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Primary School Teachers' Readiness to Address the Transformation of Science Education through Artificial Intelligence: A Systematic Literature Review

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ABSTRACT

Science education in elementary schools is still dominated by conventional methods, which are thus unable to optimally foster student engagement and conceptual understanding. Advances in Artificial Intelligence (AI) offer opportunities to transform learning into a more interactive and adaptive experience; however, its success depends heavily on teacher readiness. This study aims to describe and analyze elementary school teachers' readiness in facing the transformation of science learning based on Artificial Intelligence (AI), including aspects of attitudes, competencies, and the ability to integrate AI technology into the learning process. The method used was a Systematic Literature Review (SLR) through the PRISMA approach, with the search process utilizing a combination of keywords ("Science Education" OR "Science Learning"), ("Artificial Intelligence" OR "AI"), ("Teacher Readiness" OR "Teacher Competence"), and ("Elementary School" OR "Primary School") in the Scopus database from 2021–2025, resulting in 10 relevant and high-quality articles after the selection process. The results showed that teachers generally have positive attitudes, high interest, and strong acceptance of AI use in science learning, as it is considered capable of fostering more interactive, innovative, and student-centered learning processes in the digital era. However, teachers' readiness in terms of technical and pedagogical competencies remains at a moderate and uneven level, particularly in operating AI technology and integrating it effectively into learning activities. In addition, limited digital literacy, lack of training, and inadequate infrastructure were identified as the main challenges, indicating the need to strengthen teachers' competencies and provide adequate facilities to optimize AI implementation in science learning. This study highlights the importance of improving teachers' digital competencies and providing technological support to ensure that AI is applied more effectively and optimally in science learning.

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■ INTRODUCTION

Science education in elementary schools plays a very important role in building students' foundational conceptual understanding and in developing critical thinking skills from an early stage (Fitzgerald & Smith, 2022; Hanafi & Komalasari, 2025; Vieira & Tenreiro-Vieira, 2024). At this level, science learning is not only oriented toward mastering subject content or memorizing concepts, but also emphasizes scientific processes involving activities such as observation, data collection, simple experimentation, and systematic scientific reasoning (Klemm et al., 2020; Muzafar & Ahmad, 2025; Urdanivia Alarcon et al., 2023). However, the reality in the field indicates that science lessons still focus on conventional methods such as lectures and rote memorization (Orujlu, 2025; Parno & Agustinus, 2022). Thus, science becomes a strategic subject in shaping students' scientific thinking abilities at the elementary level.

However, the current state of science learning in practice still shows a dominance of conventional teaching methods, such as lectures, simple question-and-answer sessions, and rote memorization, without in-depth exploration (Orujlu, 2025; Parno & Agustinus, 2022). Such approaches cause students to be passive in the learning process, less actively involved in exploratory activities, and to have difficulty connecting scientific concepts to real-life phenomena. As a result, science learning

often fails to optimally achieve the goal of developing higher-order thinking skills.

The development of digital technology, particularly Artificial Intelligence (AI), provides significant opportunities to transform science education into a more innovative, interactive, and contextual learning experience (Akhmadieva et al., 2023; Boltaeva, 2025; Lee et al., 2025). AI enables more adaptive and personalized learning processes, where students can obtain learning experiences that match their individual needs and abilities, while also receiving fast and continuous feedback (Barotova, 2023; Lizano-Sánchez et al., 2025). This shows that AI does not only function as a supporting tool but also as a key enabler in developing modern instructional strategies.

