Educação, Formação & Tecnologias, volume 13, número 1, 2025, 25-57
DOI:10.5281/zenodo.16741188

Artificial Intelligence in Basic Education: A Bibliometric Analysis of Publications from 2022 to 2024

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Abstract: Artificial Intelligence (AI), a branch of computer science, allows systems to simulate typical human tasks. Its application has impacted educational, economic, and health areas, among others. In education, the use of AI presents risks and benefits, requiring critical reflection to promote knowledge and citizenship skills. This study aimed to conduct a bibliometric analysis on the application of AI in basic education. Publications from 2022 to 2024 were analyzed, verifying frequency, main authors, keywords, and institutions, identifying patterns and gaps in scientific production. The search was conducted in the Scopus database and CAPES journal portal, applying inclusion and exclusion criteria. The articles were categorized into four thematic axes: (1) Management, Pedagogy, and Curriculum; (2) Challenges and Ethical Implications; (3) Teacher Training and Perception; and (4) AI Tools and Teaching Processes. As a result of the 62 selected articles, a wide geographic distribution (35 countries), number of authors (223) and cited references (3448) were identified, in addition to an increase in publications after 2022. According to the categories, it was found that 70% of the publications emphasize the importance of teacher training to effectively incorporate AI. The analysis also revealed that its use is still incipient and with obstacles such as lack of infrastructure, connectivity and teacher training. It is concluded that its integration into the school context must occur from an ethical perspective, as a sociocultural artifact that promotes autonomy, critical thinking and citizenship.

Keywords*:* artificial intelligence, basic education, teacher training, bibliometric analysis.

Resumo: A Inteligência Artificial (IA), campo da ciência da computação, permite que sistemas simulem tarefas tipicamente humanas, sua aplicação tem impactado áreas educacionais, econômicas, de saúde, entre outras. Na educação, o uso da IA apresenta riscos e benefícios, exigindo reflexão crítica para promover conhecimento e competências cidadãs. Este estudo teve como objetivo realizar uma análise bibliométrica sobre a aplicação da IA na educação básica. Foram analisadas publicações de 2022 a 2024, verificando frequência, principais autores, palavras-chave e instituições, identificando padrões e lacunas na produção científica. A consulta foi realizada na base de dados *Scopus* e no portal de periódicos da CAPES, aplicando-se critérios de inclusão e exclusão. Os artigos foram categorizados em quatro eixos temáticos: (1) Gestão, Pedagogia e Currículo; (2) Desafios e Implicações Éticas; (3) Formação e Percepção de Professores; e (4) Ferramentas de IA e Processos de Ensino. Como resultado dos 62 artigos selecionados, identificou-se ampla distribuição geográfica (35 países), quantidade de autores (223) e de referências citadas (3448), além do aumento de publicações após 2022. Conforme as categorias, verificou-se que 70% das publicações enfatizam a importância da formação docente para incorporar eficazmente a IA, a análise também revelou o uso ainda incipiente e com entraves como as carências de infraestrutura, conectividade e de formação docente. Conclui-se que sua integração ao contexto escolar deve ocorrer sob uma perspectiva ética, como artefato sociocultural que promova autonomia, criticidade e cidadania.

Palavras-chave: inteligência artificial, educação básica, formação docente, análise bibliométrica.

Resumen: La Inteligencia Artificial (IA), una rama de la informática, permite que los sistemas simulen tareas típicamente humanas. Su aplicación ha impactado áreas como la educación, la economía y la salud, entre otras. En el ámbito educativo, el uso de la IA presenta riesgos y beneficios, requiriendo una reflexión crítica para promover el conocimiento y las habilidades de ciudadanía. Este estudio tuvo como objetivo realizar un análisis bibliométrico sobre la aplicación de la IA en la educación básica. Se analizaron publicaciones de 2022 a 2024, verificando la frecuencia, los principales autores, palabras clave e instituciones, identificando patrones y brechas en la producción científica. La búsqueda se realizó en la base de datos

Scopus y en el portal de revistas CAPES, aplicando criterios de inclusión y exclusión. Los artículos se categorizaron en cuatro ejes temáticos: (1) Gestión, Pedagogía y Currículo; (2) Desafíos e Implicaciones Éticas; (3) Formación y Percepción Docente; y (4) Herramientas de IA y Procesos de Enseñanza. Como resultado de los 62 artículos seleccionados, se identificó una amplia distribución geográfica (35 países), número de autores (223) y referencias citadas (3448), además de un aumento en las publicaciones después de 2022. Según las categorías, se constató que el 70 % de las publicaciones enfatizan la importancia de la formación docente para incorporar eficazmente la IA. El análisis también reveló que su uso sigue siendo incipiente y con obstáculos como la falta de infraestructura, conectividad y formación docente. Se concluye que su integración en el contexto escolar debe ocurrir desde una perspectiva ética, como un artefacto sociocultural que promueva la autonomía, el pensamiento crítico y la ciudadanía.

Palabras clave: inteligencia artificial, educación básica, formación docente, análisis bibliométrico.

1. Introduction

Artificial Intelligence (AI) is a field of computer science that emerged in the 1950s. Researchers such as Alan Turing, Ada Lovelace, John McCarthy, and Marvin Minsky were foundational to the establishment of the field. It has now evolved significantly, allowing systems to perform tasks autonomously. AI encompasses a range of sub-disciplines, including machine learning (ML), artificial neural networks, and natural language processing (NLP), which enable simulation, pattern recognition, and interpretation of large volumes of data (Alves, 2023; Forero-Corba & Bennasar, 2023).

In general terms, AI can be defined as the ability to develop computer systems and applications capable of simulating abilities inherent to human intellect, such as reasoning, learning, perception, and decision-making (Santaella, 2024). These technologies enable innovations such as virtual assistants, games, robotics, autonomous vehicles, AI-assisted medical diagnoses, and recommendation systems (Alves, 2023). The number of software that incorporates intelligent features increased in 2022 and 2023 (Peñalvo, Llorens-Largo & Vidal 2023).

The popularization of digital and intelligent technologies, driven by the Internet, has brought benefits and impacts to areas such as the economy, health, business, science, and, especially, education (Alves, 2023). The

spread of mobile devices and social media has intensified online interactions, accelerating during and after the COVID-19 pandemic, globalizing AI (Santos, 2023).

