Artificial intelligence in primary education: systematic review (2000-2024)

La inteligencia artificial en educación primaria: una revisión sistemática (2000-2024)

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ABSTRACT

The integration of artificial intelligence (AI) into primary education has gained significant attention due to its potential to transform teaching and learning. However, its implementation lacks a solid empirical foundation to validate its pedagogical benefits at this stage of education. Existing research remains limited, raising critical questions about how AI can be effectively and pedagogically integrated into primary education. In this context, the objective of this article is to analyze the current state of research on AI in primary education, identifying trends, challenges, and significant gaps in scientific literature. A systematic review of the literature published between 2000 and April 2024 was conducted in accordance with the PRISMA protocol. The review included 15 studies sourced from WoS, Scopus, and Dialnet databases, selected based on rigorous quality and relevance criteria. Data were analyzed using tools such as VOSViewer to explore methodological, pedagogical, and bibliometric dimensions. The findings reveal a limited body of academic work focused on areas such as AI literacy, curriculum design, and technological applications. However, most studies are descriptive and exploratory, lacking experimental research to assess the actual impact of AI on learning outcomes. This review underscores the urgent need for empirical studies and the promotion of collaboration among educators, researchers, and policymakers to develop inclusive, ethical, and evidence-based curricula. Such efforts are critical to fully harnessing the educational potential of AI in primary education.

RESUMEN

La integración de la inteligencia artificial (IA) en la educación primaria ha despertado un gran interés debido a su potencial para transformar la enseñanza y el aprendizaje. Sin embargo, su implementación carece de una base empírica sólida que valide sus beneficios pedagógicos en esta etapa educativa. La investigación existente sigue siendo limitada, lo que plantea interrogantes fundamentales sobre cómo integrar la IA de manera efectiva y pedagógica en la educación primaria. En este contexto, el objetivo de este artículo es analizar el estado actual de la investigación sobre la IA en la educación primaria, identificando tendencias, desafíos y vacíos significativos en la literatura científica. Para ello, se realizó una revisión sistemática de la literatura publicada entre 2000 y abril de 2024, siguiendo el protocolo PRISMA. La revisión incluyó 15 estudios extraídos de las bases de datos WoS, Scopus y Dialnet, seleccionados según rigurosos criterios de calidad y relevancia. Los datos fueron analizados mediante herramientas como

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VOSViewer para explorar dimensiones metodológicas, pedagógicas y bibliométricas. Los hallazgos revelan una producción académica limitada centrada en áreas como la alfabetización en IA, el diseño curricular y las aplicaciones tecnológicas. No obstante, la mayoría de los estudios son descriptivos y exploratorios, con una carencia de investigaciones experimentales que evalúen el impacto real de la IA en los resultados de aprendizaje. Esta revisión subraya la necesidad urgente de estudios empíricos y de la promoción de la colaboración entre educadores, investigadores y responsables de políticas para desarrollar currículos inclusivos, éticos y basados en evidencia. Dichos esfuerzos son fundamentales para aprovechar plenamente el potencial educativo de la IA en la educación primaria.

1. Introduction

Artificial intelligence (AI) has emerged as one of the most transformative technologies of the 21st century, impacting various sectors, including education. In primary education, AI offers the potential to reshape traditional teaching methods, providing personalized learning experiences, enhancing student engagement, and automating administrative tasks. The growing integration of AI in educational contexts underscores the importance of early exposure to AI literacy, enabling young students to develop a comprehensive understanding of how these technologies work. However, despite its increasing relevance, research into the practical applications of AI in primary education remains limited. Most studies have focused on higher education and secondary school settings, leaving a significant gap in empirical data regarding AI's efficacy at the elementary level.

As AI technologies continue to evolve, educational researchers and policymakers must critically examine how best to integrate AI into primary education curricula. The development of AI literacy programs tailored for younger learners is crucial, as it can foster computational thinking, creativity, and problem-solving skills from an early age. Additionally, teaching AI concepts to primary students may help reduce the digital divide, ensuring that all students are equipped with essential knowledge in a technology-driven world. However, challenges such as teacher preparedness, accessibility of AI tools, and ethical considerations surrounding data privacy and algorithmic bias must be addressed. This article presents a systematic review that explores the current state of AI implementation in primary education, analyzing existing studies to identify best practices and highlight key areas for future research.

Among the many definitions of AI, it is commonly understood as a combination of mathematical and computational algorithms designed to create systems with human-like capabilities (Russell & Norvig, 1994; Vicente-Yagüe-Jara et al., 2023). Within the educational context, AI has been applied to various emerging educational proposals (Bowen, 2024; Gavrilas et al., 2024; Sabzalieva & Valentini, 2023) for primary, secondary, and higher education (Ng et al., 2021, 2023)

Several theoretical studies have examined the application of AI in early education. An initial exploratory study (Su & Yang, 2022) highlighted the importance of integrating AI into early education, particularly in relation to key concepts and the efficient introduction of these concepts within the learning process. A similar analysis applies to primary education, where, according to Combéfis (2023), AI literacy should be fostered through the following activities: programming activities using App Inventor, learning about machine learning, game-based learning, computational thinking competitions, and workshops. In this context, Iris Heung (2023) proposed that, in the primary education context, designing an AI-centered curriculum should include basic concepts, technologies, applications, and social, ethical, and environmental implications. Therefore, factors such as digital leadership and literacy become indispensable (Cheng & Wang, 2023; Zhao et al., 2022) in collaborative curriculum design (Dai et al., 2023).