In the context of science education, Artificial Intelligence (AI) also has various significant implementation potentials, such as helping to visualize abstract concepts that are difficult for students to understand, providing safe and efficient experimental simulations, and supporting more structured data-driven learning processes (Alkan, 2024; Omonayajo et al., 2022). With these supports, AI has great potential to improve the quality of science learning, particularly in enhancing conceptual understanding, student engagement, and the overall effectiveness of the teaching and learning process

Although Artificial Intelligence (AI) has great potential in education, its successful implementation largely depends on teachers' readiness, as the primary facilitators of the learning process (Alshorman, 2024; Sadykova & Kayumova, 2024). Teacher readiness is determined not only by technical skills in using technology but also by pedagogical understanding and a positive attitude toward educational innovation (Ismail et al., 2024). In addition, teachers are expected to effectively integrate AI to support the achievement of science learning objectives and improve the quality of teaching and learning processes (Cabral & Palavras, 2025; Yusuf, 2024). Thus, teacher readiness can be understood as a key factor determining the success of AI-based learning transformation in elementary schools.

In reality, not all teachers are adequately prepared to deal with technological advancements, particularly AI (Azim, 2025; Kottara, 2025). Some of the obstacles frequently encountered include limited digital literacy, a lack of training, and insufficient facility support from schools (Rustandi et al., 2024). Furthermore, there are still teachers who hold negative perceptions or have reservations about the use of technology in learning. These conditions have resulted in AI use in science education not yet being optimal or evenly distributed across elementary schools.

Several previous studies have indicated that integrating technology into teaching activities can have a positive impact. The first study by Hashim et al. (2022) found that the use of AI can enhance learning personalization and improve student learning outcomes. The study by Pazmiño et al. (2024) found that the use of digital technology can boost student motivation and engagement in learning activities. A third study by Aprianto et al. (2025) found that integrating innovative technologies, including AI, can improve students' critical thinking and problem-solving skills. However, these studies still focus on implementing technology in learning and have not yet thoroughly examined teacher readiness as a key factor in the successful application of AI.

The development of Artificial Intelligence (AI) technology presents significant new challenges for the education sector, particularly for elementary school teachers, who are expected to continually adapt to rapid changes in technology-driven learning environments. As educational practices increasingly shift toward digital and AI-supported systems, teachers are required not only to understand emerging technologies but also to integrate them meaningfully into pedagogical practices that align with learning objectives. However, the absence of sufficient systematic studies focusing on teacher readiness often leads to suboptimal implementation of AI in real classroom settings.

In addition, several critical aspects still require deeper investigation, including pedagogical competence, digital literacy, attitudes toward technology, availability of training opportunities, and the adequacy of supporting facilities and infrastructure. These factors are essential to ensure that AI integration in education is not only technically feasible but also pedagogically effective and equitable. Without a comprehensive understanding of these dimensions, there is a risk that AI implementation may widen learning disparities rather than improve educational quality.

This study is considered novel because it employs a Systematic Literature Review (SLR) to analyze global teacher readiness to address the transformation of science education through AI. Unlike previous studies that have predominantly focused on the effectiveness of AI in improving student learning outcomes, this study shifts the focus toward teachers' readiness as the primary actors responsible for implementing instructional innovation in

classrooms. By synthesizing findings from internationally reputable literature, the SLR approach enables a more comprehensive and integrated understanding of teachers' knowledge, skills, and attitudes, as well as the practical challenges they face in implementing AI across diverse educational contexts.

Based on the identified research gap, this study poses the following research question: RQ1: How is the readiness of elementary school teachers to address the transformation of science education through Artificial Intelligence (AI) assessed in the existing literature? In addition, to provide a more structured analysis, this study proposes the following supporting questions: RQ2: What factors influence teachers' readiness to integrate AI into science education? and RQ3: What challenges and barriers are most frequently reported in implementing AI in elementary science education?

Accordingly, the objectives of this study are to describe and analyze teachers' readiness in integrating AI, to identify the factors influencing this readiness, and to examine the challenges encountered in its implementation. Ultimately, this study is expected to provide a comprehensive foundation for developing effective, innovative, and sustainable strategies for AI integration in elementary science education.

■ METHOD

Research Design

This study employed a Systematic Literature Review (SLR) approach, utilizing data from the Scopus database and adhering to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines as a systematic framework to enhance transparency and accuracy in the process of identifying, screening, and synthesizing scientific articles relevant to the research topic (Munir, 2025). The purpose of the SLR approach in this study is to present comprehensive and objective knowledge of previous research on elementary school teachers' readiness to face the transformation of science learning innovation through AI, while also identifying research gaps and providing direction for future research (Nor & Mahmud, 2024).