Since 2017, a true revolution has taken place with the emergence of Large Language Models (LLMs). The publication of the paper *"Attention Is All You Need"* by Ashish Vaswani and collaborators marked the introduction of the Transformer model, which significantly advanced NLP. This model enabled large-scale training with parallelization, a crucial feature for NLP tasks, allowing the generation of coherent text by analyzing not only individual words but also their surrounding context. Additionally, it provided a user-friendly interface with rapid response times. In this context, the launch of ChatGPT in late 2022 popularized AI technologies on a massive scale (Li & Ye, 2023).

Due to the increased familiarity with digital devices, we have started using them for communication, relationships, entertainment, shopping, learning, teaching, and information search (Santaella, 2024). However, education lacks provocative dialogue with technological innovations, aiming to align itself with pedagogical practices that consider not only the approaches of use, but also the underlying ideological, reflective, and cognitive objectives, with an impact on the construction of knowledge and the development of skills for citizenship in the 21st century (Heinsfeld & Pischetola, 2019).

Despite the growing demand for digital skills in education, these technologies are inserted slowly, punctually, and heterogeneously. The literature points to potential in the adoption of personalized learning tools, virtual tutors, adaptive assessment systems, augmented reality, gamification, and other innovations. When used beyond reproducing obsolete methods, they not only break down geographical barriers and generate accessibility but also create opportunities to improve sociocultural issues and enhance teaching and learning relationships (Benvenuti et al. 2023; Heinsfeld & Pischetola, 2019).

A new conception of language and culture is introduced by AI, demanding a holistic praxis to promote effective interaction among teachers, students, and technology, enabling autonomous learning (Domeneghini, 2022). The educational process, being complex, cannot be reduced to content transmission, as information is not knowledge. Thus, when using technologies, the teacher becomes essential in problematizing issues and collaboratively constructing knowledge (Lima et al., 2024).

Regarding the limitations of AI in education, a major challenge lies in the inability of current technologies to interpret students' social, emotional, and cultural contexts — essential aspects of basic schooling. The AI in Education

Framework, as cited by Luckin and Holmes (2016), emphasizes that effective AI implementation requires integrated models encompassing not only disciplinary content and pedagogical strategies, but also learner characteristics, such as motivation and emotions. However, these models remain underdeveloped and fail to account for the diversity and unpredictability of real classroom dynamics. Furthermore, ethical risks arise from the collection and use of sensitive children's data, including concerns about the inappropriate replacement of human-led activities with automated systems, which could diminish the teacher's active role. Consequently, these limitations call for caution, ethical regulation, investment, and the active involvement of educators in both the design and implementation processes — particularly in basic education, as it shapes the development of future citizens.

It is important to note that the mere presence of digital technologies in schools does not improve education. This technocratic and uncritical view that places modernity as synonymous with quality is not true. It is essential that AI is not restricted to technical training for work; it must be considered in education with a political and emancipatory character, to form critical, creative and conscious citizens (Kaufman, 2022). Having technological tools is important, but the crux of the matter is: how to use them? If used from a sociocultural perspective, they can offer new strategies, possibilities for personalized experiences and expanding interactions in a collaborative way (Alves, 2023; Heinsfeld & Pischetola, 2019).

2. Methodology

This exploratory and descriptive research used the bibliometric analysis methodology, an essential tool for conducting systematic literature reviews, allowing the integration of quantitative data with a qualitative interpretation (Lim & Kumar, 2024).

The systematic review was conducted carefully, aiming to identify the main studies on the topic through rigorously structured strategies, followed by a detailed evaluation of them (Galvão & Pereira, 2014).

In this context, bibliometric analysis stands out for enabling a comprehensive understanding of the research scenario in each area of knowledge, revealing advances, weaknesses, and gaps (Galvão & Pereira, 2014; Lim & Kumar, 2024). Thus, it is possible to organize, reflect, and analyze the research developed around AI in education, enriching the discussion and expanding the understanding of this emerging theme.

2.1. Search strategy

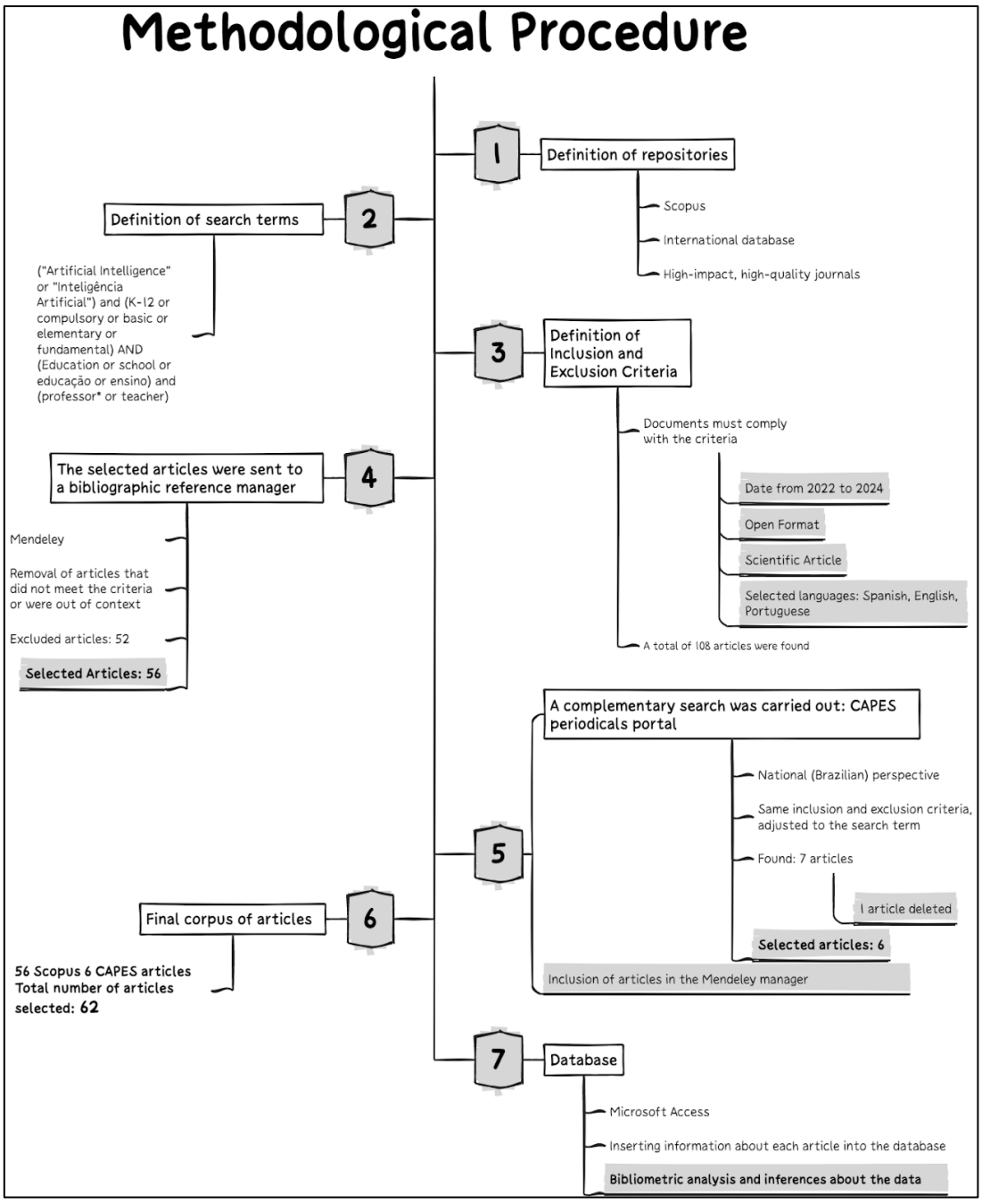
The searches were conducted in two scientific databases that bring together a wide variety of articles, scientific journals and other relevant resources. The preference for these databases was based on the high quality of both: *Scopus* was selected for its international scope and for including high-impact journals, with approximately 227 million records (Elsevier, 2023). *The Journal Portal of the Coordination for the Improvement of Higher Education Personnel* (CAPES) contributed with a national perspective, providing a broader and more contextualized view of the researched topic.

