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MAPPING THE RESEARCH LANDSCAPE OF AI LITERACY IN PRIMARY EDUCATION: A BIBLIOMETRIC ANALYSIS AND SCIENCE MAPPING

Syaiful Kiram[1], Nadya Fitri[2], Handaru Baskara Aji[3], Farina Fikria Aulia[4], Genie Alan Saputra[5], Fajriah Mahroja[6], Andin Ardiani[7]
Universitas Islam Negeri Sunan Kalijaga Yogyakarta[1235], Universitas Islam Negeri Syekh Wasil Kediri[4], Universitas Negeri Jakarta[6], Universitas Ciputra Surabaya[7]
syaifulkiram3@gmail.com[1], fitrinadia320@gmail.com[2], handarubaskaraaji@gmail.com[3], farinafikria@gmail.com[4], geniealan99@gmail.com[5], fajriahmahroja@gmail.com[6], aardiani@magister.ciputra.ac.id[7]

Abstrak
Perkembangan kecerdasan buatan (AI) dalam pendidikan mendorong perlunya pemahaman mengenai perkembangan penelitian literasi AI pada jenjang pendidikan dasar. Penelitian ini bertujuan memetakan pola publikasi dan sitasi, kontributor utama, kolaborasi internasional, hubungan konseptual, serta perkembangan tema penelitian. Analisis bibliometrik dilakukan terhadap 123 publikasi berbahasa Inggris terindeks Scopus periode 2016–2026 yang diambil pada 20 September 2026. Bibliometrix/Biblioshiny dan VOSviewer digunakan untuk analisis kinerja publikasi, jaringan kolaborasi antarnegara, kemunculan bersama kata kunci penulis, pemetaan tematik, dan evolusi tema. Hasil menunjukkan peningkatan publikasi sejak 2024, dengan 109 publikasi (88,62%) terbit selama 2024–2026; data tahun 2026 belum mencakup satu tahun penuh. Amerika Serikat (24 publikasi), China (21), dan Hong Kong (20) merupakan kontributor utama, meskipun produktivitas publikasi tidak identik dengan kekuatan kolaborasi. AI literacy menjadi kata kunci penulis paling sering muncul (68 kemunculan) dan berkaitan dengan tema teknologi, pedagogi, pendidikan guru, serta etika. Analisis tematik menunjukkan kesinambungan konsep dasar sekaligus diversifikasi menuju generative AI, pengembangan profesional guru, dan critical AI literacy. Temuan ini memberikan pemetaan terfokus mengenai struktur pengetahuan serta mendukung agenda penelitian tentang asesmen sesuai usia, kesiapan guru, dan penggunaan AI secara bertanggung jawab di sekolah dasar dan madrasah ibtidaiyah.
Kata Kunci: ***AI Literacy*****, Pendidikan Dasar, Bibliometrik,** ***Science Mapping*****,** ***Generative AI***

Abstract
The growing presence of artificial intelligence (AI) in education calls for a clearer understanding of how AI literacy research has developed in primary education. This study mapped publication and citation patterns, leading contributors, international collaboration, conceptual relationships, and thematic development. Bibliometric analysis was conducted on 123 English-language Scopus-indexed publications from 2016–2026, retrieved on September 20, 2026. Bibliometrix/Biblioshiny and VOSviewer supported performance analysis, country-level co-authorship mapping, author-keyword co-occurrence, thematic

mapping, and thematic evolution. Publication output rose sharply from 2024, with 109 publications (88.62%) appearing during 2024–2026; the 2026 data represent an incomplete year. The United States (24 publications), China (21), and Hong Kong (20) contributed the most publications, although productivity and collaboration strength were distinct. AI literacy was the most frequent author keyword (68 occurrences), associated with technological, pedagogical, teacher-related, and ethical themes. Thematic analyses indicated continuity in foundational concepts alongside diversification toward generative AI, teacher professional development, and critical AI literacy. These findings provide a focused account of the field's knowledge structure and inform future research on age-appropriate assessment, teacher readiness, and responsible AI engagement in primary schools and madrasah ibtidaiyah.
Keywords: AI Literacy, Primary Education, Bibliometric Analysis, Science Mapping, Generative AI

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INTRODUCTION

The development of artificial intelligence (AI) has transformed how technology is used in education and expanded the ways in which students interact with digital systems. AI is no longer limited to technologies used by developers or professionals but is increasingly embedded in everyday life through search engines, recommendation systems, virtual assistants, adaptive learning applications, and generative AI. This shift positions students not merely as technology users but also as individuals who need to understand how AI works, recognize its capabilities and limitations, and critically evaluate its outputs. In educational contexts, this need becomes increasingly relevant as interactions with AI begin at school age. Therefore, AI education should extend beyond the ability to use technology and should develop students' knowledge and capacity to engage with AI meaningfully, critically, and responsibly (Dabbagh et al., 2025). Research in K–12 education indicates that AI literacy encompasses not only technical and applied skills but also conceptual understanding and awareness of the implications of AI use (Casal-Otero et al., 2023; Wang & Lester, 2023).

AI literacy concerns the knowledge and capabilities needed to understand, use, critically evaluate, and engage responsibly with AI systems. Long and Magerko (2020) conceptualized these capabilities as essential for informed interaction with AI, while Ng et al. (2021) identified four overlapping dimensions: knowing and understanding, using and applying, evaluating and creating, and ethical issues. A related but not identical concept is AI competency. Chiu, Ahmad, et al. (2024) distinguish literacy as what individuals know about AI from competency as their capacity and confidence to apply that knowledge in meaningful situations. Accordingly, AI literacy should not

be reduced either to operating AI applications or to a single measure of technical proficiency. In this study, AI competence-related search terms were included to identify potentially relevant literature, but eligibility was determined by substantive attention to AI literacy in a primary-education context rather than by the presence of a search term alone.