Search Strategy

Data collection for this study was conducted through a literature search in the Scopus database, which serves as the primary source due to its international reputation and provision of high-quality scientific articles. The search process utilized a combination of keywords relevant to the research topic, namely ("Science Education" OR "Science Learning"), ("Artificial Intelligence" OR "AI"), and ("Elementary School" OR "Primary School"). The search was limited to the publication years 2021 to 2025 to obtain an overview of the latest research developments related to the topic under study. Subsequently, the search results were filtered based on inclusion criteria: articles focusing on the use of AI in science learning and relevant to the context of elementary education. Exclusion criteria included articles that did not align with the topic, were not available in full-text format, or contained duplicate data.

Inclusion and Exclusion Criteria

After the identification, screening, and eligibility stages were completed, the articles that met the inclusion criteria were further assessed using the Mixed Methods Appraisal Tool (MMAT). MMAT was employed to evaluate the methodological quality of studies across qualitative, quantitative, and mixed-methods designs. The assessment considered several methodological aspects, such as the clarity of the research objectives, the appropriateness of the research design, data collection procedures, data analysis methods, and the consistency between the findings and conclusions. Each article was evaluated according to the MMAT criteria relevant to its methodological approach. This quality assessment was conducted to ensure that the selected studies were methodologically sound and relevant to the objectives of the review. Based on the article selection process and the MMAT quality assessment, a total of 10 articles met the inclusion criteria and were included in the final analysis, as presented in Figure 1.

The figure illustrates the systematic stages of article selection in this study. During the identification stage, an initial search using the keywords ("Science Education" OR "Science Learning") yielded 29,412 results, which were then filtered to the years 2021–2025, resulting in 12,937 articles. Next, the search was narrowed by adding the keywords ("Artificial Intelligence" OR "AI"), yielding 752 articles. The subsequent stage involved adding the keywords ("Elementary School" OR "Primary School"), resulting in 59 more specific articles aligned with the study's focus.

Data Analysis

A screening phase was conducted by limiting the publication year to the 2021–2025 range and selecting articles based on the relevance of their titles and abstracts. In the analysis stage, articles were reselected based on