In the selection process, the following were considered: inclusion criteria (date filter, language, access and others), exclusion criteria and information sources (Scopus and CAPES). Thus, it was possible to situate the topic within the academic field, avoid repetitions, identify gaps, define objectives and contribute to the advancement of knowledge in the field of AI for education (Morosini, Kohls-Santos & Bittencourt, 2021).

Figure 1 presents a summary of the methodological procedures used for bibliometric analysis. The process began with the selection of scientific databases for research, establishment of criteria and organization of information from selected articles. This flowchart provides methodological transparency and allows the process to be replicated.

Figure 1

Summary of methodological procedures



Source. Prepared by the authors.

Initially, the search terms were defined and filters applied in the Scopus database, resulting in the identification of 108 articles indexed in the period from 2022 to 2024. This period was established due to the popularization of this technology, due to the launch of ChatGPT, which encouraged the emergence of new tools and the debate around the risks, challenges and

potential of these innovations (Santaella, 2024; Forero-Corba & Bennasar, 2023). The search and analysis of the data were conducted manually in Scopus between October 2 and 31, 2024.

To better understand the scientific production on the topic, the searches were expanded, given that the initial search did not include articles in Portuguese, only in English and Spanish. Therefore, as a supplementary form, a consultation was conducted on the CAPES journals portal, which generated a more representative collection of Brazilian academic production. The search and analysis took place from October 15 to 31, 2024, generating 7 articles indexed between 2022 and 2024, thus allowing a more precise analysis of the scientific contributions published in Portuguese.

2.2. Methodological Procedures

The systematic review to produce the bibliometric survey was subdivided into stages as described below. This survey focused on the most recent research on AI in educational contexts, through analysis of articles published between the established period.

— Step 1: Specification of search terms for database queries

The research is restricted to publications obtained exclusively from the selected scientific databases. Regarding the inclusion criteria, the search was conducted using the terms: Artificial Intelligence, Elementary Education, Education and Teacher. Considering that each database has its own specificities, the search expression was customized for each one without altering the fundamental terms. The expression used was the following:

("Artificial Intelligence" or "Inteligência Artificial") and (K-12 or compulsory or basic or elementary or fundamental) AND (Education or school or educação or ensino) and (professor* or teacher)

— Step 2: Consulting scientific databases

After creating the search expression, inclusion and exclusion criteria were defined to select the most relevant works. Inclusion criteria prioritized unrestricted access articles in the final stages of publication, guaranteeing immediate access, and in English, Spanish, and Portuguese. The exclusion criteria eliminated texts published before 2022 and after October 2024 that pertained to health, business, or other unrelated fields, as well as studies focused on higher education, to concentrate on AI within the context of basic education.

— Step 3: Exporting the retrieved records to Mendeley

The results of the searches in Scopus and CAPES resulted in a total of 115 articles, which were imported into the Mendeley bibliographic reference manager. This tool facilitates the organization and storage of references, as well as the generation of citations and bibliographies. The import of data made it possible to create a single set of documents, bringing together the main bibliometric information, such as title, authors, year of publication and place of dissemination, among other elements for academic analysis.

— Step 4: Implementation of pre-established criteria for the selection of works

In addition to the filters and criteria configured in the scientific databases, the scope of the articles will be systematically organized and systematized on the Mendeley platform, with the application of additional criteria for screening the studies. Articles without author identification, duplicates, publications that do not address the use of AI in basic education, as well as those that are not available for full and free access were excluded.

— Step 5: Categorization of articles into thematic axes

The articles were categorized into four thematic axes, as proposed by Bula and Bonilla (2024): (1) Management, Pedagogy and Curriculum; (2) Challenges and Ethical Implications in the Use of AI; (3) Teacher Training and Perception; and (4) AI Tools and Teaching Processes. Each axis was defined based on the themes explored in the publications, enabling a structured investigation. The analysis of the titles, abstracts and keywords of the articles facilitated the classification into the thematic axes. This approach allowed organizing the material so that each article contributed to a broad understanding of the topic.

— Step 6: Standardization of data from different databases

Due to the use of two databases with differing formatting criteria, it was necessary to standardize the data to ensure consistency in the analysis. To ensure reliability and accuracy, the information was organized within a structured database.

Microsoft Access software was used to characterize the set of articles analyzed, creating a database that facilitated the manipulation, organization, analysis and reporting of bibliometric data in an objective manner from tables generated according to previously established criteria. In Microsoft Access, general information for each article was filled in, such as title, authors, language, year, name of the journal, abstract, keywords and references. At this stage, the geolocation of the institutions to which the authors are linked was included.

Regarding the references, the NotebookLM tool, a Google note-taking and research assistant, was used to assist the conversion of the references of the articles analyzed into structured data. For each document in PDF format, a prompt was created containing the command: In references to the selected article, create a table containing the first author's surname, the abbreviated name with the initial letters, year and title of the publication. Finally, the results generated by NotebookLM were manually reviewed and compared to the original records. This independent review process aimed to minimize potential standardization errors and ensure methodological consistency. Following these adjustments, the references were incorporated into the database created in Microsoft Access.