From the few published theoretical studies, three main lines of thought about literacy can be inferred: 1) to know and understand the basic techniques, concepts and tools of AI (Lin et al., 2021); 2) to use and apply AI to solve problems (Vazhayil et al., 2019); and 3) to evaluate and create AI to develop scientific and computational thought based on scientific research (Han et al., 2018).

In a general sense, promoting AI literacy in early education involves utilizing hardware-based learning devices such as robotics, sensors, and Arduino computers, as well as software for basic programming, AI systems like expert systems, automated learning, and chatbots, or even unplugged activities that do not require computers (Kaspersen et al., 2021). Additionally, diverse pedagogic approaches based on project-based learning and game activities (Kaspersen et al., 2021) are essential, along with the creation of educational content (Rodríguez-García et al., 2021). These studies explore and reflect on the use of AI in early education (elementary and primary), but they lack the empirical knowledge needed to confirm its effectiveness in educational settings.

1.1. Preliminary systematic review of the use of AI in primary education

During the search using the Web of Science (WoS), Scopus, Dialnet, and ERIC databases, as well as the Google Scholar search engine, only six studies were identified (Table 1) that describe, albeit superficially, the use of AI in primary education and, in a similar case, elementary education (Su et al., 2023).

Table 1. Localized Systematic Reviews

Article	Period	Analyzed articles	Databases
(Su et al., 2023)	2016-2022	16	WoS, EBSCO, IEEE, ACM, Scopus and Google Scholar
(Cao & Li, 2023)	Articles published before October 26th 2022	35	Scopus, EBSCO, WoS, ProQuest, PubMed y PsycINFO
(Martínez-Comesaña et al., 2023)	2010-2023	9	ACM Digital Library, Elsevier (ScienceDirect), IEEE Xplore Digital Library, Springer, Taylor and Francis, and Wiley Online Library
(Forero-Corba & Negre Bennasar, 2023)	2021-2023	55	WoS and Scopus
(Ojeda-Bazaran et al., 2021)	2016-2021	64	Scopus, WoS, IEEE Xplore, ACM Digital library, Springer Link and, ScienceDirect
(Kim, 2021)	No data	145	Research Foundation of South Korea

Source: Own elaboration (2024).

Interestingly, only one study focused on primary education (Kim, 2021), but it was only a local analysis (South Korea). The other articles analyze a few studies from this stage but focus more on elementary education (Su et al., 2023), secondary education (Martínez-Comesaña et al., 2023), and secondary education along with higher education (Forero-Corba & Negre Bennasar, 2023). Meanwhile, others conduct a comprehensive analysis of all education levels (Ojeda-Bazaran et al., 2021).

From the analyzed studies, the following conclusions are drawn:

- The paper by Su et al. (2023) is the first study related to AI in elementary education. Some key ideas include the following: 1) the use of AI tools and platforms such as PopBots, the Jibo robot, the Cozmo robot from Anki, Amazon's Alexa, and Google's teachable machine to foster the understanding of basic AI concepts in children; and 2) the importance of improving tools, educational methods, and training for teachers in AI literacy.
- The research undertaken by Cao & Li (2023) does not focus on AI because it analyzes educational technologies in a general sense from the perspective of digital wellness. It explores definitions, assessments, and interventions to guarantee balanced and healthy use of technologies. Research reveals the lack of consensus about the definition of digital wellness and the effective measurements used to assess it.
- On the other hand, Martínez-Comesaña et al. (2023) highlighted the use of natural language processing and neurological networks to improve academic performance. The study highlights the specific applications of AI in evaluating students in primary and secondary education, as well as the creation of learning activities using robots.
- Other studies, such as that from Forero-Corba & Negre Bennasar (2023), highlight the use of AI-based technologies to assess academic performance, diversify teaching practices, and integrate them into the curriculum. The authors emphasize the importance of AI literacy among teachers.
- A conference paper by Ojeda-Bazaran et al. (2021) provides general insights that could be further developed through detailed research. The authors state that the topics taught to children include educational robotics, block programming, theory workshops on AI, and machine learning code design. Furthermore, the primary teaching and learning methodologies are centered on project-based learning and research. The tools most commonly used are Scratch, Google Teachable, and LEGO.
- Finally, Kim (2021) carried out a generic analysis of digital literacy (including AI) within the South Korean context and justified educational policies. The documentation is scarce and local-only.