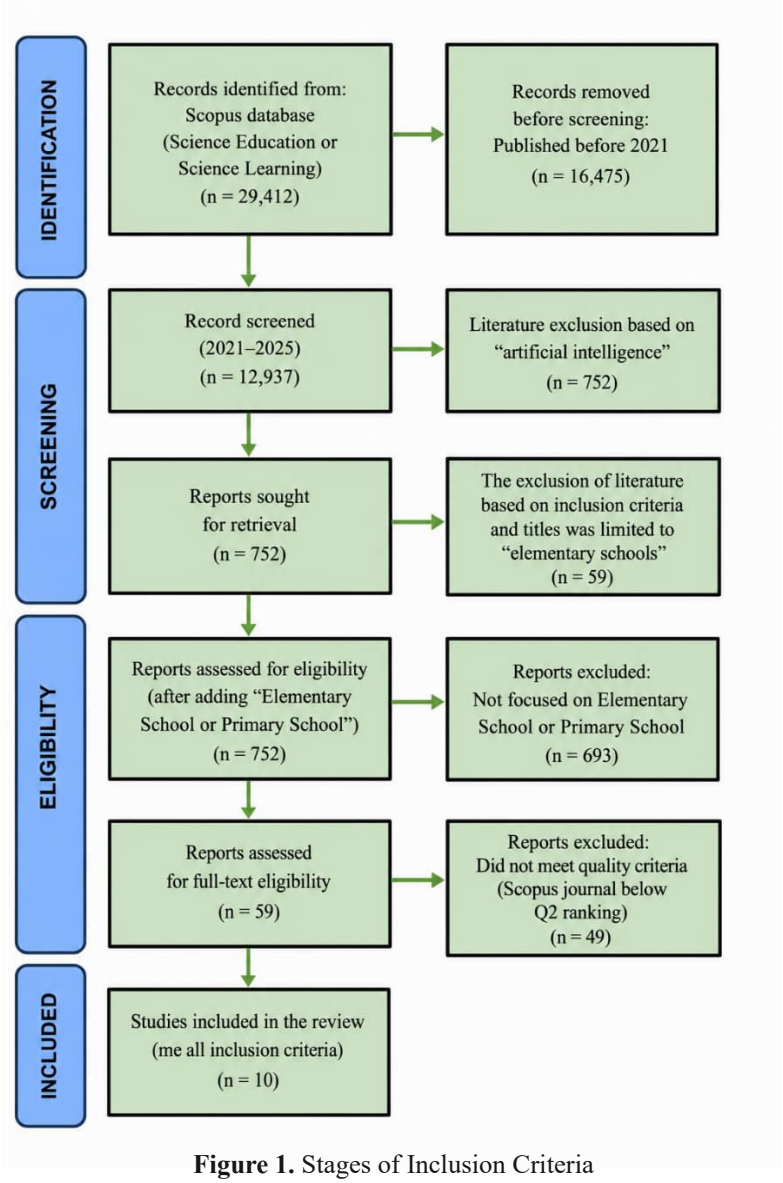

Figure 1. Stages of Inclusion Criteria

quality criteria, namely, being indexed in Scopus and having a Q2 ranking as an indicator of academic impact. Through this process, 10 articles that met the criteria were identified and used as the final analysis material in the study.

■ RESULT AND DISCUSSION

The data for this study were sourced from scientific articles identified through a search of the Scopus database, yielding an initial total of approximately 29,412 publications. The literature review focused on scientific articles relevant to elementary school teachers' readiness to address the transformation of science education through AI. The search was conducted using a combination of keywords ("Science Education" OR "Science Learning"), ("Artificial Intelligence" OR "AI"), and ("Elementary School" OR "Primary School"). It was limited to the period 2021–2025 to identify research trends, as presented in Figure 2.

As shown in Figure 3, the number of Scopus-indexed articles has increased consistently from 2021 to 2025. In 2021, there were 6 publications, which increased to 9 in 2022. This upward trend continued in 2023 with 11 publications and saw a more significant surge in 2024 to 16 publications. In 2025, the number of articles increased again, albeit not as sharply, to 17. This pattern indicates growing interest and increasing research contributions year over year, suggesting that the field of study has shown positive, sustainable development over the past five years. Based on the average (mean) number of publications

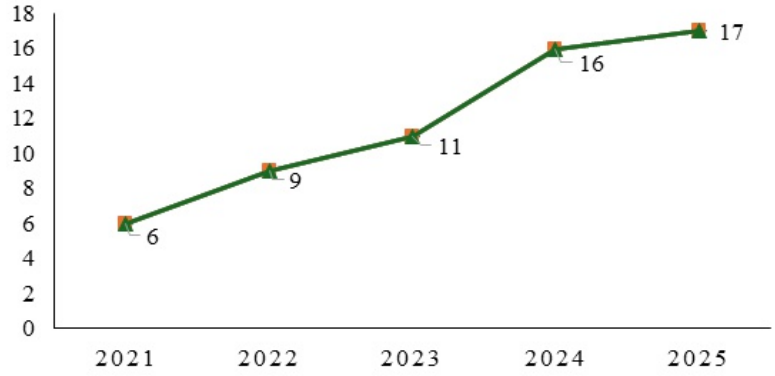

Figure 2. Growth in the number of articles from 2021 to 2025

from 2021 to 2025, the average is 11.8 articles per year, indicating a clear upward trend in researchers' attention to elementary school teachers' readiness for Artificial Intelligence (AI)-based learning. This condition suggests that teacher readiness is no longer viewed merely as a supporting aspect, but as a key factor determining the successful implementation of AI in science learning at the elementary school level.