— Step 7: Data analysis

Following data standardization, frequencies were calculated, facilitating bibliometric analyses. These analyses encompassed the number of publications per year, types and sources of publication, authors, institutions, and their respective countries, with the aim of identifying key researchers and research groups in the studied area. Additionally, keywords, covered topics, and the most cited references were examined to identify the principal theoretical frameworks addressing the theme.

— Step 8: Overview of main works

Based on the articles retrieved from the databases, the most frequently cited references in AI education research were identified. The three most cited works within the selected studies were analyzed and comprehensively summarized.

— Step 9: Compilation of the final document

Upon completion of all stages, the research was contextualized, described, and analyzed, and subsequently organized into a scientific article. The analyses and discussions of the results obtained from the aforementioned stages are presented below.

3. Results

This section presents the results of the analyses and summaries of the information selected from research conducted in the scientific databases: Scopus and CAPES.

Out of the 108 articles identified in Scopus, 52 were excluded for not meeting the inclusion criteria defined in this research. Consequently, 56 articles remained, which, when combined with 6 articles from CAPES, constitute the 62 articles that form the corpus of analysis.

The methodological procedure enabled the selection of relevant articles on the use of AI in education, which are listed in the references of this work. The breadth of the bibliography referenced ensures the currentness and relevance of the evidence analyzed, and the rigorous application of the specifications guaranteed a corpus aligned with the research objectives, enabling a well-founded review of the topic.

As an initial step, a quantitative analysis is presented to highlight information regarding the academic production compiled in this review. This quantitative approach enables the identification of patterns and trends in the distribution of articles. Table 1 summarizes the data from the research corpus, including the total number of articles, authors, institutions, and countries. These data provide a comprehensive overview of the breadth and diversity of the publications analyzed, underscoring the collaborative nature of the research.

Table 1

Quantitative data synthesis regarding the research corpus

Variable	Amount
Articles that have been selected	62
Authors of the articles	223
General *corpus* of references used by authors	3448
Single references cited	2578
Countries of the institutions to which the authors are affiliated	35
Institutions to which the authors of the publications are affiliated	104
Publication locations	45
Keywords	187

Source. Prepared by the authors.

The analyzed articles span from 2022 to 2024, reflecting an increase in the number of publications over these years, particularly from 2023 onwards, as illustrated as indicated in Table 2. According to Pinto (2024), bibliometric data on AI in education in Brazil indicate that the first publication appeared in 2007, followed by a hiatus until 2015, with a subsequent surge in research beginning in 2022.

Corroborating Pinto (2004), Santaella (2024) states that the expansion of the debate on AI technologies can be attributed to the popularization with the launch of ChatGPT at the end of 2022, which is a chatbot based on language

models, offering free versions, with an intuitive and user-friendly interface, which facilitated its adoption in various environments, including the educational one. With widespread adoption, after one week of launch, the platform surpassed one million users and currently has more than 200 million users (Santaella, 2024).

Table 2

Compilation of Selected Articles for Bibliometric Analysis

Title	Publication language	Year
The Effectiveness of Teacher Support for Students' Learning of Artificial Intelligence Popular Science Activities	English	2022
Needs and requirements for an additional AI qualification during dual vocational training: Results from studies of apprentices and teachers	English	2022
Teachers' Perceptions of Teaching Sustainable Artificial Intelligence	English	2022
Teachers' Perspective on Artificial Intelligence Education	English	2022
Teachers' readiness and intention to teach artificial intelligence in schools	English	2022
Teachers' trust in AI- powered educational technology and a professional development program to improve it	English	2022
The Attitudes of K–12 Schools' Teachers in Serbia towards the Potential of Artificial Intelligence	English	2022
The Turing Teacher: Identifying core attributes for AI learning in K-12	English	2022
Designing for human–AI complementarity in K-12 education	English	2022
A systematic review of teaching and learning machine learning in K-12 education	English	2022
Collaborative construction of artificial intelligence curriculumin primary schools	English	2023
Promoting AI Education for Rural Middle Grades Students with Digital Game Design	English	2023
Exploring the AI competencies of elementary school teachers in South Korea	English	2023
Negotiation of Epistemological Understandings and Teaching Practices Between Primary Teachers and Scientists about Artificial Intelligence in Professional Development	English	2023
Ethical principles for artificial intelligence in K-12 education	English	2023
Embracing Computational Thinking as an Impetus for Artificial Intelligence in Integrated STEM Disciplines through Engineering and Technology Education	English	2023
Educational Technology in the Post-Pandemic Era	English	2023
Education and Awareness for Artificial Intelligence	English	2023
Leading digital transformation and eliminating barriers for teachers to incorporate artificial intelligence in basic education in Hong Kong	English	2023

Lessons Learned From Teaching Artificial Intelligence to Middle School Students	English	2023
Modeling English teachers' behavioral intention to use artificial intelligence in middle schools	English	2023
Co-creating digital art with generative AI in K-9 education: Socio-material insights	English	2023
The Influence of ChatGPT on the Professional Development of Elementary Education Teachers and Its Countermeasures	English	2023
Personalization in Australian K-12 classrooms	English	2023
Investigating pre-service teachers' artificial intelligence perception from the perspective of planned behavior theory	English	2023
AI + Ethics Curricula for Middle School Youth	English	2023
AI and ML in School Level Computing Education	English	2023
AI Curriculum for European High Schools	English	2023
Artificial intelligence and human behavioral development	English	2023
Advancing AI education	English	2024
Developing Standards for Educational Datasets by School Level	English	2024
An Effectiveness Study of Teacher-Led AI Literacy Curriculum in K-12 Classrooms	English	2024
Artificial Intelligence in Education: Mathematics Teachers' Perspectives, Practices and Challenges	English	2024
Co-creation in action	English	2024
Artificial Intelligence in K-12 Education	English	2024
Artificial Intelligence from Teachers' Perspectives and Understanding	English	2024
Attitudes towards and expectations on the role of artificial intelligence in the classroom among digitally skilled Finnish K-12 mathematics teachers	English	2024
Artificial Intelligence in Compulsory K-12 Computer Science Classrooms	English	2024
Artificial intelligence in compulsory level of education	English	2024
Development of Artificial Intelligence education Programs Centered on Deep Learning Principles	English	2024
Creativity and artificial intelligence: A study with prospective teachers	English	2024
Teacher Opinions on the Role of Educational Robots in Enhancing Programming Skills among Hearing-Impaired Students	English	2024
Using ChatGPT for Science Learning: A Study on Pre-service Teachers' Lesson Planning	English	2024
Use of Virtual Reality as an Educational Tool: A Comparison Between Engineering Students and Teachers	English	2024
The Application of Artificial Intelligence in Education – The Current State and Trends	English	2024
Teachers' and students' perceptions of AI-generated concept explanations	English	2024

