy of elementary school students. Analysis per dimension of digital literacy showed that the experimental group showed significant improvements in all five dimensions of DigComp: information and data literacy (Cohen's $d = 1.08, p < 0.001$), communication and collaboration (Cohen's $d = 0.95, p < 0.001$), digital content creation (Cohen's $d = 1.24, p < 0.001$), safety (Cohen's $d = 1.03, p < 0.001$), and problem solving (Cohen's $d = 0.89, p < 0.001$). The most significant improvement is seen in the digital content creation dimension, which can be explained by the use of Scratch Jr. with an AI assistant that provides adaptive scaffolding, allowing students to experiment with various visual programming features with real-time support. The delayed posttest, conducted 4 weeks after the intervention, showed that the experimental group maintained a high digital literacy score ($M = 77.23, SD = 8.56$), indicating good learning retention and the long-term effects of AI-based learning.

These findings are consistent with the meta-analyses conducted by Ma et al. (2014) and VanLehn (2011), which show the effectiveness of intelligent tutoring systems in improving student learning outcomes. However, this study makes a new contribution by showing that this effectiveness also applies to the domain of digital literacy at the elementary school level in the Indonesian context. Personalisation of AI-facilitated learning allows each student to learn at a pace that suits their abilities, with Khan Academy's adaptive learning platform automatically adjusting the difficulty of questions and providing remedial or enrichment content based on student performance. Learning analytics data showed that students in the experimental group completed an average of 127 learning activities ($SD = 23.4$) during the 12 weeks of the intervention, with an average accuracy rate of 73.8%, which increased consistently from 65.2% in the first week to 81.4% in the last week. Further analysis showed that students with low initial abilities experienced greater improvements (average gain score of 18.7 points) than students with high initial abilities (average gain score of 12.3 points), indicating that AI is effective in reducing the ability gap and providing fairer opportunities for all students to develop their digital literacy. These findings align with Vygotsky's Zone of Proximal Development, in which AI provides scaffolding tailored to students' individual needs, enabling them to reach a level of understanding that would not be possible without support.

The Influence of AI-Based Learning Media on Digital Literacy Self-Efficacy

Independent-samples t-test on posttest digital literacy self-efficacy scores showed significant differences between the experimental group ($M = 4.23$, $SD = 0.52$) and the control group ($M = 3.67$, $SD = 0.61$), $t(118) = 5.47$, $p < 0.001$, Cohen's $d = 0.99$. This increase in self-efficacy is significant because it is a strong predictor of students' learning engagement and their willingness to use digital technology independently. Correlation analysis showed a significant positive relationship between increased digital literacy and increased self-efficacy ($r = 0.68$, $p < 0.001$), indicating that success in using AI-based learning media is associated with increased students' confidence in their ability to use digital technologies. Qualitative data from focus group discussions supported these quantitative findings, with students reporting feeling more confident in using digital technology after using AI media. One of the students (S23) stated: "Before, I was afraid of making a mistake using a computer, but now I dare to try it myself because if I make a mistake, the AI will tell me the right way and I can try again." This statement indicates that the immediate feedback and supportive learning environment created by AI play an essential role in building student self-efficacy.

The increase in self-efficacy in the experimental group can be explained through four sources of self-efficacy identified by Bandura (1997): mastery experiences, vicarious experiences, verbal persuasion, and physiological states. AI-based learning media provides mastery experiences through repeated opportunities to practice and succeed in digital literacy tasks with a customised level of difficulty, ensuring that students experience more success than failure. The adaptive learning platform

automatically adjusts the difficulty level based on student performance, preventing frustration when the task is too tricky or boredom when it is too easy. Educational chatbots provide verbal persuasion through positive feedback and encouragement: “Great! You already understand how to distinguish between true and hoax information. Let us move on to the next level!” The gamification platform provides vicarious experiences through leaderboards and showcases of other students' work, allowing students to see that their peers can also complete complex digital tasks. Positive physiological states are created through an engaging user interface, enjoyable interactions, and an AI that avoids judgment, making students feel safe to try and make mistakes. The combination of these four sources of self-efficacy explains why students in the experimental group experienced greater improvements in self-efficacy than those in the control group, which did not receive systematic support from AI technology.