In line with the increasing trend in such publications in the Scopus database, this study further focuses on articles most relevant to elementary school teachers' readiness to address the transformation of science education through Artificial Intelligence (AI). Using a Systematic Literature Review (SLR) process and data from the Scopus database, a systematic screening identified 10 articles that met the inclusion and eligibility criteria for in-depth analysis. The results of the analysis of these selected articles are presented in a table to provide a concise, structured overview, as shown below.

To provide a more structured overview of the findings from the 10 systematic review articles, the following charts illustrate the readiness levels of elementary school teachers across two competency dimensions: Technical Competency (the ability to use AI tools and digital literacy) and Pedagogical Competency (the ability to integrate AI into instructional design and assessment). Each article was categorized based on the reported readiness level (High, Medium, or Low) for each competency category.

Figure 3 presents a grouped bar chart comparing technical competencies and pedagogical competencies across three levels of readiness. Regarding technical competencies, only 1 article reported a high level of readiness (Al Darayseh, 2023), while 6 articles indicated a moderate level (Alshorman, 2024; Huang, 2022; Park et al., 2023; Wu & Yang, 2022; Zorlu, 2025; Chen et al., 2025), and 3 articles reported a low level of readiness (Heeg & Avraamidou, 2023; Abualrob, 2025; Efe & Aslan, 2025). For Pedagogical Competence, 2 articles reported high readiness (Al Darayseh, 2023; Wu & Yang, 2022), 5 articles reported moderate readiness, and 3 articles reported low readiness. These results confirm that the majority of teachers operate at a moderate level across both types of competencies, with pedagogical readiness showing a slightly higher proportion of high-level reports than technical competencies.

For Technical Competence, a total of 10 articles were distributed as follows: 1 High (10%), 6 Moderate (60%), and 3 Low (30%). For Pedagogical Competence, the distribution was as follows: 2 High (20%), 5 Moderate (50%), and 3 Low (30%). The stacked format makes it clear that the moderate readiness level dominates both categories. In contrast, the proportion of articles with high readiness is significantly higher for Pedagogical Competence (20%) than for Technical Competence (10%). This suggests that while teachers have made some progress in integrating AI pedagogically, the basic technical skills required to operate AI tools remain a greater challenge for most elementary school teachers.

Teacher Attitudes Toward AI Integration

The use of Artificial Intelligence (AI) in elementary science education shows strong potential to support educational transformation, particularly regarding teachers' readiness to integrate this technology. Studies indicate that teachers generally have positive attitudes toward AI, but their readiness varies, with limitations in technological literacy, understanding of AI-based pedagogy, and confidence in classroom application (Heeg & Avraamidou, 2023; Park et al., 2023). AI can support the creation of interactive and

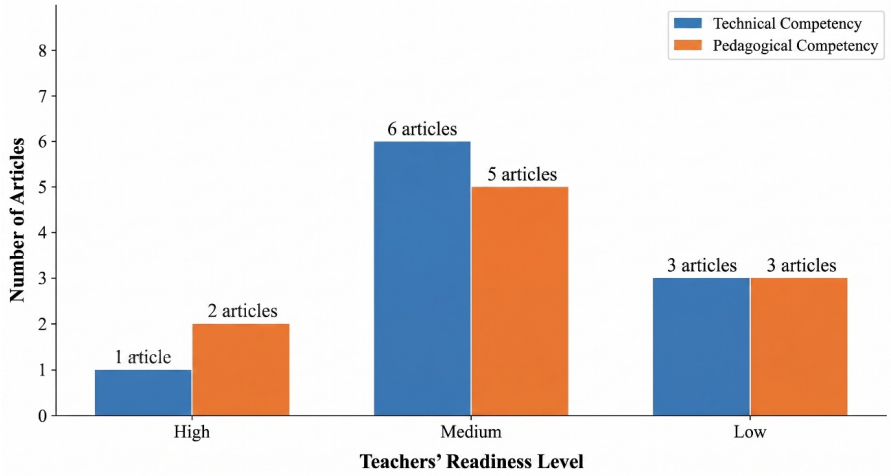

Figure 3. Teacher readiness levels by competency category

contextual learning materials (Abualrob, 2025), and its use in tasks such as question design can also enhance teachers' 21st-century skills, including critical thinking, collaboration, and digital literacy (Zorlu, 2025), showing that AI contributes to the ongoing development of teacher readiness.