These reviews both measure the impact of AI in elementary and primary education. They highlight persistent challenges such as 1) accessibility and equality in the use of technology; 2) adaptability and personalization

of algorithms according to learning styles; 3) creating transparent policies to protect the personal information of the students; 4) designing ground-breaking teaching techniques; and 5) promoting techno-pedagogical and edu-communicative training for teachers. Confronting these challenges requires a collaborative approach among educators, researchers, technology developers, and policymakers to ensure that AI is used effectively and ethically to enhance primary education.

This preliminary literature review confirms that a systematic review analyzing the empirical experience of AI use in primary education has not yet been conducted.

1.2. Objectives and research questions

This study aimed to analyze, through a systematic review, studies related to AI in primary education, focusing on literacy, curriculum design, and the use of AI-based technologies. For this goal, the literature (2000-2/4/2024) available from WoS, Scopus, and Dialnet was reviewed.

Based on the identified objective and theoretical gaps, the following questions were formulated to be addressed.

Question 1: ¿What are the topics explored in educational research? It was answered through the bibliometric dimension (networks and their clusters via VOSviewer).

Question 2: What are the methodologies that were used (research and instruments), and what is their reach? It was answered through the methodological dimension.

Question 3: What are the main results of the research regarding the implementation of AI in primary education? It was answered through the pedagogical dimension.

2. Methodology

The current PRISMA statement and quantitative procedure (Page et al., 2021) were used to ensure the validity of the study (Hammersley, 2020).

2.1. Search string and strategies. Inclusion and exclusion criteria

Due to the limited scientific literature, articles were selected from peer-reviewed journals to ensure their quality and reliability. The search period ranged from 2000 to 2024, ending on April 2, 2024. The selection criteria allowed us to obtain articles from the last 23 years. Mendeley was used to obtain the articles, generate references, and delete duplicates.

The search protocol involved the use of Scopus, DialNet, and WoS (all their databases), considering the availability of more than 3000 journals across these databases.

The Boolean search centered around the string "artificial intelligence" OR "AI" yielded generic results; thus, it was necessary to select those that focused on AI. Afterward, the results were filtered according to the search string "Primary education" OR "elementary school" OR "grade school" OR "grammar school" to obtain the papers related to the study. The final search string was ("Artificial intelligence " OR "Artificial intelligence literacy" OR "Artificial intelligence curricula" OR "technologies based on artificial intelligence") AND ("Primary education" OR "elementary school" OR "grade school" OR " OR "grammar school"), with the inclusion and exclusion criteria shown in Table 2.

Table 2. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
• Scientific articles published on indexed journals on Scopus, Dialnet and WoS	• Conference reports, books, reports not peer-reviewed and with not enough information on the topic
• The studies must be related with AI in Primary education	• Articles that did not described the methodological design enough
• Published in English or Spanish	
• Publication period 2000-2024 the day the search began being April 2nd 2024	

2.2. Codification and Data Analysis

The research started with the objective and the research questions. The 15 articles resulting from the application of the PRISMA protocol (Figure 1) were analyzed using the comparative method proposed by Glaser (1965), which has been employed in similar systematic reviews (Ng et al., 2021). Each study was codified, and metadata (title, summary, keywords, main results, methodological design, and conclusions) were obtained and analyzed in depth (Table 3).

Figure 1. PRISMA diagram
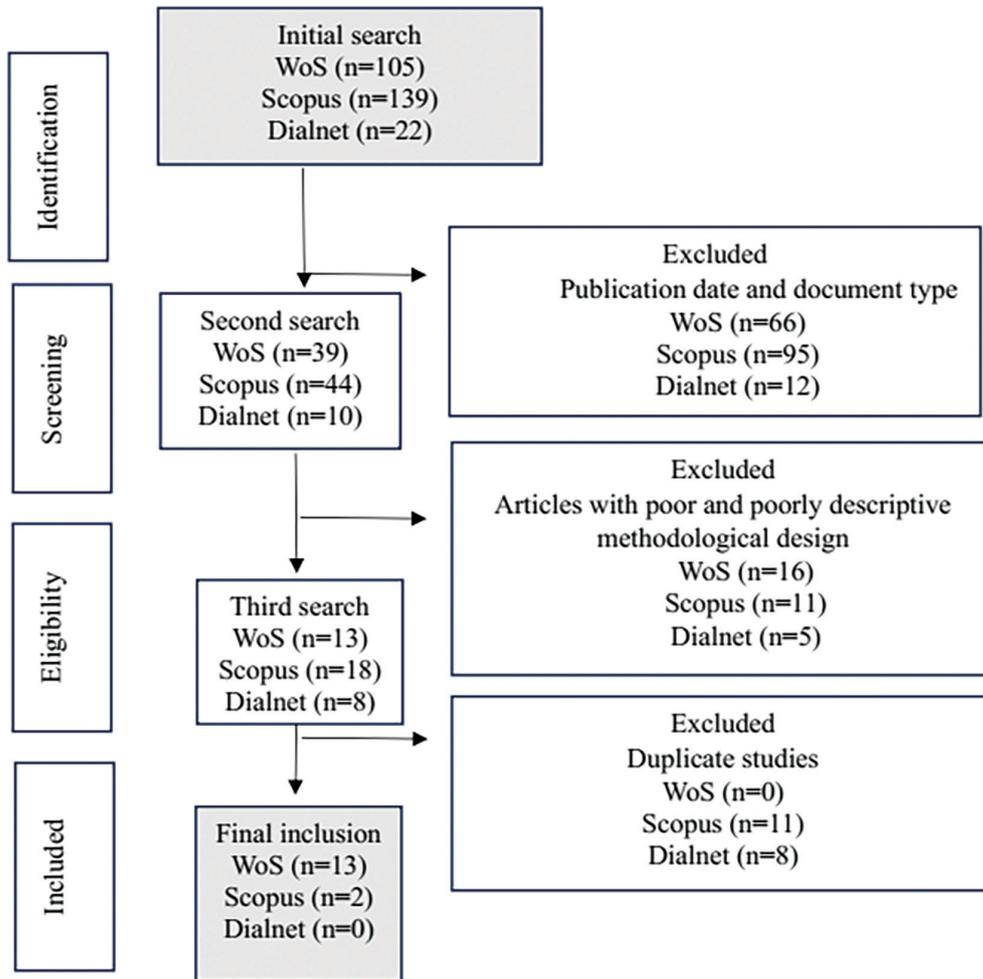
Source: Own elaboration.