AI literacy in primary education requires approaches aligned with students' cognitive development and pedagogical needs. Existing frameworks have predominantly addressed older learners, leaving conceptual and instructional challenges for primary education (Yim, 2024a). Research has identified diverse approaches involving pedagogical strategies, learning tools, assessment, and educational outcomes (Yim & Su, 2025). Foundational initiatives have emphasized age-appropriate AI concepts (Touretzky et al., 2019), while interactive robotics and arts-based activities offer opportunities to introduce AI literacy to younger learners (Williams et al., 2019; Yim, 2024b). Recent studies have also examined pedagogical approaches suited to elementary students, including interdisciplinary and developmentally appropriate learning activities (Cheng et al., 2025; Dai, 2024). Nevertheless, challenges remain in curriculum design, teacher preparation, and instructional implementation, particularly for younger children (Su et al., 2023). These findings highlight the importance of developing AI literacy education that responds to the developmental characteristics and learning needs of primary school students.

Previous reviews differ in their units of analysis and intended contributions. Casal-Otero et al. (2023) synthesized the content and implementation of AI literacy in K–12 education, whereas Yim (2024a) examined conceptual and age-related pedagogical challenges and Yim and Su (2025) reviewed 25 primary-school empirical studies on frameworks, learning approaches, assessment, outcomes, and barriers. Feng and Carolus (2026) considered AI literacy across school stakeholders from a psychological perspective. In contrast, Abroto et al. (2026) bibliometrically mapped 547 Scopus-indexed journal articles on artificial intelligence in primary education generally, including applications such as personalized learning and AI-supported instruction. That wider topic is not equivalent to the more specific domain of AI literacy, which concerns the capacities needed to understand, evaluate, and engage with AI. These studies establish complementary, rather than interchangeable, evidence bases.

Although previous studies have advanced understanding of AI literacy frameworks, pedagogical approaches, and educational outcomes, the development of AI literacy as a distinct research domain within primary education requires further bibliometric examination. Existing systematic reviews have synthesized conceptual and empirical evidence across K–12 and primary-school contexts, while bibliometric studies have predominantly addressed broader applications of artificial intelligence in education. Consequently, a more focused examination is needed to identify the publication and citation patterns, major scientific contributors, international collaboration networks, conceptual relationships, and thematic development of AI literacy research specifically within primary education. Addressing this need, the present study integrates performance analysis and science mapping to examine the scientific development and knowledge structure of this research domain. Its contribution lies in providing a focused bibliometric perspective that complements previous conceptual reviews and broader mappings of artificial intelligence in education. Furthermore, the findings may inform future research priorities concerning age-appropriate AI

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literacy assessment, teacher preparedness, and ethical AI education in primary schools and *madrasah ibtidaiyah.* These implications are interpreted as research directions rather than direct evidence of educational practices or intervention effectiveness.

Based on this research gap, this study aims to map the development and knowledge structure of AI literacy research in primary education through a bibliometric analysis of Scopus-indexed publications. Specifically, the study addresses the following four research questions:

RQ1. How have publication output and citation patterns in AI literacy research in primary education developed?

RQ2. Who are the major contributors, and what geographical collaboration patterns characterize AI literacy research in primary education?

RQ3. What is the conceptual structure of AI literacy research in primary education based on author-keyword co-occurrence relationships?

RQ4. How have research themes in AI literacy in primary education evolved over time, and what thematic directions have emerged in recent developments?

METHODS

This study employed a bibliometric research design to examine the development, knowledge structure, and thematic evolution of artificial intelligence (AI) literacy research in primary education. Bibliometric analysis enables the systematic examination of scientific publications through bibliographic metadata to identify publication trends, citation patterns, research contributors, collaborative relationships, and conceptual structures (Donthu et al., 2021; Zupic & Čater, 2015). The analytical framework integrated performance analysis and science mapping. Performance analysis was used to assess publication productivity and citation patterns, whereas science mapping examined collaboration networks, keyword relationships, and thematic development. Combining these approaches provided a comprehensive understanding of the quantitative and conceptual development of the research field.

Data Source and Search Strategy

Bibliographic data were retrieved from the Scopus database on September 20, 2026. Scopus was selected to ensure consistency in the bibliographic metadata used for performance analysis and science mapping. The search strategy combined two conceptual groups: AI literacy and primary education. The first group included variations of AI literacy and related AI competency terminology, while the second incorporated terms associated with primary or elementary schools, students, and teachers. AI competency terms were included to broaden the identification of potentially relevant studies without treating competency and literacy as conceptually identical. The search was conducted within titles, abstracts, and keywords using the Scopus TITLE-ABS-KEY field.

The following search query was used:

TITLE-ABS-KEY ("AI literacy" OR "artificial intelligence literacy" OR "AI literacies" OR "artificial intelligence literacies" OR "AI competence" OR "AI competencies") AND TITLE-ABS-KEY ("primary education" OR "primary school" OR "primary schools" OR "primary student" OR "primary students" OR "primary teacher" OR "primary teachers" OR

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"elementary education" OR "elementary school" OR "elementary schools" OR "elementary student" OR "elementary students" OR "elementary teacher" OR "elementary teachers")

The initial search identified 173 records, which were subsequently screened according to the eligibility criteria established for the study.

Eligibility Criteria and Screening Process

Document selection was conducted through five sequential stages to ensure the consistency and relevance of the bibliometric dataset. The initial Scopus search identified 173 records. First, document-type filtering retained research articles, conference papers, and review articles, while excluding 21 records, including 17 other document types and four conference reviews. This restriction prioritized publications presenting substantive scholarly contributions rather than conference summaries or other peripheral publication formats. Second, the English-language filter excluded three records to maintain consistency in bibliographic terminology and keyword analysis. Third, source-type filtering retained publications from journals and conference proceedings, excluding 13 records from other source categories. Fourth, publication-stage filtering excluded nine records that had not reached final publication status, resulting in 127 records eligible for substantive relevance screening.