Dr. R.O. Bott Will See You Now: Exploring AI for Wellbeing with Middle School Students	English	2024
Pedagogical agents communicating and scaffolding students' learning	English	2024
Korean in-Service Teachers' Perceptions of Implementing Artificial Intelligence (AI) Education for Teaching in Schools and Their AI Teacher Training Programs	English	2024
Investigating the moderating effects of social good and confidence on teachers' intention to prepare school students for artificial intelligence education	English	2024
ImageSTEAM: Teacher Professional Development for Integrating Visual Computing into Middle School Lessons	English	2024
A systematic review of learning task design for K-12 AI education	English	2024
Exploring the future of learning and the relationship between human intelligence and AI. Na interview with Professor Rose Luckin	English	2024
Empirical Research on AI Technology-Supported Precision Teaching in High School Science Subjects	English	2024
Incidencias de la inteligencia artificial en la educación contemporánea	Spanish	2023
Role of artificial intelligence in education: Perspectives of Peruvian basic education teachers	Spanish	2024
Educação híbrida e cultura digital: reflexões sobre docência, aprendizagem e tecnologias na contemporaneidade	Portuguese	2023
Roteiro para a integração da inteligência artificial em experiências de ensino	Portuguese	2023
Aprendizagem ativa: experiências e pesquisas com metodologias ativas	Portuguese	2023
Educação e Chatbots: aprendência e movimentos rizomáticos em tempos de web 4.0	Portuguese	2023
A influência das TIC na construção da criticidade discente: reflexões em contexto de ia	Portuguese	2024
Contributos do GeoGebra para exploração do Pensamento Computacional no contexto da Geometria	Portuguese	2024

Source. Prepared by the authors.

Studies by Velander et al. (2023) indicate a significant increase in publications on AI in education over the past four years, reflecting growing academic interest and expansion in the field. The research highlights discussions on technologies that, in addition to computational thinking, address ethics, social impacts, and AI literacy. Moreover, Peñalvo, Llorens-Largo, and Vidal (2023) reported that 84% of articles in this domain were concentrated in 2023, with a subsequent growth of 45.1% observed in 2024.

The most frequent publication outlets are as follows: Computers and Education: Artificial Intelligence, with 7 articles (15%) – a UK journal with international coverage; Education and Information Technologies, with 5 articles (11%) – a journal published by Springer on technologies, communication and education; The Thirty-Eighth AAAI Conference on

Artificial Intelligence, with 3 articles (6%) – a conference linked to the North American academic community; and Sustainability, with 3 articles (6%) – a multidisciplinary journal with global participation.

Concerning the research methodologies employed in the papers, mixed-method approaches predominate (43%), followed by qualitative methodologies (40%). This reflects the complexity of studying AI in education and the necessity of triangulating data to capture impacts and perceptions across diverse contexts. In this context, Aires (2011) asserts that qualitative analysis from a multi-method and interpretative perspective is essential for addressing educational complexity. This is further supported by Pinto (2024), who notes that all the research analyzed in his bibliometric study emphasizes qualitative and descriptive approaches, with the primary aim of understanding and explaining social phenomena.

In the Scopus database, filters were applied for publications in English, Spanish, and Portuguese. English was the predominant language, accounting for over 96% of the analyzed publications, thus reaffirming its status as the dominant academic language for disseminating global research on AI in education. The articles in Portuguese were identified through a complementary search conducted on the CAPES journal portal.

There was extensive geographic diversity, with contributions from 35 countries, each providing at least one article. Data from the authors' affiliated institutions enabled the generation of a map (Figure 2) illustrating the geographic distribution of AI research in education. The red dots on the map indicate the regions of the institutions with publications included in this study, with larger red circles representing higher research productivity. Accordingly, a greater concentration is observed in North America.

Figure 2

World map with the main research locations of this study

Source. Created by the authors with GPSVisualizer.

Numerous studies have resulted from collaborations between universities across various countries, demonstrating a global interest in the subject. The United States, however, emerged as the primary center of scientific production, accounting for more than 16% of the identified publications. This finding aligns with Mahon, Becker, and Namee's (2023) observation of the predominance of AI research in K-12 education in the U.S. Besides the United States, significant contributions also came from China and Finland (Table 2), which lead in terms of the number of articles, institutions, and authors. Among institutions, the most prolific were the Massachusetts Institute of Technology (MIT) with 13 contributions, the University of Eastern Finland with 10, and the Chinese University of Hong Kong with 7.

With respect to Brazil and scientific production in Portuguese, the six articles selected by CAPES were produced by the following institutions: Universidade Federal de São Carlos, Universidade Católica de São Paulo (PUC-SP), Universidade de Caxias do Sul, Universidade Nove de Julho (UNINOVE), Universidad Interamericana and Universidade Estadual do Oeste do Paraná (UNIOESTE).

Table 3 summarizes the number of authors and institutions by country, revealing the geographic distribution of publications on AI in basic education. These data illustrate the main centers of scientific production (United States, Finland and China), reinforcing the relevance of these countries in the area of study.

Table 3

Number of authors and institutions by country

Country	Authors	Institutions	Country	Authors	Institutions
United States	46	15	Colombia	3	2
China	27	12	Ireland	3	1
Finland	15	7	Israel	3	1
Brazil	14	6	Saudi Arabia	2	2
South Korea	11	4	United Arab Emirates	2	2
Spain	9	3	Kenya	2	2
Peru	9	3	Nigeria	2	2
Germany	8	3	Taiwan	2	1
Italy	8	2	South Africa	1	1
Australia	7	4	Hungary	1	1
Canada	7	3	Indonesia	1	1
United Kingdom	6	5	Jordan	1	1
Ecuador	5	3	Lebanon	1	1
Morocco	5	1	North Macedonia	1	1
Austria	4	4	Oman	1	1
Romania	4	3	Paraguay	1	1
Serbia	4	2	Singapore	1	1
Sweden	4	2			

Source. Prepared by the authors.

A total of 187 distinct keywords were identified, with 'Artificial Intelligence' appearing in 41 publications, followed by 'Education' in 10, 'K-12' in 9, 'Teachers' in 7, 'Professional Development' in 6, 'AI Education' in 6, and 'Teachers Education' in 6. The diversity of keywords underscores the interdisciplinary nature of the field and indicates that the research is still evolving, with no consolidated terminology. Additionally, the prevalence of terms such as 'teachers' and 'professional development' highlights the authors' focus on training educators to integrate AI into the educational context. Figure 3 presents a word cloud highlighting the most frequent terms; notably, 'Artificial Intelligence' was removed to balance the image, as it constitutes more than 66% of the keyword occurrences.