Table 3. Quality assessment criteria

Questions	Criteria
Q1	Is the study focused on Primary Education?
Q2	Is the research objective stated?
Q3	Are instruments applied? Are they validated?
Q4	Is the type of study determined?
Q5	Does the study contribute to Education or focus on computational aspects?
Q6	Are the results properly collected and analyzed?
Q7	Are the limitations of the study stated?
Q8	Are the pedagogical and educational implications declared?

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Each researcher analyzed the articles separately and then compared their observations; if discrepancies arose, they were duly discussed and addressed. The kappa de Fleiss (0.89) coefficient was used to ensure reliability (Tang et al., 2015). The Fleiss kappa technique was preferred over Cohen's kappa since more than two evaluators participated. Table 4 presents the percentages obtained for each question in the selected studies, following the application of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol.

The different metadata were paired to facilitate examination in VoSViewer.

Table 4. Results of the quality assessment

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
(Dai et al., 2024)	0.89	0.97	0.95	0.96	0.97	0.93	0.90	0.91
(Dai et al., 2023)	0.89	0.94	0.95	0.95	0.96	0.93	0.92	0.91
(Masneri et al., 2023)	0.89	0.86	0.89	0.86	0.89	0.90	0.91	0.91
(Cheng & Wang, 2023)	0.86	0.87	0.86	0.85	0.86	0.85	0.85	0.89
(Huang, 2022)	0.86	0.87	0.86	0.84	0.86	0.86	0.85	0.87
(Pardamean et al., 2022)	0.90	0.91	0.86	0.92	0.95	0.86	0.87	0.89
(Shi & Rao, 2022)	0.86	0.95	0.89	0.87	0.86	0.89	0.86	0.90
(Zhao et al., 2022)	0.9	0.86	0.89	0.86	0.89	0.96	0.86	0.89
(Mertala et al., 2022)	0.86	0.86	0.87	0.86	0.86	0.84	0.86	0.87
(Kim, 2021)	0.95	0.86	0.89	0.90	0.91	0.93	0.90	0.91
(Miranda Veiga & Valente de Andrade, 2021)	0.89	0.86	0.87	0.91	0.87	0.86	0.86	0.86
(Sun-Ho et al., 2020)	0.90	0.86	0.86	0.86	0.9	0.86	0.86	0.9
(Jeon et al., 2020)	0.90	0.86	0.9	0.86	0.86	0.9	0.9	0.95
(Hyun, 2020)	0.88	0.86	0.91	0.95	0.86	0.9	0.86	0.86
(Dai et al., 2020)	00.95	0.86	0.88	0.86	0.86	0.95	0.86	0.88

3. Results

3.1. General bibliometric indicators

Low academic productivity is evident, as only 15 articles met the criteria (Figure 2). The countries (Figure 3) that stand out in this area are China (Dai et al., 2023, 2024; Huang, 2022; Shi & Rao, 2022; Zhao et al., 2022) and Australia (Cheng & Wang, 2023; Dai et al., 2023, 2024) and, to a lesser extent, Spain, Portugal, and Indonesia.