The final screening examined titles, abstracts, and author keywords to determine whether each publication addressed AI literacy or closely related AI competencies within primary education. Studies involving broader K–12 populations were retained when primary education was explicitly represented. Conversely, publications focusing exclusively on secondary or higher education, or addressing AI applications without a substantive AI literacy component, were excluded. This process removed four additional records, yielding a final dataset of 123 publications comprising 86 journal articles and 37 conference papers. The sequential identification, filtering, and inclusion procedures are presented in Figure 1.

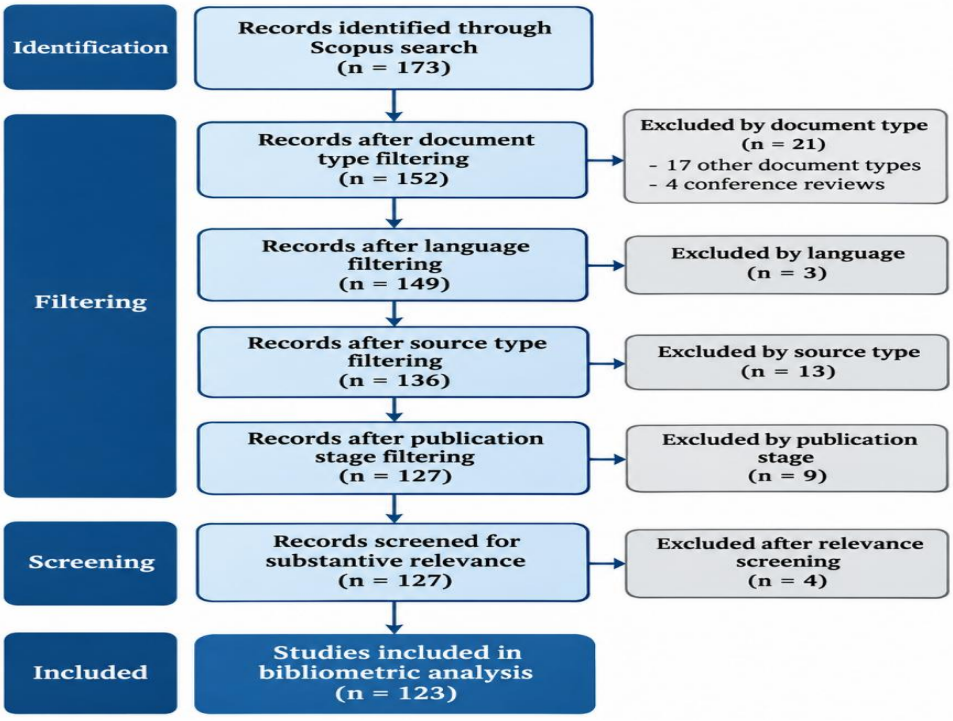


Figure 1 - Document Identification and Selection Process

Figure 1 illustrates the sequential screening process, showing how the initial 173 Scopus records were reduced to 123 eligible publications. Document-type and bibliographic restrictions were applied before substantive relevance screening to ensure that the final dataset was consistent with the research scope. The selected publications constituted the common corpus for the subsequent performance analysis and science mapping.

Data Processing and Bibliometric Analysis

Before analysis, bibliographic metadata were examined and author keywords were normalized to minimize inconsistencies arising from abbreviations and terminological variations. Thesaurus and synonym files were used in VOSviewer and Bibliometrix/Biblioshiny, respectively, to harmonize equivalent expressions. For example, variations of artificial intelligence literacy were standardized as AI literacy, while elementary school and primary school were grouped under primary education. Similarly, variations of generative artificial intelligence were harmonized, while conceptually distinct terms were maintained separately. Generic terms with limited discriminatory value were excluded from the relevant keyword mapping where applicable.

Bibliometric analyses were conducted using Bibliometrix/Biblioshiny and VOSviewer version 1.6.20. Bibliometrix/Biblioshiny was employed for descriptive and thematic analyses (Aria & Cuccurullo, 2017), while VOSviewer was used to map collaboration networks and keyword co-occurrence (Van Eck & Waltman, 2010). Both tools analyzed the same dataset of 123 Scopus-indexed publications. Keyword co-occurrence analysis followed the co-word approach (Callon et al., 1991), while differences in mapping results were considered in relation to normalization procedures and analytical methods (Moral-Muñoz et al., 2020). The analyses were organized according to the four research questions.

To address RQ1, performance analysis examined annual scientific production, publication growth, global citations, average citation indicators, and the most globally cited documents. To address RQ2, scientific contributors and international collaboration were examined through publication productivity and country-level co-authorship networks. The country-level co-authorship analysis employed full counting, with a minimum threshold of one document and zero citations per country or territory. Of the 36 countries or territories meeting these criteria, the largest connected component comprising 13 interconnected items was selected for visualization. Total link strength (TLS) was used to describe collaborative connectivity rather than publication productivity or research quality.

To address RQ3, the conceptual structure was analyzed through author-keyword co-occurrence using VOSviewer. The analysis employed full counting, a minimum threshold of three keyword occurrences, association-strength normalization, and a clustering resolution of 1.00. Following thesaurus normalization, 19 keywords met the threshold and were included in the network. Keyword occurrences, links, and cluster relationships were used to examine the principal conceptual associations within the literature.

To address RQ4, thematic development was analyzed using thematic maps, thematic evolution, and trend-topic analysis in Bibliometrix/Biblioshiny. All analyses used author keywords (DE). Thematic mapping classified themes according to centrality and density into motor, basic,

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niche, and emerging-or-declining themes (Cobo et al., 2011). The thematic analyses employed the Louvain clustering algorithm and synonym-based terminology harmonization. Thematic evolution examined three periods: 2016–2023, 2024–2025, and 2026, with cutting points in 2023 and 2025. Temporal analyses were interpreted complementarily to distinguish conceptual continuity from changes in research attention.

The interpretation of findings considered the limitations of bibliometric indicators and the scope of the Scopus dataset. Publication productivity was distinguished from citation impact, and keyword relationships were not interpreted as direct evidence of educational implementation or effectiveness. Furthermore, the 2026 data were treated cautiously because the retrieval date preceded the end of the calendar year.