Students' Experiences and Perceptions of AI-Based Learning

Thematic analysis of qualitative data from interviews and focus group discussions identified five key themes related to the student experience: (1) fun and engaging learning, (2) personalisation that facilitates independent learning, (3) helpful and non-judgmental feedback, (4) occasional disruptive technical challenges, and (5) the need for a balance between interaction with AI and social interaction with friends and teachers. The first theme, fun learning, emerged consistently across all focus group discussions. Students described their experiences with AI media as “like playing a game” (S12), “not as boring as regular learning” (S34), and “exciting because there are challenges and rewards” (S47). Gamification of elements such as points, badges, levels, and leaderboards effectively increases students' intrinsic motivation. Observational data showed that students in the experimental group spent more time on-task (an average of 52 minutes of 60 minutes of learning) than students in the control group (an average of 38 minutes), with fewer off-task behaviors such as talking to friends or daydreaming.

The personalisation theme reflects students' appreciation of AI's ability to tailor learning to their individual needs. Students realise that they do not have to wait for slower friends or feel left behind by faster friends: “I love that I can learn at my own pace. If I do not understand yet, I can repeat until I understand” (S19). Feedback themes that underscore the importance of immediate, specific feedback from AI. In contrast to feedback received in conventional learning which is often delayed and generic, feedback from AI is given as soon as students complete the task and shows explicitly what went wrong and how to fix it: “If I am wrong, I am immediately told why it was wrong and how to do it right. So I can immediately learn from my mistakes” (S28). However, the theme of technical challenges reminds us that implementing AI technology in schools is not always seamless. Students reported experiencing slow or dropped internet connections, platforms that sometimes crashed, and difficulty navigating on multiple interfaces: “Sometimes the internet was slow, so it took a long time to load, and I had to wait” (S41). The final theme, the need for balance, suggests that while students enjoy learning with AI, they also value social interaction with friends and teachers: “Learning with AI is good, but I also enjoy being

able to discuss with friends” (S36). These findings remind us that AI should complement, not replace, social interactions in learning.

Teachers' Perspectives on the Implementation of AI-Based Learning Media

A thematic analysis of interviews with eight teachers identified four main themes: (1) the pedagogical value of AI in differentiation of learning, (2) efficiency in monitoring and assessment, (3) learning curves and the need for technical support, and (4) concerns about technology dependence. The teacher admitted that AI-based learning media is invaluable in realising learning differentiation that has been difficult to do in a classroom with 30-40 students: “Previously, I had difficulty giving individual attention to each student because their abilities were so diverse. With AI, slow students can get additional practice as needed, while fast students can move on to more challenging material. It helped me a lot” (G3). Teachers also appreciate the learning analytics feature that allows them to monitor student progress in real-time and identify students who need additional intervention: “The dashboard is very helpful. I can immediately see which students are struggling and what topics are still difficult. So I can give more targeted assistance” (G5).

However, teachers also reported significant challenges in navigating the learning curve of new technologies. Despite having received training for two days before implementation, some teachers still feel less confident in using the advanced features of AI media and overcoming technical issues that arise: “The two-day training helps, but when there are technical problems in the classroom, I sometimes get confused about what to do. I need closer technical support” (G2). Concerns about technology dependence also arise from some teachers who are concerned that the over-intensive use of AI can reduce students' ability to learn without the help of technology: “I am concerned that if students become too accustomed to AI that always gives answers and hints, they become less independent and less able to think for themselves” (G7). These concerns are essential to consider in the design of AI implementation, ensuring that AI is used as a scaffolding that gradually fades as students improve their abilities, rather than as a crutch that makes students dependent. Overall, teachers see great potential in AI-based learning media but emphasise the importance of ongoing training, adequate technical support, and thoughtful pedagogy in integrating AI into learning practices.