Figure 2. Academic publications—no duplicates—(n=15)
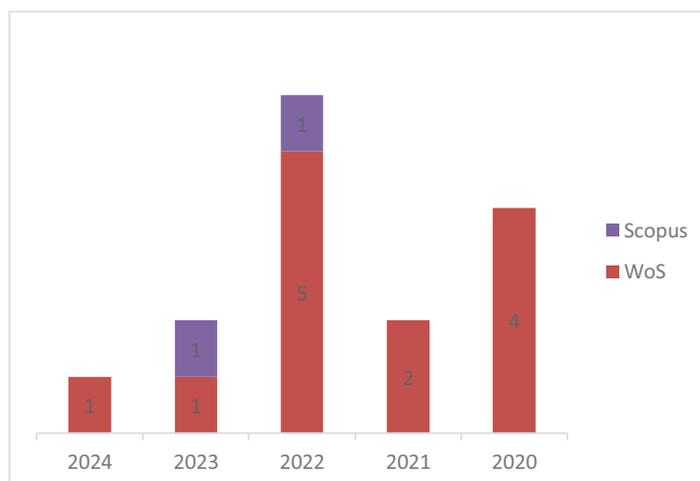
Source: Own elaboration.

Figure 3. Geographic Data

Source: Own elaboration.

3.2. Bibliometric dimension (Question 1)

Fifty-six keywords were identified; however, logical terms were excluded to avoid altering the networks, such as artificial intelligence, primary education, and students, resulting in a total of seven networks (Figure 4).

Figure 4. Secondary clusters

Source: Own elaboration.

The first cluster (red) highlights the importance of technological adoption and AI literacy (Miranda Veiga & Valente de Andrade, 2021; Zhao et al., 2022). Similarly, the second cluster (green) centers on AI literacy from the perspective of technological anxiety, which can hinder the learning experience (Dai et al., 2020). Moreover, the third cluster is related to the use of AI for prediction and for personalized learning. (Pardamean et al. 2022).

Regarding the fewer clusters (Figure 4) (yellow network, from left to right), the creation of an AI-based study plan is notable (Dai et al., 2023). Similarly, the curriculum (violet network) introduces the use of technological resources for curriculum assessment (Huang, 2022). The third network (orange) investigates AI literacy and its relationship to sustainability (Zhao et al., 2022), while the fourth network examines the development of educational resources for learning the fundamental concepts of AI and augmented reality (Masneri et al., 2023). Only one consistent network was detected by VoSViewer: the first network (color red, Figure 5). The regularity of this network stems from technology acceptance and literacy among both the teacher and student bodies (Dai et al., 2020; Huang, 2022; Miranda Veiga & Valente de Andrade, 2021; Shi & Rao, 2022; Zhao et al., 2022).

Figure 5. Main clusters
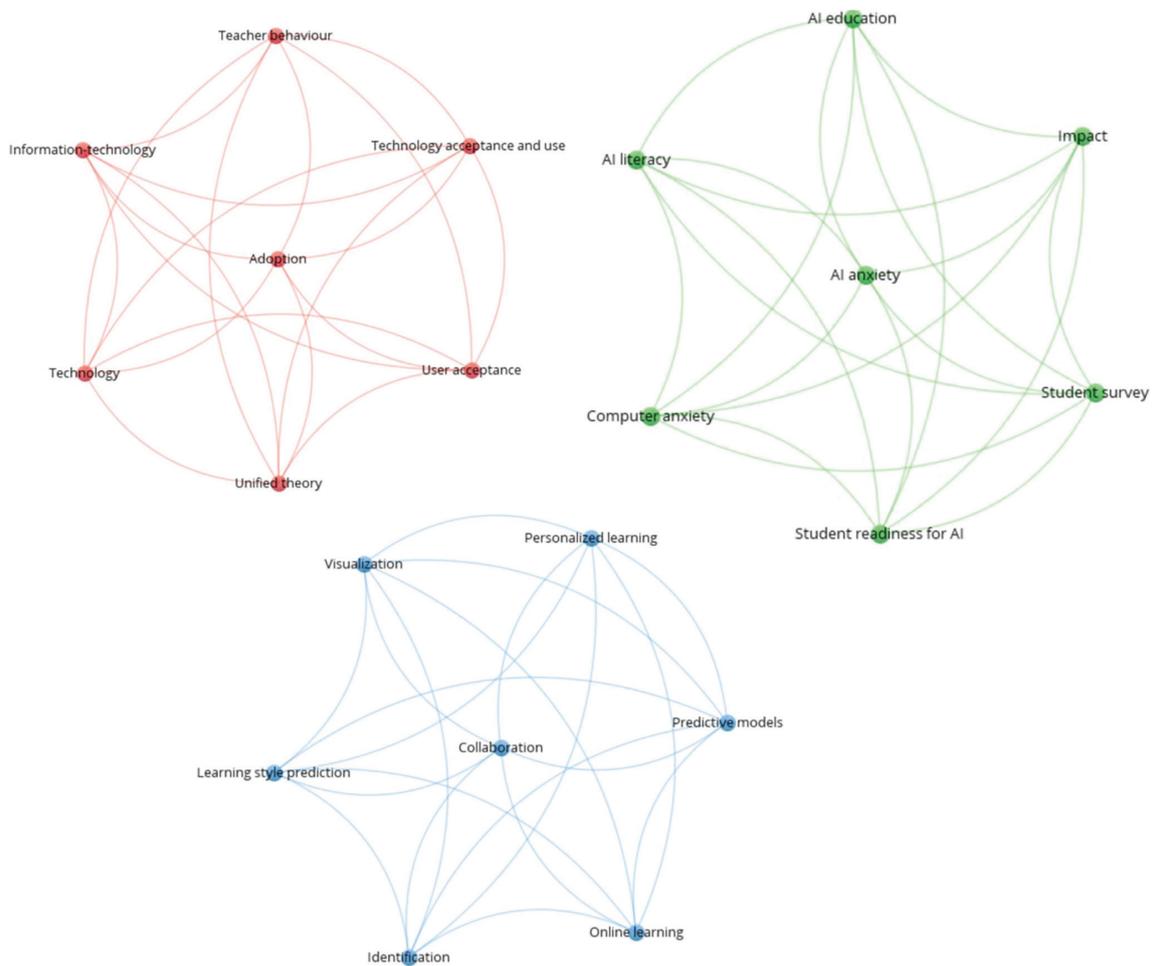
Source: Own elaboration.