RESULTS AND DISCUSSION

Results

The bibliometric analysis of 123 Scopus-indexed publications provides an overview of the development, scientific productivity, collaboration patterns, conceptual structure, and thematic evolution of AI literacy research in primary education. The findings are presented according to the four research questions, beginning with the characteristics of the dataset and publication trends, followed by scientific contributors, international collaboration, keyword relationships, and thematic development.

General Characteristics of the Dataset

The final dataset comprised 123 publications published between 2016 and 2026 across 89 publication sources, consisting of 86 journal articles and 37 conference papers. Bibliometrix reported an annual publication growth rate of 45.32%, indicating substantial expansion in the retrieved literature over the period examined. The dataset contained 380 distinct author keywords and 5,238 cited references, with an average document age of 1.21 years and 24.64 citations per document. International co-authorship accounted for 13.01% of the publications. The principal characteristics of the dataset are summarized in Table 1.

Table 1 - Main Information of the Bibliometric Dataset

Indicator	Value
Timespan	2016–2026
Sources	89
Documents	123
Journal articles	86
Conference papers	37
Annual growth rate	45.32%
Authors	342
Author keywords	380
References	5,238
Average document age	1.21 years
Average citations per document	24.64
International co-authorship	13.01%

Table 1 indicates that the research landscape is characterized by a relatively recent publication base and participation from multiple publication sources and contributors. The short

average document age reflects the concentration of publications in recent years, while the proportion of international co-authorship indicates that cross-country collaboration represents a limited share of the dataset. These descriptive characteristics provide the basis for examining publication development, citation patterns, and the geographical distribution of scientific contributions.

Publication Growth and Influential Documents

Annual scientific production reveals substantial differences in publication activity across the observation period. The dataset contained one publication in 2016, with no records identified between 2017 and 2019. Publication activity resumed in 2020 with two documents, followed by three in 2021 and four publications in both 2022 and 2023. A marked increase occurred in 2024, when 17 publications were recorded, followed by 50 publications in 2025. The dataset also contained 42 publications dated 2026, although this figure represents an incomplete publication year because the data were retrieved on September 20, 2026. The annual distribution is illustrated in Figure 2.

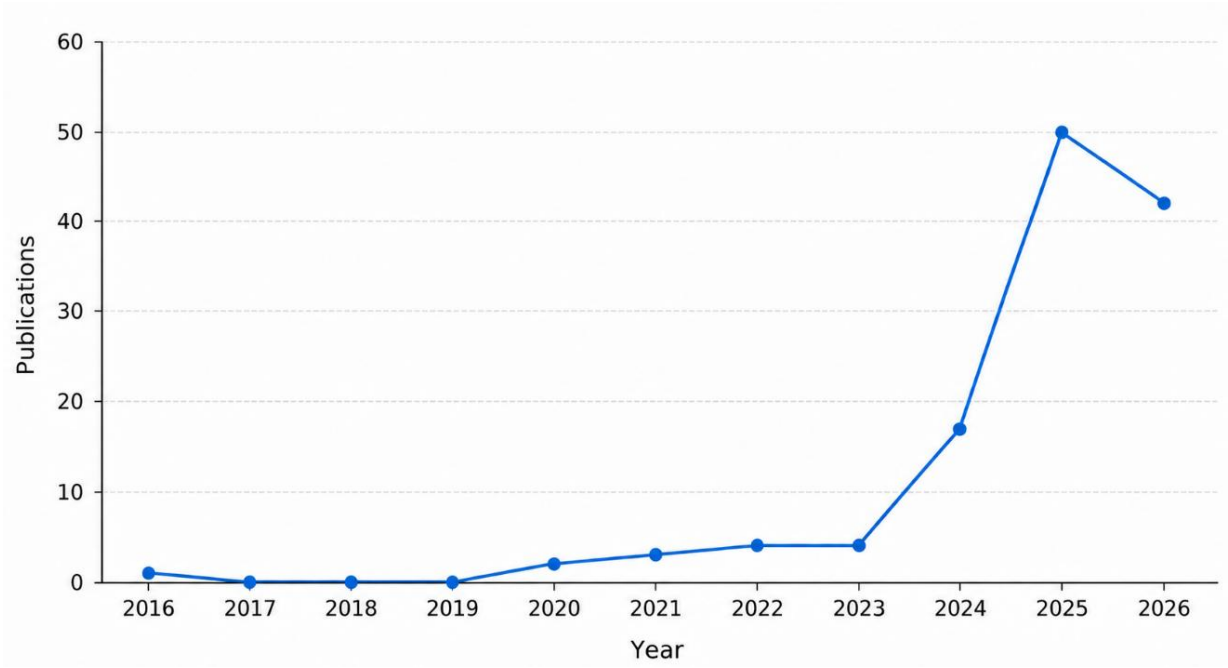


Figure 2 - Annual Scientific Production of AI Literacy Research in Primary Education (2016–2026)

Figure 2 shows that publication growth became particularly pronounced from 2024 onward. Of the 123 publications, 109 (88.62%) appeared between 2024 and 2026, indicating that the retrieved literature is dominated by recent research. The highest complete-year publication output occurred in 2025, with 50 documents. Although the 2026 dataset contains 42 publications, this number should not be interpreted as a definitive annual decline because the observation period does not cover the entire year.

In addition to publication growth, citation analysis was conducted to identify documents receiving substantial scholarly attention. Citation counts were examined separately from publication productivity because older publications generally have longer exposure periods in which to accumulate citations. The ten most globally cited documents are presented in Figure 3.