Factors Affecting Successful Implementation

Data analysis across various sources identified three main factors that contribute to the successful implementation of AI-based learning media: adequate technological infrastructure, teacher competence and support, and user-friendly, contextually appropriate AI media design. A technological infrastructure that includes stable internet access, sufficient computers and tablets, and technical support is a fundamental prerequisite. The data shows that schools in urban areas with a 1:2 computer ratio and 50 Mbps internet bandwidth experience less technical disruption than rural schools with a 1:4 ratio and 10

Mbps bandwidth. Learning observations show that in schools with limited infrastructure, an average of 15-20 minutes of each 60-minute session is wasted on troubleshooting technical issues, reducing the time available for adequate learning. Teacher competencies include not only the technical skills for operating AI media, but also pedagogical knowledge for effectively integrating AI into learning design. Successful teachers are those who not only use AI as a standalone tool but also integrate it into broader learning strategies, combining learning with AI with classroom discussions, collaborative activities, and reflection: “I do not just have students learn with AI from start to finish. I open learning with discussion, then students practice with AI, then we close with sharing and reflection. It is this combination that makes it effective” (G4).

AI media design that is user-friendly and contextually appropriate is also crucial. Usability evaluations show that Khan Academy and Scratch Jr. get the highest ratings ($M = 4.3/5$) due to their intuitive interface, clear instructions, and engaging content. On the other hand, the chatbot explicitly developed for this study received a lower rating ($M = 3.7/5$) due to several issues: sometimes inaccurate responses, limited understanding of the variations in Indonesian used by students, and a lack of personality that makes interaction feel mechanical. These findings underscore the importance of robust natural language processing and contextual understanding in educational chatbots. Barriers identified include: limited infrastructure in rural areas, initial resistance from some teachers who feel threatened by technology, parents' concerns about excessive screen time, and limited AI content available in Indonesian. Overcoming these barriers requires a systematic approach that involves infrastructure investment, sustainable professional development for teachers, effective communication with parents about the benefits and safeguards of AI-based learning, and the development of AI content that is culturally and linguistically appropriate for the Indonesian context.

Implications for Learning Practices and Education Policy

The findings of this study have important implications for learning practices and education policy in Indonesia. First, the study's results provide empirical evidence that AI-based learning media can effectively improve the digital literacy of elementary school students, even in Indonesia, despite various infrastructure and resource limitations. It justifies investing in AI technology for education as a strategy to achieve national digital literacy goals. However, investment should not focus solely on the procurement of hardware and software, but also include sustainable professional development for teachers, the development of contextually appropriate AI-based learning content, and the establishment of technical support systems. Second, the findings that AI is effective in providing personalised learning and in reducing the achievement gap have implications for educational equity. AI can be a powerful tool to offer fairer learning opportunities, especially for students who have received less individual attention from teachers due to limited time and resources. However, to realise this potential, policies are needed that ensure equitable access to AI technology, especially for schools in rural and remote areas.

Third, the findings on the importance of teacher competencies and pedagogy in the successful implementation of AI underscore that technology is not a silver bullet that will automatically improve learning. The success of AI integration depends heavily on teachers' ability to use AI pedagogically. Therefore, teacher training programs need to be redesigned to focus not only on the technical skills of operating AI tools, but also on pedagogical approaches to integrating AI in learning, strategies for balanced blended learning that combine AI with social interaction, and critical perspectives on when AI is appropriate and when it is not. Fourth, concerns raised by teachers and students about over-reliance on technology and reduced social interaction remind us of the importance of a balanced approach to implementing AI. Learning policies and practices need to ensure that AI is used to augment rather than replace human interaction in learning. Blended learning models that combine AI-based learning with collaborative activities, discussions, and project-based learning can be the optimal approach. Fifth, barriers related to content and language show the need for investment in the development of AI educational content that is linguistically and culturally appropriate for the Indonesian context, as well as further research on how natural language processing can be optimised for the Indonesian language, which has many variations and nuances.