3.3. Methodological dimension (Question 2)

The studies (Table 5) lack experimentation; thus, they are insufficient to confirm the pedagogical advantages of introducing AI in primary education. They are primarily descriptive (Dai et al., 2023; Hyun, 2020; Jeon et al., 2020; Masneri et al., 2023; Miranda Veiga & Valente de Andrade, 2021; Pardamean et al., 2022; Shi & Rao, 2022; Sun-Ho et al., 2020; Zhao et al., 2022) and exploratory (Cheng & Wang, 2023; Huang, 2022; Mertala et al., 2022). There is only one explanatory study (Dai et al., 2024), one review (Kim, 2021), and one ethnographic study (Dai et al., 2023).

Table 5. Methodological analysis of 15 studies

Study	Instruments	Main subject
(Dai et al. 2024)	Drawing test Assessment rates Focus group interviews	Understanding of complex AI concepts
(Dai et al. 2023)	Interviews and ethnographic observations	Collaborative curriculum development
(Masneri et al. 2023)	Questionnaire to teachers	Interoperable architecture design
(Cheng & Wang, 2023)	Questionnaire	Digital leadership
(Huang 2022)	Delphi method	Science education
(Pardamean et al. 2022)	Model's performance test. Learning performance Test t	Prediction of learning styles
(Shi & Rao, 2022)	Questionnaire	STEAM teaching system based on a back-propagation neural network model
(Zhao et al., 2022)	Survey	AI Literacy
(Mertala et al., 2022)	Survey	Students' conceptions in relation to AI
(Kim 2021)	Articles published in the South Korea Research Foundation Modeling technique	AI literacy
(Miranda Veiga & Valente de Andrade, 2021)	Model "Unified Theory of Acceptance and Use of Technology" (UTAUT) Questionnaire	AI Literacy
(Sun-Ho et al. 2020)	Surveys	Teaching English through chatbots
(Jeon et al., 2020)	Satisfaction surveys and analysis of teacher needs	AI training program for primary school teachers
(Hyun, 2020)	Survey to teachers	AI Literacy
(Dai et al. 2020)	Questionnaire	Measure students' readiness to learn about AI

3.4. Pedagogical dimension (Question 3)

The analysis of studies on the teaching of AI in primary education reveals several key trends and limitations in the current research. First, the importance of pedagogical approaches and AI literacy is highlighted. A notable example is the study by Dai et al. (2024), which demonstrated that using analogies to teach AI significantly enhances students' understanding compared with conventional methods. However, this study is limited in its representativeness, as it was conducted in a specific region of China, which may reduce the generalizability of the results. Additionally, while data were collected through tests and interviews, a more direct and continuous observation of learning dynamics could have provided a deeper understanding of how students interact with the material and grasp AI concepts.

Another study by Dai et al. (2023) focused on creating an AI curriculum in collaboration with universities and implementing it in a primary school in the metropolitan area of Beijing. Despite these efforts, the study does not assess the effectiveness of the curriculum and fails to analyze students' experiences with it, limiting its scope in terms of educational impact.

With respect to technological development and applications, the work of Masneri et al. (2023) is relevant, as they designed an interoperable architecture for augmented reality applications aimed at teachers. However, the lack of practical application in teaching makes it difficult to evaluate its educational impact. Similarly, Shi and Rao (2022) developed a teaching system with high accuracy in improving student performance, but the study is too brief to provide a thorough pedagogical analysis.

Teacher training and AI literacy are also key areas of research interest. Cheng and Wang (2023) emphasize that digital leadership is essential for successfully integrating AI in primary schools, based on a survey conducted with principals and teachers in Hong Kong. Zhao et al. (2022) emphasized the need to design AI training programs for teachers, highlighting their importance for practical application in classrooms. Studies such as those by Jeon et al. (2020) and Hyun (2020) focus on enhancing AI literacy among teachers through training programs. However, both primarily rely on descriptive analysis and participant opinions, with limited evaluation of training effectiveness.

In terms of student perceptions and understanding of AI, the study by Mertala et al. (2022) explored Finnish children's preconceptions about AI, revealing fascinating insights. However, the generalizability of the results is limited due to the small sample size.