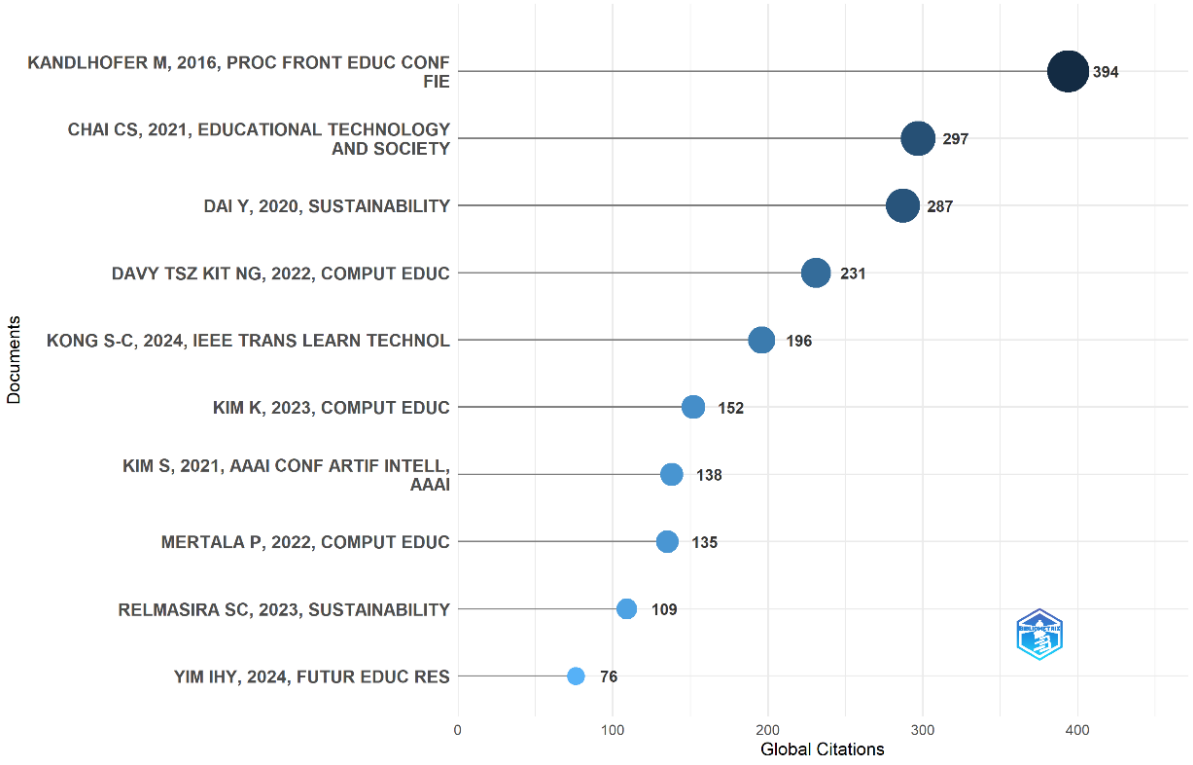


Figure 3 - Most Globally Cited Documents in AI Literacy Research in Primary Education

Figure 3 shows that Kandlhofer et al. (2016) received the highest number of global citations (394), followed by Chai et al. (2021) with 297 citations and Dai et al. (2020) with 287 citations. Other highly cited documents include Ng et al. (2022) with 231 citations and Kong and Yang (2024) with 196 citations. These findings indicate that citation accumulation is not directly proportional to the period of highest publication output. Earlier publications remain prominent in raw citation counts, while more recent research contributes substantially to the volume of scientific production. Consequently, global citation counts are interpreted as indicators of recorded scholarly attention rather than direct measures of research quality.

Sources, Authors, Institutions, and Geographical Concentration

Scientific production was distributed across journals, conference proceedings, authors, institutions, and geographical locations. *Computers and Education: Artificial Intelligence* was the most productive publication source, contributing seven documents, followed by *Education and Information Technologies* with six publications. *Education Sciences* and *Sustainability* each contributed four publications. At the author level, Dai, Y. contributed seven documents, followed by Kong, S.-C. with five, while Wong, G. K. W., Vandenberg, J., and Mott, B. each contributed four publications. The leading contributors across the principal units of analysis are summarized in Table 2.

Table 2 - Leading Sources, Authors, Institutions, and Countries in the Dataset

Category	Contributors	Documents
Source	Computers and Education: Artificial Intelligence	7
	Education and Information Technologies	6

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	Education Sciences	4
	Sustainability	4
Author	Dai, Y.	7
	Kong, S.C.	5
	Wong, G.K.W.	4
	Vandenberg, J.	4
	Mott, B.	4
Institutions	The Education University of Hong Kong	9
	Chinese University of Hong Kong	7
	The University of Hong Kong	6
	North Carolina State University	5
	Korea National University of Education	5
Country/Territory	United States	24
	China	21
	Hong Kong	20
	Spain	7
	South Korea	7

Table 2 shows that research output is distributed across multiple sources but that the leading contributors are concentrated in particular institutions and geographical locations. The United States recorded the highest publication output (24 documents), followed by China (21) and Hong Kong (20). At the institutional level, universities in Hong Kong are prominently represented. These findings describe the distribution of scientific production within the selected dataset; publication counts alone do not indicate the strength of international research collaboration.

To examine geographical collaboration separately from publication productivity, country-level co-authorship relationships were mapped using VOSviewer. Although 36 countries or territories met the initial inclusion thresholds, the visualization focused on the largest connected component, comprising 13 interconnected countries or territories. The resulting collaboration structure is presented in Figure 4.