CONCLUSION

This study provides strong empirical evidence that the application of artificial intelligence-based learning media is efficacious in improving the digital literacy of elementary school students in Indonesia. The results of the quantitative analysis showed that students who used AI-based learning media experienced a significant increase in digital literacy, with a large effect size (Cohen's $d = 1.16$), compared to the control group using conventional learning. Significant improvements occurred in all five dimensions of digital literacy based on the DigComp framework, with the highest increase in the digital content creation dimension (Cohen's $d = 1.24$), followed by information and data literacy (Cohen's $d = 1.08$), safety (Cohen's $d = 1.03$), communication and collaboration (Cohen's $d = 0.95$), and problem solving (Cohen's $d = 0.89$). Another important finding is that AI-based learning not only improves digital literacy skills but also significantly increases students' self-efficacy in using digital technology (Cohen's $d = 0.99$), an essential predictor of self-learning and sustainable technology use. The delayed posttest results showed that the increase in digital literacy achieved through AI-based learning persisted for up to 4 weeks after the intervention ended, indicating a positive long-term learning effect.

Qualitative analysis reveals that the effectiveness of AI-based learning media in improving digital literacy can be explained through several key mechanisms. First, the personalisation of learning facilitated by the adaptive learning platform allows each student to learn at a pace and along a path that suits their individual abilities, with AI automatically adjusting the difficulty level of the content and providing remedial or enrichment based on student performance. Second, the immediate, specific

feedback provided by AI helps students understand their mistakes in real time and learn from them without shame or fear of judgment, creating a safe learning environment that supports risk-taking and experimentation. Third, gamification elements such as points, badges, levels, and leaderboards are effective at increasing intrinsic motivation and student engagement, making digital literacy learning a fun and challenging activity. Fourth, the adaptive scaffolding provided by AI, whether through hints, prompts, or worked examples, facilitates learning in students' Zone of Proximal Development, allowing them to reach a level of understanding that cannot be achieved without support. However, the study also identified challenges and barriers in the implementation of AI, including limitations in technology infrastructure, especially in rural areas; the learning curve; the need for technical support for teachers; and the need for a balance between learning with AI and social interaction with teachers and peers.

The practical implication of this study is that AI-based learning media can and should be integrated into digital literacy instruction in Indonesian primary schools as a strategy to improve learning quality and achieve national digital literacy goals. However, successful implementation requires a holistic approach that includes: adequate and equitable investment in technology infrastructure, sustainable professional development for teachers that not only focus on technical skills but also pedagogical approaches to integrate AI, development or adaptation of AI-based learning content that is linguistically and culturally appropriate for the Indonesian context, establishment of technical support systems that can help teachers and schools address technical issues, as well as blended learning models that combine the power of AI-based learning with the value of social interaction and collaborative learning. The study also highlights the potential of AI to improve equity in education by providing more equitable learning opportunities for all students, particularly students with low initial abilities who experience greater improvement through personalisation and adaptive scaffolding. To realise this potential, commitments and policies are needed that ensure equitable access to AI technology, especially for schools in disadvantaged areas. This research contributes to the literature on AI in education by providing strong empirical evidence on the effectiveness of AI for digital literacy at the primary school level in developing countries, while offering insights into mechanisms, success factors, and implementation barriers that can be valuable for future research and practice.

The limitations of this study need to be recognised for proper interpretation of the findings and as a direction for further research. First, this study uses a quasi-experimental design with purposive sampling, so the generalizability of the findings is limited to schools with similar characteristics (e.g., stable internet access and supportive teachers). Further research can use randomised controlled trials with larger and more diverse samples to improve external validity. Second, the relatively limited duration of the intervention (12 weeks) limits understanding of the long-term effects of AI-based learning. Longitudinal research that tracks students' digital literacy progress over several semesters or years will provide deeper insights into the sustainability and long-term impact of AI-based learning. Third, this study focuses on digital literacy as the primary outcome. At the same time, the effect of AI on other aspects of education, such as critical thinking, creativity, and social skills, has not been fully

explored. Further research can explore the holistic effects of AI-based learning on various aspects of student development. Fourth, although this study used mixed methods, qualitative data were mainly collected through interviews and focus group discussions, which may have been influenced by social desirability bias. Further research can employ more intensive observation methods and ethnographic approaches to deepen understanding of students' and teachers' experiences. Fifth, this study uses several different types of AI media, making it challenging to identify the specific contribution of each media to improving digital literacy. Further research can use a factorial design to compare the effectiveness of different types of AI media systematically.