Teachers' Competencies and Professional Readiness

Furthermore, the success of Artificial Intelligence (AI)-based learning in elementary science education is strongly influenced by teachers' readiness, particularly in providing appropriate pedagogical and technological support that can improve students' conceptual understanding, engagement, and learning outcomes through interactive learning activities (Wu & Yang, 2022; Efe & Aslan, 2025). Although AI has the potential to support more systematic and data-driven assessment processes, most studies indicate that its implementation in elementary schools remains at a basic level, such as assisting with question design, learning media development, and simple monitoring of students' learning progress (Huang, 2022; Zorlu, 2025). This condition is caused by teachers' limited competencies, especially in digital literacy, AI-based pedagogical understanding, as well as insufficient training and infrastructure support (Kaswar et al., 2023; Kurniawati et al., 2025; Murwani et al., 2025). Therefore, AI integration in science learning has not yet fully progressed toward the use of complex adaptive evaluation systems, but is still mainly focused on utilizing AI as a supportive tool for basic learning and assessment activities in elementary school classrooms (Kaswar et al., 2023; Kurniawati et al., 2025; Murwani et al., 2025).

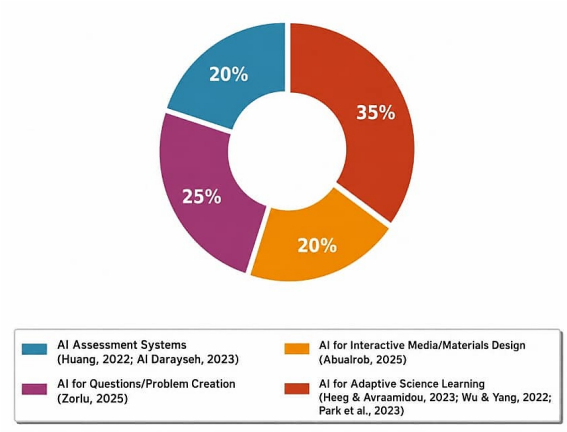

Figure 4. Distribution of AI use in elementary school science education

Based on Figure 4, the distribution of AI use in science education in elementary schools across the 10 sample articles shows that the AI category for Adaptive Learning Support/ General Science dominates with the highest proportion at 35%, encompassing studies such as Heeg & Avraamidou (2023), Wu & Yang (2022), and Park et al. (2023). The AI category for Question Generation ranks second at 25% (Zorlu, 2025), followed by AI for Assessment Systems and AI for Interactive Media/Material Design, each at 20% (Huang, 2022; Al Darayseh, 2023; Abualrob, 2025). This distribution pattern indicates that, while the use of AI at the elementary school level has touched on various aspects of learning, its implementation is still dominated by supportive and administrative functions such as question creation, assessment, and media design, and the use of AI for more complex adaptive systems remains uneven. This aligns with findings in the discussion, which state that AI implementation in elementary schools remains at a basic level and has not yet fully evolved toward the use of complex adaptive assessment

systems (Chen et al., 2025).

Benefits of AI in Science Learning

Based on a synthesis of various research findings, elementary school teachers' readiness to integrate Artificial Intelligence (AI) into science learning shows a positive trend in attitudes, interest, and acceptance of the technology. However, in terms of technical and pedagogical competencies, most studies still indicate limitations in technological literacy, AI-based instructional design, and the ability to integrate AI effectively into learning and assessment processes. Therefore, in this study, teacher readiness was not categorized using a specific quantitative scale but was assessed qualitatively based on the dominant findings from the analyzed articles. In addition, limited infrastructure and a lack of training remain major barriers to implementing AI in elementary schools. Thus, continuous efforts through training, competency development, and support for facilities and infrastructure are needed to ensure that the integration of AI into science learning is implemented more effectively and sustainably.