Figure 3

Visual representation of keyword distribution

Source. Created by the authors using WordArt.

To assess the prominence of key authors, an analysis of the frequency of their contributions was performed. Table 4 highlights the most prolific authors, including Sanusi, Ayanwale, and Oyelere, whose research has significantly impacted the field of AI in education.

Table 4

Key authors of selected studies

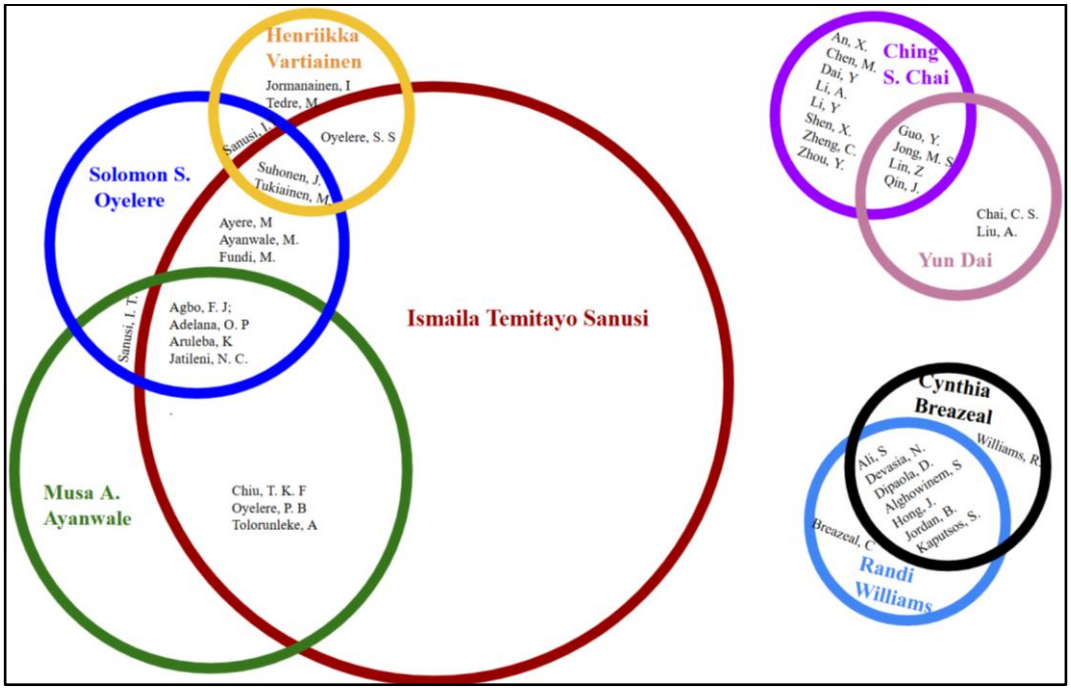
Authors	Articles	Institutions to which the authors are linked
Ismaila Temitayo Sanusi	6	University of Eastern Finland
Musa Adekunle Ayanwale	4	University of Johannesburg
Solomon Sunday Oyelere	3	Luleå University of Technology
Ching Sing Chai	2	Chinese University of Hong Kong
Cynthia Breazeal	2	Massachusetts Institute of Technology (MIT)
Henriikka Vartiainen	2	University of Eastern Finland
Randi Williams	2	Massachusetts Institute of Technology (MIT)
Yun Dai	2	Chinese University of Hong Kong

Source. Prepared by the authors.

Co-authorships among these researchers were also verified, revealing a consolidated collaborative network that drives scientific production and the dissemination of knowledge about AI in education (Figure 4). Furthermore, when comparing the total number of selected articles (62) with the number of authors (223), the predominance of co-authored publications is evident, with 93% of the works involving two or more authors; only 4 articles were published without co-authorship. This indicates that most of these studies are developed through collaboration.

Figure 4

Set of authors and co-authors, forming the collaboration network



Source. Prepared by the authors.

Among the 62 selected studies, the most frequently referenced article is the research by Ayanwale et al. (2022), titled 'Teachers' Readiness and Intention to Teach Artificial Intelligence in Schools,' which was cited in six other articles. This study identifies professional development for teachers as a crucial factor in AI education. Another frequently cited article is that of Wu and Yang (2022), 'The Effectiveness of Teacher Support for Students' Learning of Artificial Intelligence Popular Science Activities,' referenced in four other articles. This study examined the effectiveness of AI science activities in informal curricula, analyzing the relationship between students' cognitive outcomes in these popular AI activities, with and without teacher support, achieving better results when teachers functioned as mediators.

The references cited in the selected articles showed recurrence, highlighting the relevance of certain works within the context of this research, as detailed in Table 5.

Table 5

Frequently cited references

Title of referenced article	Author	Amount
Envisioning AI for K-12: What should every child know about AI?	Touretzky	17
Sustainable Curriculum Planning for Artificial Intelligence Education: A Self-determination Theory Perspective	Chiu	14
What is AI literacy? Competencies and design considerations	Long	13
Engaging teachers to Co-design integrated AI curriculum for K-12 classrooms	Lin	12
A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)	Hair	11
Promoting students' well-being by developing their readiness for the artificial intelligence age	Dai	8
Preparing high school teachers to integrate AI methods into STEM classrooms	Lee	8
Perceptions of and Behavioral Intention towards learning Artificial Intelligence in primary school students	Chai	8
Exploring teachers' preconceptions of teaching machine learning in high school: A preliminary insight from Africa	Sanusi	8
Perceived usefulness, perceived ease of use, and user acceptance of information technology	Davis	7
Designing AI Learning Experiences for K-12: Emerging Works, Future Opportunities and a Design Framework	Zhou	7

Source. Prepared by the authors.

Among the 3,448 references analyzed, three works stood out: Envisioning AI for K-12 (Touretzky et al. 2019), Sustainable Curriculum Planning for AI Education (Chiu & Chai, 2020), and What is AI Literacy? (Long & Magerko, 2020). These works constitute the theoretical basis for discussions on AI in education, providing relevant perspectives.

— Touretzky et al. (2019) propose educational guidelines to empower citizens by teaching concepts and offering practices with AI tools. Organized into themes and adapted by age group, the proposal addresses everything from computational perception to social and ethical impacts, highlighting transparency and justice in systems.