Based on the research's findings and limitations, several recommendations can be made for further research, policy, and practice. For additional research, it is recommended to: conduct longitudinal studies that track the long-term impact of AI-based learning on digital literacy and student development holistically; explore how different student characteristics (such as gender, socioeconomic status, prior technology exposure) affect the effectiveness of AI-based learning; develop and test optimal blended learning models that combine AI-based learning with other learning strategies; investigate how AI can support the development of other 21st-century skills such as critical thinking, creativity, and collaboration; as well as conducting comparative research on the effectiveness of different types of AI media for various learning purposes. For education policy, it is recommended that: the government allocate adequate budgets not only for the procurement of technological infrastructure but also for teacher professional development, content development, and technical support; develop clear policies and guidelines on the use of AI in education that consider pedagogical, ethical, and data security aspects; ensuring equitable access to AI technology for all schools, particularly in rural and remote areas; and supporting the research and development of AI educational content that is linguistically and culturally appropriate for the Indonesian context. For learning practices, it is recommended that: schools and teachers adopt a blended learning model that combines AI-based learning with social interaction and collaborative activities; teachers participate in continuous professional development to improve competence in integrating AI pedagogically sound; schools build technical support systems that can help teachers overcome technical problems; and engage parents in understanding the benefits and ways to support AI-based learning at home. By paying attention to these recommendations, the potential of AI-based learning media to support digital literacy and educational transformation in Indonesia can be realised to the fullest.

REFERENSES

- Bandura, A. (1997). *Self-efficacy: The exercise of control*. W.H. Freeman and Company.
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101. <https://doi.org/10.1191/1478088706qp063oa>
- Chen, X., Zou, D., Cheng, G., & Xie, H. (2020). Detecting latent topics and trends in educational technologies over four decades using structural topic modeling: A retrospective of all volumes