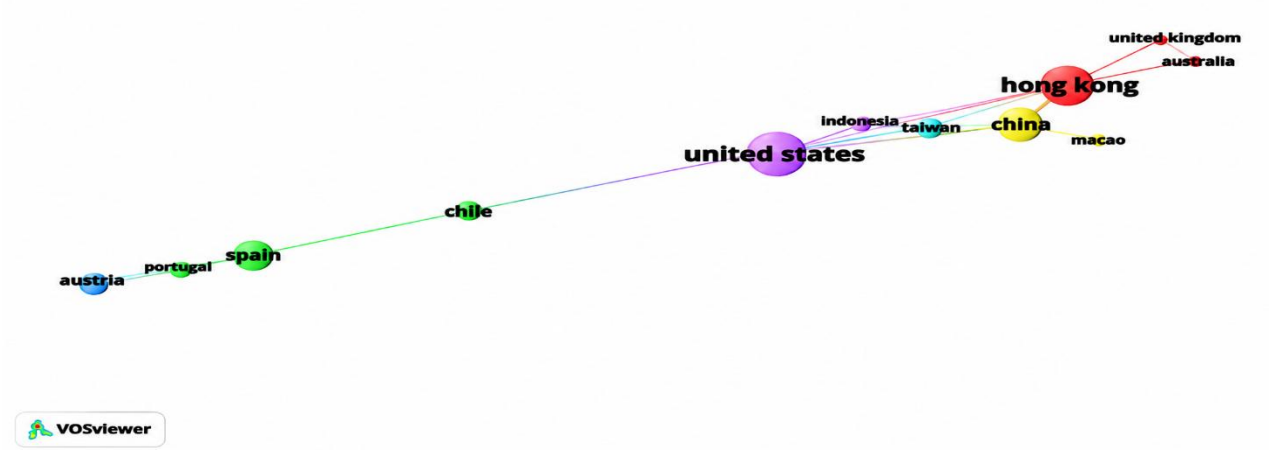


Figure 4 - International Collaboration Network in AI Literacy Research in Primary Education

Figure 4 illustrates the country-level co-authorship relationships within the largest connected component of the network. The component comprises 13 countries or territories distributed across four clusters, with 18 links and an aggregate link weight of 23. The United States has the highest total link strength (TLS = 9), followed by Hong Kong (TLS = 8), China (TLS = 7), Spain (TLS = 5), Taiwan (TLS = 4), and Indonesia (TLS = 3). These results indicate that international collaboration is concentrated among a relatively small number of connected geographical contributors. However, TLS represents the strength of co-authorship relationships and should not be interpreted as an indicator of publication productivity or research quality.

Conceptual Structure of the Research Field

The conceptual structure of AI literacy research was examined through author-keyword co-occurrence analysis. Following keyword normalization and application of a minimum occurrence threshold of three, 19 keywords were retained in the VOSviewer network. The resulting map consisted of seven clusters, 59 links, and an aggregate total link strength of 163.

AI literacy was the most frequently occurring keyword, with 68 occurrences and a TLS of 87. It was followed by artificial intelligence (38 occurrences; TLS = 48), primary education (29 occurrences; TLS = 45), artificial intelligence in education (20 occurrences; TLS = 33), and generative AI (16 occurrences; TLS = 22). These indicators show that AI literacy occupies the most prominent position in terms of both keyword frequency and connectivity within the processed network. The relationships among these concepts are illustrated in Figure 5.

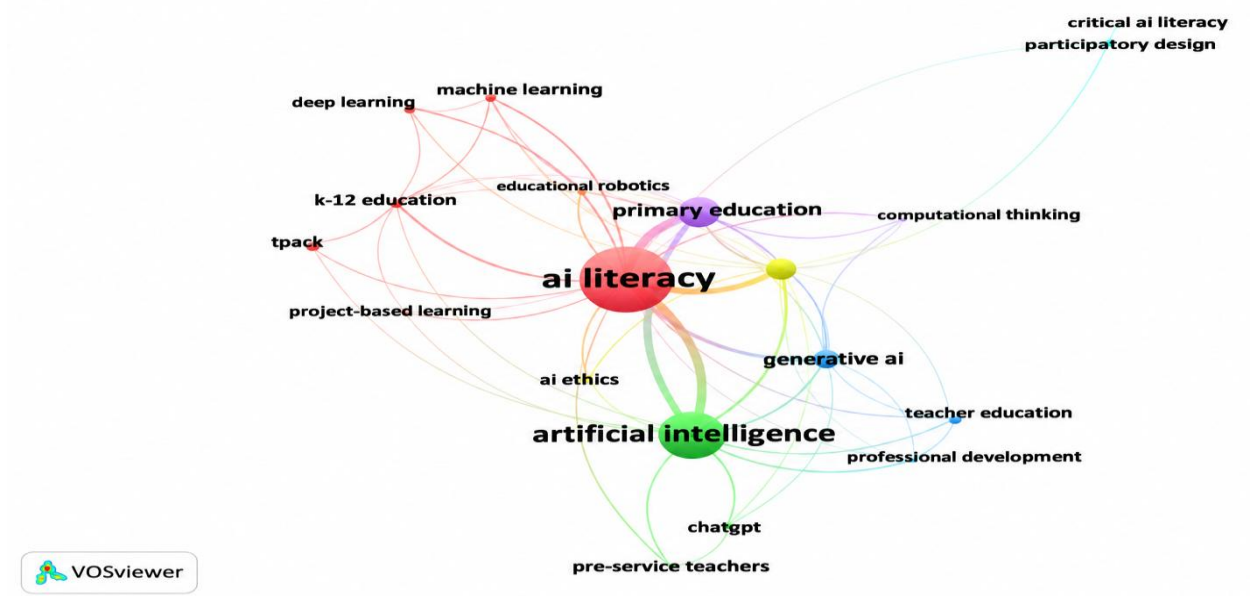


Figure 5 - Keyword Co-occurrence Network of AI Literacy Research in Primary Education

Figure 5 shows that AI literacy is connected with concepts relating to AI technologies, educational contexts, teaching approaches, and teacher development. Keywords such as machine learning, deep learning, K–12 education, TPACK, and project-based learning occur within the broader network, while generative AI is associated with teacher education and professional

development. Other terms, including AI ethics, pre-service teachers, and critical AI literacy, reflect the presence of additional conceptual concerns within the literature.

The configuration of the network suggests that AI literacy research in primary education encompasses technological, pedagogical, professional, and ethical dimensions. However, these relationships represent patterns of keyword co-occurrence in scientific publications and do not establish that the corresponding approaches have been integrated or evaluated together in classroom practice.