Barriers to AI Implementation

The findings indicate that elementary school teachers generally have positive attitudes toward the use of Artificial Intelligence (AI), although their technical and pedagogical competencies remain limited. This condition is consistent with the Technology Acceptance Model, where perceived benefits of technology can encourage acceptance and interest in its use, even when implementation skills are not yet fully optimal, as teachers perceive AI as beneficial for administration, learning media development, and more personalized learning (Heeg & Avraamidou, 2023; Park et al., 2023). However, low digital literacy, limited training, and the absence of clear guidelines remain obstacles to the effective use of AI (Alshorman, 2024; Efe & Aslan, 2025). As a result, the use of AI remains limited to basic tasks and has not fully supported curriculum goals, such as differentiated learning. Therefore, alignment between teacher competencies, instructional design, and curriculum implementation is needed to ensure that AI can truly transform science learning in elementary schools (Chen et al., 2025).

Based on Figure 5, the Pareto analysis of 10 sample articles identified four major challenges most frequently reported in the implementation of AI in elementary school science education. The most dominant challenge is the lack of AI training, reported in 6 articles: Alshorman (2024), Efe & Aslan (2025), Park et al. (2023), Heeg & Avraamidou (2023), Wu & Yang (2022), and Chen et al. (2025). The second challenge is the limited digital literacy of teachers, which appears in 5 articles: Alshorman (2024), Heeg & Avraamidou (2023), Efe & Aslan (2025), Zorlu (2025), and Al Darayseh (2023). Furthermore, the challenge of insufficient school infrastructure was noted in 4 articles: Efe & Aslan (2025), Park et al. (2023), Wu & Yang (2022), and Huang (2022). The challenge of the absence of clear guidelines or a curriculum was reported in only 2 articles: Heeg & Avraamidou (2023) and Chen et al. (2025). The cumulative line in the diagram indicates that the first two challenges, the lack of AI training and limitations in teachers' digital literacy, together

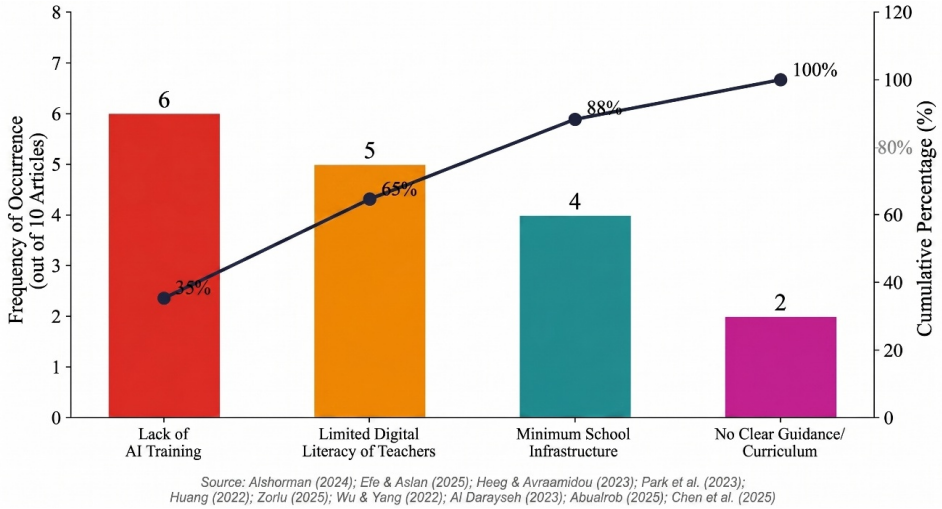

Figure 5. Key challenges in the implementation of artificial intelligence in science education in elementary schools

account for 65% of all reported issues, meaning both are top priorities that must be addressed immediately. This finding reinforces the argument presented in the discussion that limitations in teachers' technical and pedagogical competencies directly linked to limited access to training and low digital literacy constitute the greatest structural barriers hindering the optimal implementation of AI-based science learning transformation in elementary schools (Alshorman, 2024; Efe & Aslan, 2025).