- of Computers & Education. *Computers & Education*, 151, 103855. <https://doi.org/10.1016/j.compedu.2020.103855>
- Chiu, T. K., Xia, Q., Zhou, X., Chai, C. S., & Cheng, M. (2022). Systematic literature review on opportunities, challenges, and future research recommendations of artificial intelligence in education. *Computers and Education: Artificial Intelligence*, 4, 100118. <https://doi.org/10.1016/j.caeai.2022.100118>
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences (2nd ed.)*. Lawrence Erlbaum Associates.
- Creswell, J. W., & Clark, V. L. P. (2018). *Designing and conducting mixed methods research (3rd ed.)*. SAGE Publications.
- Dicheva, D., Dichev, C., Agre, G., & Angelova, G. (2015). Gamification in education: A systematic mapping study. *Educational Technology & Society*, 18(3), 75–88. <https://doi.org/10.2307/jeductechsoci.18.3.75>
- Eshet-Alkalai, Y. (2004). Digital literacy: A conceptual framework for survival skills in the digital era. *Journal of Educational Multimedia and Hypermedia*, 13(1), 93-106. <https://doi.org/10.1007/s11423-015-9391-2>
- Gilster, P. (1997). *Digital literacy*. John Wiley & Sons. <https://doi.org/10.1002/pra2.1997.273034801117>
- Holmes, W., Bialik, M., & Fadel, C. (2019). Artificial intelligence in education: Promises and implications for teaching and learning. *Center for Curriculum Redesign*. <https://doi.org/10.1007/s10639-021-10686-9>
- Hwang, G. J., Xie, H., Wah, B. W., & Gašević, D. (2020). Vision, challenges, roles, and research issues of artificial intelligence in education. *Computers and Education: Artificial Intelligence*, 1, 100001. <https://doi.org/10.1016/j.caeai.2020.100001>
- Kulik, J. A., & Fletcher, J. D. (2016). Effectiveness of intelligent tutoring systems: A meta-analytic review. *Review of Educational Research*, 86(1), 42–78. <https://doi.org/10.3102/0034654315581420>
- Kumar, J. A., & Kumar, P. (2021). Artificial intelligence chatbots in digital education: An investigation of learning outcomes and student perception. *International Journal of Emerging Technologies in Learning*, 16(18), 107–121. <https://doi.org/10.3991/ijet.v16i18.24269>
- Luckin, R., Holmes, W., Griffiths, M., & Forcier, L. B. (2016). *Intelligence unleashed: An argument for AI in education*. Pearson Education.
- Ma, W., Adesope, O. O., Nesbit, J. C., & Liu, Q. (2014). Intelligent tutoring systems and learning outcomes: A meta-analysis. *Journal of Educational Psychology*, 106(4), 901–918. <https://doi.org/10.1037/a0037123>
- Martin, A. (2006). *Literacies for the digital age*. In A. Martin & D. Madigan (Eds.), *Digital literacies for learning* (pp. 3–25). Facet Publishing.
- Mayer, R. E. (2014). *The Cambridge handbook of multimedia learning (2nd ed.)*. Cambridge University Press.
- Nwana, H. S. (1990). Intelligent tutoring systems: An overview. *Artificial Intelligence Review*, 4(4), 251–277. <https://doi.org/10.1007/BF00168958>
- Owan, V. J., Abang, K. B., Idika, D. O., Etta, E. O., & Basse, B. A. (2023). Exploring the potential of artificial intelligence tools in educational measurement and assessment. *Journal of Educational and Social Research*, 13(4), 244–259. <https://doi.org/10.36941/jesr-2023-0109>
- Piaget, J. (1952). *The origins of intelligence in children*. International Universities Press.
- Roll, I., & Wylie, R. (2016). Evolution and revolution in artificial intelligence in education. *International Journal of Artificial Intelligence in Education*, 26(2), 582–599. <https://doi.org/10.1007/s40593-016-0110-3>
- Siemens, G. (2005). Connectivism: A learning theory for the digital age. *International Journal of Instructional Technology and Distance Learning*, 2(1), 3–10. <https://doi.org/10.1111/j.1467-8535.2005.00445.x>
- UNESCO. (2021). *AI and education: Guidance for policy-makers*. UNESCO Publishing.
- VanLehn, K. (2011). The relative effectiveness of human tutoring, intelligent tutoring systems, and other tutoring systems. *Educational Psychologist*, 46(4), 197–221. <https://doi.org/10.1080/00461520.2011.611369>

- Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.
- Wahyuni, S., & Bahriah, E. S. (2022). Digital literacy competence of elementary school students and the contributing factors. *Jurnal Pendidikan IPA Indonesia*, 11(1), 78-92. <https://doi.org/10.15294/jpii.v11i1.32837>
- Walkington, C. A. (2013). Using adaptive learning technologies to personalise instruction to student interests: The impact of relevant contexts on performance and learning outcomes. *Journal of Educational Psychology*, 105(4), 932–945. <https://doi.org/10.1037/a0031882>
- Winkler, R., & Söllner, M. (2018). Unleashing the potential of chatbots in education: A state-of-the-art analysis. *Academy of Management Annual Meeting Proceedings*, 2018(1), 15903. <https://doi.org/10.5465/AMBPP.2018.15903abstract>
- Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). Systematic review of research on artificial intelligence applications in higher education. *International Journal of Educational Technology in Higher Education*, 16(1), 39. <https://doi.org/10.1186/s41239-019-0171-0>
- Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. *Theory Into Practice*, 41(2), 64–70. https://doi.org/10.1207/s15430421tip4102_2