Thematic Structure and Developmental Position of Research

The thematic structure of AI literacy research in primary education was examined through thematic mapping based on centrality and density. These dimensions indicate the degree of connection between a theme and the broader research field and the level of internal development within each thematic cluster. The resulting map classifies research themes into four categories: motor themes, basic themes, niche themes, and emerging-or-declining themes, as presented in Figure 6.

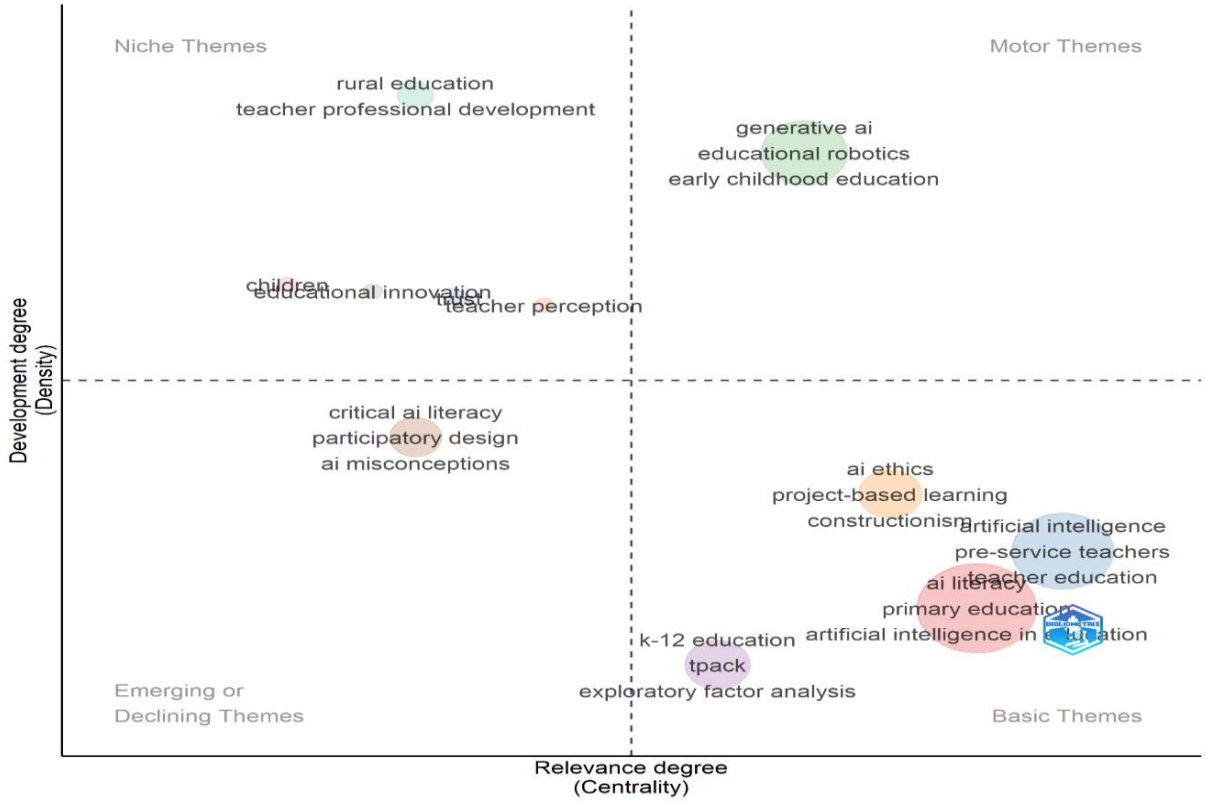


Figure 6 - Thematic Map of AI Literacy Research in Primary Education

Figure 6 shows that the cluster comprising AI literacy, primary education, and artificial intelligence in education is positioned within the basic themes quadrant, indicating its broad relevance to the research field. Themes associated with generative artificial intelligence, educational robotics, and early childhood education appear in the motor themes quadrant, reflecting relatively high centrality and internal development. Meanwhile, rural education and teacher professional

development are represented within the niche themes quadrant, suggesting more specialized areas of research attention.

In contrast, critical AI literacy, participatory design, and AI misconceptions are positioned within the emerging-or-declining quadrant, characterized by relatively low centrality and density. However, this position does not establish whether these themes are increasing or decreasing in prominence. Their developmental trajectories must therefore be interpreted alongside the thematic evolution and trend-topic analyses rather than inferred from the thematic map alone.

Evolution and Recent Directions of Research Themes

Thematic evolution analysis was conducted to examine continuity and differentiation in the research structure across three periods: 2016–2023, 2024–2025, and 2026. The first period comprised 14 publications, followed by 67 publications in the second period and 42 publications in the partial 2026 period. These unequal distributions were considered when interpreting the relationships among themes.

The earliest period was characterized primarily by themes associated with AI literacy, artificial intelligence, and artificial intelligence in education. During 2024–2025, these thematic trajectories remained visible, alongside a more explicit representation of primary education. The 2026 period included additional thematic labels relating to generative AI, professional development, pre-service teachers, and critical AI literacy. The relationships across the three periods are illustrated in Figure 7.