Overall, several studies present everyday observations and limitations. For example, Huang (2022) employed the Delphi method to evaluate AI-based mobile applications in STEM classes; however, the study was more analytical than empirical in nature. Kim (2021) conducted a limited review of AI literacy in South Korean curricula, focusing on the relationship between technological literacy and AI literacy. Miranda Veiga and Valente de Andrade (2021) provide a comprehensive overview of teachers' acceptance of technologies, including AI, highlighting the need for increased investment in technology, training, and educational support. Sun-Ho et al. (2020) analyzed the use of AI chatbots in English-language learning, but their study was primarily descriptive and did not establish causal relationships.

In conclusion, while interest in AI education in primary schools is increasing, more robust empirical research is needed to validate the educational benefits and explore the practical applications of AI in teaching and learning environments. Most current research focuses on teacher training and curriculum design, with fewer studies directly assessing the impact of AI on student learning outcomes.

4. Discussion and conclusions

The objective was to analyze, through a systematic review, studies related to AI in primary education that focused on literacy, curriculum design, and the use of AI-based technology. In addressing the first research question, three possible trends can be identified, despite the low volume of academic production:

- *AI literacy* (Dai et al., 2020; Huang, 2022; Miranda Veiga & Valente de Andrade, 2021; Shi & Rao, 2022; Zhao et al., 2022) is a growing area of interest, which is consistent with recent systematic reviews (Su & Yang, 2022; Su et al., 2023). There is an increasing educational and political focus on training teachers in digital competencies to understand AI concepts and utilize technological tools to develop students' digital skills, critical and computational thinking, ethical education, and algorithmic problem-solving. However, there is a notable lack of guidance on how to effectively integrate AI into early education (Su & Yang, 2022).
- With respect to *curriculum development and the introduction of new technological resources* (Dai et al., 2023, 2024; Huang, 2022; Masneri et al., 2023; Sun-Ho et al., 2020), the limited research to date has not yet determined which content and competencies should be included in primary education curricula in relation to AI. This gap may be due to the cost of technologies, tools, and educational resources, as well as the theoretical and practical knowledge deficit among teachers and administrators concerning the opportunities presented by AI literacy and its relationship with digital and algorithmic skills in students. The few experiments conducted have focused on proposals such as introducing AI concepts, understanding binary numbers and pixels, and exploring automated reasoning related to algorithms (Dai et al., 2023; Lin et al., 2021).
- *Prediction and personalized learning* based on monitored learning models have been less frequently addressed (Bajaj & Sharma, 2018; Pardamean et al., 2022). To achieve this, various learning style indicators and models are used. Although the AI models demonstrate good computational performance, there is a lack of pedagogical experimentation, resulting in a lack of empirical evidence of their educational effectiveness.

In response to the second research question, the scarcity of experimental and mixed-method studies makes it difficult to generalize findings. This may be due to the novelty of AI in primary education, the need for teacher training, and the diverse technical skills and resources required for its implementation. Although exploratory and descriptive studies offer some insights into how AI can be applied in primary education, it is essential to conduct controlled and longitudinal experimental studies to evaluate its impact on learning accurately.

From a pedagogical perspective, as discussed in the third research question, the analysis suggests that AI literacy (for both teachers and students) has the potential to help develop critical and computational thinking, logical reasoning, digital skills, collaborative learning, creativity, and ethical awareness in primary students. However, the current research indicates that the full potential of AI in education has not yet been realized. Future research should focus on refining curriculum designs and developing comprehensive, longitudinal studies to explore the long-term impact of AI literacy on students' cognitive and ethical development.

The lack of pedagogical experience in this field can be attributed to several factors. AI is a relatively new and constantly evolving field, and many educators and education systems are still becoming familiar with its applications and integration into the school curriculum. AI-based teaching requires access to pertinent technologies, resources, and trained teachers, which are not yet universally available. Additionally, primary education systems often prioritize traditional skills, such as reading, writing, and mathematics, which means that AI cannot yet become a priority. The absence of specific professional training programs further limits its application in classrooms.

Despite these challenges, AI literacy is gaining recognition, and pedagogical experiences will likely increase alongside technological advancements. However, current educational experiences related to AI in primary education are scarce. The lack of experimentation, small sample sizes, and insufficient pedagogical analysis limit the generalization of findings and hamper the validity and applicability of results. Thus, this systematic review provides an exploratory overview of the current academic publications. Despite positive perceptions among students and teachers regarding the implementation of AI in the curriculum, it is essential to conduct more in-depth pedagogical analyses to assess its effectiveness.