Elementary School Teachers' Readiness to Address the Transformation of Science Education through Artificial Intelligence

Artificial Intelligence is increasingly being used in elementary science education because it supports interactive, adaptive, and data-driven learning processes, helping students understand concepts through visualization, simulation, and immediate feedback (Gontina & Asyhar, 2023; Rahman & Mehnaz, 2024; Rathore et al., 2023). However, the success of AI integration largely depends on teacher readiness, which includes knowledge, skills, and attitudes toward technology, where teachers are expected to understand and apply AI in effective instructional strategies

Teachers' attitudes and acceptance of Artificial Intelligence are crucial factors in its integration into elementary science education (Guo, 2025; McBean, 2025). Although many teachers view AI positively because it can make learning more interactive and support conceptual understanding, others remain hesitant due to limited experience and knowledge (Guo, 2025; McBean, 2025; Nasrah et al., 2025). In addition, gaps in technical and pedagogical competencies indicate that teachers still require more structured and continuous training in order to effectively integrate AI into meaningful learning processes (Gontina & Asyhar, 2023).

Based on the synthesis of the reviewed studies, the implementation of AI in elementary science education is still in a developmental stage, with the main challenges not only related to technology acceptance but also to teachers' pedagogical and technical readiness to operate and integrate AI into the learning process. Therefore, it is necessary to strengthen teachers' competencies through training focused on AI integration in instruction, the development of technology-based instructional design, and enhanced institutional support so that AI utilization can be implemented effectively and sustainably in elementary science education (Syamdani et al., 2025; Tuan et al., 2025; Wu et al., 2024).

■ CONCLUSION

Based on the research findings, it can be concluded that elementary school teachers' readiness to face the transformation of science learning based on Artificial Intelligence (AI) shows a positive trend, particularly in attitudes, interest, and acceptance of AI use in education. However, in terms of technical and pedagogical competencies, this readiness remains suboptimal and uneven. Limited digital literacy, lack of continuous training, and insufficient facilities and infrastructure support are the main obstacles in implementing AI in elementary science learning. Therefore, systematic efforts through continuous training, strengthening digital literacy, and providing policy and infrastructure support are needed to ensure AI is implemented more effectively and optimally.

This study has several limitations because it analyzed only articles indexed in the Scopus database during the 2021–2025 publication period, which may not capture all studies on AI implementation in elementary science education. In addition, this research was conducted as a literature review and therefore does not directly represent empirical conditions in the field. Future studies are recommended to conduct field research through observations or interviews to obtain a more in-depth understanding of teachers' readiness to implement AI in elementary schools. For policymakers, the findings of this study may serve as a basis for designing AI training programs for teachers, providing adequate digital infrastructure, and developing clear and sustainable guidelines for AI implementation in science education.

It is recommended that the government and educational institutions provide ongoing training to enhance teachers' technical and pedagogical competencies in the use of AI. Additionally, schools need to improve infrastructure support and ensure adequate access to digital technology. Teachers are also expected to actively develop digital literacy and innovative skills in designing AI-based learning. On the other hand, future researchers are encouraged to conduct direct empirical field studies to examine the implementation of AI in science education in greater depth and in more context-specific ways, thereby providing a comprehensive description.

DECLARATION OF GENERATIVE AI USAGE IN THE WRITING PROCESS

The authors used several artificial intelligence (AI)-based tools in preparing this manuscript. ChatGPT (OpenAI) and Prof AI were utilized to assist with language

refinement, organization of ideas, and clarity in academic writing. In addition, DeepL was used to support translation and grammar checking, enhancing the manuscript's readability and linguistic accuracy. The authors carefully reviewed, edited, and validated all outputs generated by these tools. All literature searches, data collection, data analysis, interpretation of findings, and conclusions were conducted solely by the authors. The authors take full responsibility for the content of this manuscript and its scientific integrity.

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