— Chiu and Chai (2020) emphasize the strategic inclusion of AI in the curriculum, with autonomy and self-directed learning as pillars. They

advocate a flexible curriculum, updated periodically, supported by professional development networks, considering the teacher as a facilitator and their perceptions essential for the effectiveness of implementation.

— Long and Magerko (2020) define AI literacy as the ability to evaluate, communicate, and use AI critically and collaboratively. The research highlights fundamental concepts and proposes student-centered education, emphasizing the need for empirical research to clarify teaching concepts and practices for non-technical audiences.

A relevant aspect identified in this survey is the extensive variety of bibliographic references used (2578), underscoring the scientific rigor and theoretical robustness of the research. Among the references in the selected articles, the guidelines of the United Nations Educational, Scientific and Cultural Organization (UNESCO) were cited sixteen times, while those of the Organization for Economic Cooperation and Development (OECD) were referenced in ten articles.

Classic authors in the area were also referenced, such as Seymour Papert (6 citations), Mitchel Resnick (5) and Neil Selwyn (4). However, it was observed that the predominant references were publications with contemporary authors. Table 6 consolidates the references with the main authors, number of works cited, respective institutional affiliations and country of origin.

Table 6

Authors with the highest number of referenced articles in this section

Authors	Total	Authors' institutions
Ismaila Temitayo Sanusi	45	University of Eastern Finland
Daniel Touretzky	31	Carnegie Mellon University
Ching Sing Chai	25	Chinese University of Hong Kong
Joseph F. Hair Jr.	25	University of South Alabama
Thomas Kin-Fung Chiu	25	Chinese University of Hong Kong
Irene Lee	22	Massachusetts Institute of Technology (MIT)
Musa Adekunle Ayanwale	17	University of Johannesburg
Phoebe Lin	17	Chan Zuckerberg Initiative
Annabel Lindner	15	Universidade de Erlangen
Duri Long	15	Instituto de Tecnologia da Geórgia

Source. Prepared by the authors.

According to the categories proposed by Bula and Bonilla (2024), the selected articles were classified and summarized (table 7) in the following axes: (1) Management, Pedagogy, and Curriculum, with 20 articles; (2) Challenges and Ethical Implications in the Use of AI, with 26; (3) Teacher Training and Perception, with 44; and (4) AI Tools and Teaching Processes, with 32. In the baseline research, the most discussed topic was teaching processes, especially chatbots, which accounted for 50% of the discussions in the articles, followed by teacher training, with 22%. In this section, both topics were also widely discussed, with a particular emphasis on teachers, their perceptions, and their professional development.

Table 7

Synopsis of the main points described in the thematic axes

Thematic axes	References
1) The importance of digital leadership in educational management and training to use digital tools collaboratively was highlighted. Diagnostic management with AI allows assessing school demands and automating bureaucratic processes. Adaptable and accessible data sets are relevant for strategic decisions and improving educational policies. AI teaching is associated with constructivist approaches, situated learning, and project- and problem-based learning, aiming at interactive experiences. The introduction of AI into curricula, aligned with STEM, active learning, ethics, and accessibility are important to have criticality in the use of AI. In professional development, the DAILy curriculum is cited for its collaborative and continuous training. Dialogic curriculum development promotes cooperative practices, enabling personalization and adaptation.	Asunda et al., 2023; Bellas et al., 2022; Benvenuti et al., 2023; Cavalcante, 2023; Cheng & Wang, 2023; Dai et al., 2022; Fundi et al., 2024; Jatileni et al., 2023; Jeon, Kim, & Kang, 2024; Kim & Kwon, 2023; Lee & Zhai, 2024; Li, Yu, & Zhang, 2024; Lin et al., 2022; Mahon, Becker, & Namee, 2023; Sanusi et al., 2022; Souza, 2024; Veloso et al., 2023; Webber & Flores, 2023; Williams et al., 2022; Zhang, Lee, & Moore, 2024.
2) Technical, social and cultural challenges are highlighted, such as teacher resistance, infrastructure limitations, inappropriate use of data and algorithmic biases, in addition to a limited understanding of fundamental concepts. Ethical concerns include plagiarism, technological dependence, use of commercial platforms and the reduction of jobs. A "humanized posthuman" and decolonized ethics should promote collaboration between humans and AI, guided by principles such as transparency, justice, non-maleficence, responsibility, privacy, autonomy and dignity. Critical reflection on AI-mediated interactions ensures that technology supports teachers without replacing their authority. The incorporation of AI into education requires regulations and public policies that guarantee data privacy, accessibility, digital inclusion and social equality, in addition to fostering digital literacy and critical thinking.	Adams et al., 2023; Arantes, 2022; Cavalcante, 2023; Cheng & Wang, 2023; Dai et al., 2022; Fakhar et al., 2024; Fundi et al., 2024; Kim & Kwon, 2023; Lee & Song, 2024; Li, Yu, & Zhang, 2024; Li & Ye, 2023; Lin et al., 2022; Luckin et al., 2024; Mahon, Becker, & Namee, 2023; Milićević, Lazarova, & Pavlovic, 2024; Polak, Schiavo, & Zancanaro, 2022; Pörn et al., 2024; Sanabria-Navarro et al., 2023; Sanusi, Ayanwale, & Chiu, 2023; Souza, 2024; Vartiainen, Tedre, & Jormanainen, 2023; Velander et al., 2023; Wardat et al., 2024; Williams et al., 2022; Yuwono et al., 2024; Zhang, Lee, & Moore, 2024.