4.1. Key Messages

Rising interest in AI literacy has led to increasing educational and political support for its incorporation into primary education, despite the scarcity of systematic reviews on the subject. While studies indicate positive perceptions among students, teachers, and administrators regarding the use of AI in primary education, there is a notable lack of empirical evidence validating its pedagogical impact. Current research suffers from methodological gaps, with most studies being descriptive or exploratory, underscoring the need for more rigorous, controlled, and longitudinal studies to evaluate the effectiveness of AI-based educational interventions. There is a pressing need to develop comprehensive AI-centered curricula that encompass basic AI concepts, applications, and the ethical, social, and environmental implications of AI, as efforts in this direction are currently minimal and inconsistent. The effective integration of AI in primary education requires digital leadership and extensive teacher training, with studies suggesting that teachers need both theoretical knowledge and practical skills in AI to incorporate it effectively into their teaching practices. AI-based educational tools, such as robots, programming platforms, and AI-driven learning applications, show potential for enhancing learning experiences; yet, their practical application in classrooms remains limited and under-researched. Furthermore, teaching students about the ethical use of AI and fostering responsible attitudes toward technology are essential, including understanding privacy concerns and the broader societal impact of AI.

4.2. Principal contributions

This systematic review of the literature from 2000 to April 2, 2024, examines studies on AI in primary education using databases such as Web of Science, Scopus, and Dialnet, and applies the PRISMA protocol for rigorous selection and analysis. Key research trends identified include AI literacy, curriculum development, and personalized learning models, with notable geographical contributions from countries such as China and Australia.

One of the primary contributions of this review is the identification of critical gaps in empirical research on AI literacy in primary education. While much of the existing literature explores AI's potential across various educational levels, this study highlights the lack of robust experimental designs specifically tailored to the primary education context. By focusing on this stage, the review sheds light on the unique needs and challenges that educators and students face, particularly in terms of teacher training and the development of age-appropriate AI curricula. Furthermore, the study stresses the importance of integrating AI literacy with broader educational goals, including creativity, ethical reasoning, and problem-solving. The findings provide a foundation for future research aimed at developing and implementing AI-based interventions that can enhance both teaching practices and student outcomes.

Using both qualitative and quantitative analysis methods, including tools such as VoSViewer, this research identifies key networks and clusters within the literature, offering a comprehensive overview of the field. It underscores the need for more empirical research, especially experimental studies, to better evaluate the educational impact of AI in primary settings. The current literature lacks sufficient studies that measure the effectiveness of AI interventions in these environments.

The findings also suggest that collaborative efforts between educators, researchers, policymakers, and technology developers are crucial for creating effective and ethical AI education strategies. These collaborations should address pressing issues such as accessibility, teacher training, and curriculum integration. Additionally, the review proposes future research directions, including the exploration of specific technologies and algorithms used in primary education, as well as expanding the search to other databases to corroborate and enhance the current findings.

4.3. Limitations and lines of research

This study examined the recent scientific literature available in WoS, Scopus, and Dialnet. However, it is recommended to expand the search to other databases such as ERIC, ACM Digital Library, and IEEE Xplore to locate additional studies that could corroborate or expand the findings. One key area for future research is the analysis of technologies and algorithms used in early childhood and primary education, which would help identify emerging trends and inform curriculum development.

Additionally, although expanding the analysis to include specific details about the courses, types of educational institutions, or student characteristics in the 15 studies examined would provide further insights, this was not the primary objective of the systematic review. The study was designed to analyze broader research trends, pedagogical applications, and methodological gaps in the integration of AI in primary education. Many of the selected studies did not provide detailed descriptions of these aspects, making it challenging to extract consistent and comparable data. Furthermore, variations in educational policies, institutional frameworks, and curricular designs across different countries introduce significant heterogeneity, which limits the generalizability of such an analysis. Future studies could address this gap by conducting meta-analyses or comparative research that systematically categorize and evaluate these variables more effectively better to understand their role in AI implementation in primary education.

The integration of artificial intelligence in primary education presents significant opportunities but also notable challenges. While AI literacy is increasingly recognized as a critical skill for future generations, the current state of research reveals gaps, particularly in empirical studies that assess the effectiveness of AI interventions in educational settings. This review highlights the need for more comprehensive research that not only explores AI's theoretical potential but also evaluates its practical application in classrooms. Key issues, such as teacher training, accessibility, and data privacy, must be addressed to ensure equitable and effective implementation of AI. As AI evolves, collaboration among policymakers, educators, and researchers will be essential in developing curricula that foster technical skills, critical thinking, creativity, and ethical awareness. Without adequate teacher training and well-designed curricula, the full benefits of AI in education will remain unrealized.

In future research, it will be essential to conduct action-based studies in classrooms that allow for a practical and concrete evaluation of how AI literacy proposals are implemented and what outcomes they generate, both in pedagogical and ethical terms. These studies would provide valuable insights into the real-world application of AI education, identifying best practices and potential challenges in different learning environments.

In summary, the successful integration of AI in primary education depends on creating a balanced curriculum and equipping educators with the necessary skills and knowledge. The collaboration of educational institutions, policymakers, and AI experts will be critical in ensuring that AI literacy becomes an integral part of primary education, preparing young learners for a future where technology plays an increasingly central role.

Authors' contribution

Odiel Estrada-Molina: Conceptualization, Data curation, Research, Methodology, Supervision, Validation, Visualization, Writing—original draft, Writing—review and editing.
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