3) Many teachers are interested in integrating AI tools into their teaching practices, but some are reluctant to use them because they feel unprepared due to the lack of specific training and the lack of materials in Portuguese. Teacher training is essential and needs to encompass specific pedagogical knowledge, technological skills, and teaching competencies, allowing teachers to effectively integrate these tools into their daily practices. Teachers' confidence in integrating AI is related to sharing experiences with their peers, knowledge of ethics, and the relevance of AI for social good. There is a demand for professional development, but training programs are limited. Digital competence requires a technologically savvy teaching posture; many countries have adjusted their educational laws to include digital technologies. In addition, ethical aspects must be considered and a holistic view of the use of AI must be developed to foster teachers' confidence and critical thinking. Training models such as TPACK (Technological Pedagogical Content Knowledge) argue that having technological, pedagogical and content skills is essential for comprehensive AI literacy, as it focuses on the intersection between pedagogical, technological and content knowledge. The creation of collaborative networks and mentoring are important to support pedagogical innovation. In addition to infrastructure and investment, teacher training is essential to overcome the challenges of AI in education.	An et al., 2022; Aparecida & Vieira, 2024; Arantes, 2022; Asunda et al., 2023; Ayanwale et al., 2022; Bellas et al., 2022; Cavalcante, 2023; Cheng & Wang, 2023; Dai, 2022; Dai et al., 2022; Estrada-Araoz et al., 2024; Fakhar et al., 2024; Fundi et al., 2024; Hao, Wang, & Peng, 2024; Jatileni et al., 2023; Jayasuriya et al., 2024; Jeon, Kim, & Kang, 2024; Jetzinger, Baumer, & Michaeli, 2024; Khasawneh, 2024; Kim & Kwon, 2023; Kuleto et al., 2022; Lee, Davis, & Ryu, 2024; Lee & Song, 2024; Lee & Zhai, 2024; Li & Ye, 2023; Lin et al., 2022; Nazaretsky et al., 2022; Pelaez et al., 2022; Pont-Niclos et al., 2024; Pörn et al., 2024; Sanusi et al., 2022; Sanusi, Ayanwale, & Chiu, 2023; Sanusi, Ayanwale, & Tolorunleke, 2024; Sikström et al., 2024; Souza, 2024; Teixeira & Guazzelli, 2023; Touretzky, 2022; Velander et al., 2023; Veloso et al., 2023; Wardat et al., 2024; Webber & Flores, 2023; Wu & Yang, 2022; Yuwono et al., 2024; Zhang, Lee, & Moore, 2024.
4) AI tools have the potential to create flexible, student-centered learning environments that promote autonomy and personalization. Technologies such as voice assistants, intelligent tutoring systems, chatbots (ChatGPT, Dall-E, Midjourney), augmented reality (AR), and virtual reality (VR) complement teaching by encouraging interdisciplinarity and the development of contemporary skills. These resources facilitate communication, collaboration, and co-creativity. Despite the benefits, the cost and need for infrastructure limit access, especially in vulnerable contexts. Smartphones stand out as affordable alternatives for AI teaching, facilitating the use of educational applications. However, their use faces resistance in some schools due to inattention and dependency. Technologies such as NLP, gamification, and adaptive platforms personalize learning and provide instant feedback. A critical approach is essential, encouraging students to reflect on ethical and social aspects in digitalized educational contexts.	Aparecida & Vieira, 2024; Bellas et al., 2022; Benvenuti et al., 2023; Cavalcante, 2023; Criollo-C et al., 2024; Estrada-Araoz et al., 2024; Fakhar et al., 2024; Fundi et al., 2024; Jatileni et al., 2023; Kim & Kwon, 2023; Khasawneh, 2024; Lee, Davis, & Ryu, 2024; Lee & Song, 2024; Lee & Zhai, 2024; Li & Ye, 2023; Li, Yu, & Zhang, 2024; Lin et al., 2022; Mahon, Becker, & Namee, 2023; Milićević, Lazarova, & Pavlovic, 2024; Pelaez et al., 2022; Pörn et al., 2024; Pont-Niclos et al., 2024; Souza, 2024; Teixeira & Guazzelli, 2023; Touretzky et al., 2022; Vartiainen, Tedre, & Jormanainen, 2023; Velander et al., 2023; Wardat et al., 2024; Webber & Flores, 2023; Williams, Alghowinem, & Breazeal, 2024; Yuwono et al., 2024; Zhang & Wasie, 2023.

Source. Prepared by the authors

It is important to note that a single article often addresses multiple categories, as issues related to AI in education are inherently interconnected. By integrating fields such as pedagogy, computer science, and ethics, AI exemplifies its interdisciplinary nature, fostering critical thinking and problem-solving from a holistic perspective. The thematic axes

not only delineate the overall landscape but also provide a nuanced understanding of the various dimensions involved.

Based on the analysis, it is asserted that teachers' perceptions are crucial in curriculum design, teaching processes, and in mitigating the risks associated with the use of AI. According to the analyzed articles, the theme related to teachers was the most extensively debated; approximately 70% of the selected articles emphasize the importance of teachers and reveal a consensus on the necessity of effective professional development programs. These programs should provide holistic training to ensure AI is integrated into teaching practices in a critical and ethical manner.

4. Conclusions

This study conducted a bibliometric analysis of the application of AI in basic education, revealing a significant increase in publications on the subject from 2023 onwards. The review highlighted that, despite its potential, AI faces considerable challenges, including the lack of adequate infrastructure and the need for ongoing, critical teacher training. The predominance of international studies suggests a need to expand research in the Brazilian context, where socioeconomic and cultural realities demand tailored approaches for implementation. Of the 62 articles reviewed, most employed mixed methodologies, integrating qualitative and quantitative approaches to capture the multifaceted nature of AI in education.

The study also uncovered a diverse range of references and co-authored publications, indicating global academic collaboration, with the largest output concentrated in the United States, China, and Finland. Additionally, the predominance of publications in English underscores its status as the dominant language in the dissemination of AI research. The publications were categorized into four thematic axes: Management, Pedagogy and Curriculum; Ethical Challenges and Implications; Teacher Training and Perception; and AI Tools and Teaching Processes. The analysis indicates that the adoption of AI in education remains nascent, encountering obstacles related to infrastructure, digital inclusion, and the need for critical and reflective teacher training. The studies particularly underscore the significance and deficiencies of teacher training, alongside the necessity for ethical and equitable public policies to promote the responsible use of AI. Therefore, this technology must be approached from a sociocultural perspective rather than merely as a technical tool; its implementation in education should encompass ethical, political, and emancipatory dimensions to achieve transformative impacts.

The contribution of this work lies in mapping the recent landscape and identifying trends and gaps in scientific production on the use of AI in basic education. The results highlight the crucial need for in-depth debate on AI in the educational context, providing awareness for researchers, teacher trainers, and policymakers. It is recommended that qualitative studies be conducted to expand teachers' perceptions of AI, as well as empirical research aimed at analyzing its impacts in different school settings. Furthermore, the development of integrated curricula, sensitive to regional and national specificities, may foster a critical and effective adoption of these technologies, promoting inclusive and transformative pedagogical practices.

However, it is important to highlight the limitations of this investigation. The defined timeframe (2022–2024) may restrict the understanding of the historical development of the field. The search strategy was limited to three descriptors, which may have excluded some studies, particularly those published in Portuguese and Spanish. The limited representation of publications in these languages constrains the generalizability of the findings to these educational contexts. Future research could expand the temporal scope, broaden the search strategy across databases, diversify search terms, and incorporate theoretical frameworks to deepen pedagogical, ethical, and sociotechnical debates on AI in basic education.

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