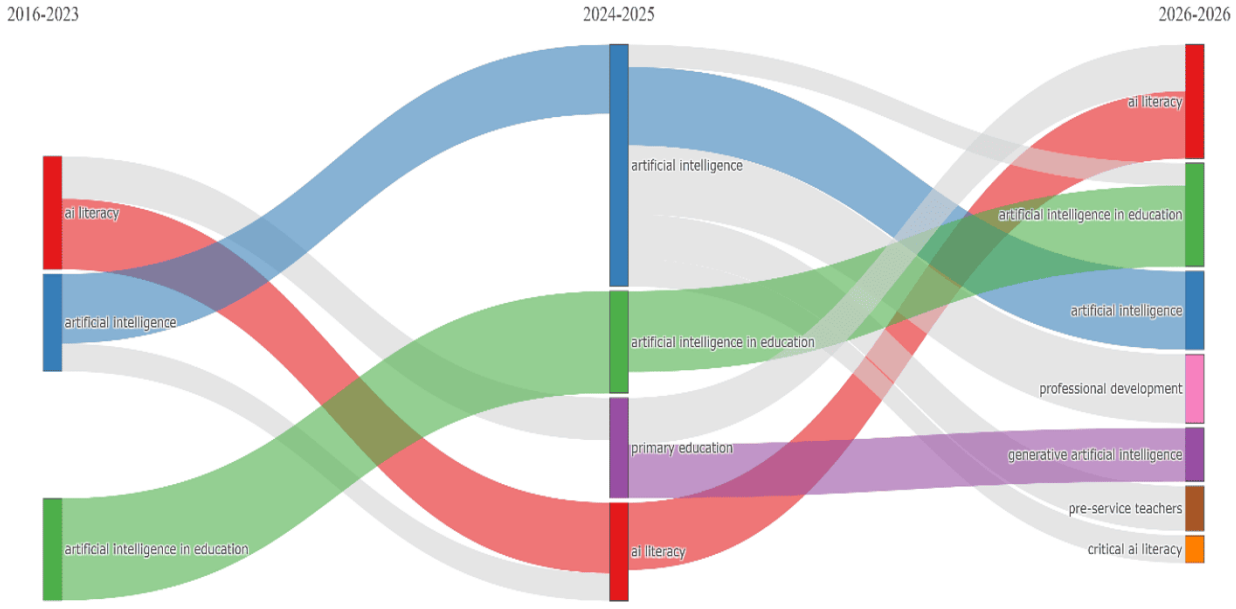


Figure 7 - Thematic Evolution of AI Literacy Research in Primary Education (2016–2026)

Figure 7 illustrates the continuity and differentiation of keyword-derived themes across the three observation periods. AI literacy and artificial intelligence-related themes remain represented across successive periods, while teacher-related and generative AI themes appear more explicitly in the final period. The presence of critical AI literacy among the 2026 themes indicates that this

concept is represented in recent literature. However, the visualization does not establish that its research prominence is increasing, particularly given the limited number of occurrences and the incomplete coverage of 2026.

Trend-topic analysis was used to complement thematic evolution by examining the temporal placement of recurring author keywords. The visualization provides an additional perspective on the relative timing and frequency of research terms, as shown in Figure 8.

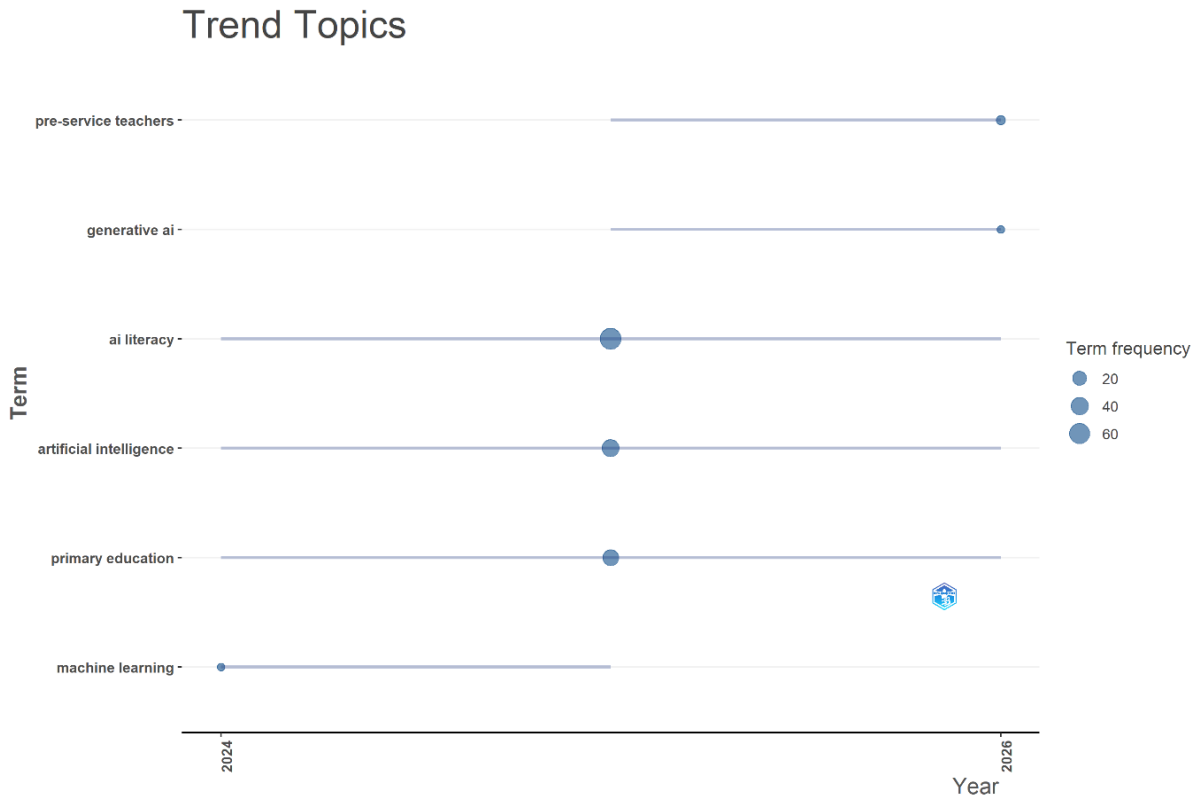


Figure 8 - Trend Topics in AI Literacy Research in Primary Education

Figure 8 shows that recurring terms such as AI literacy, artificial intelligence, and primary education are represented across the recent observation period, while generative AI and pre-service teachers have more recent temporal positions. Machine learning is also represented within the selected terms. The visualization complements thematic evolution by distinguishing broadly recurring concepts from terms concentrated in more recent publications. Nevertheless, temporal placement should not be interpreted as evidence of sustained growth or future dominance without additional longitudinal evidence.

Taken together, the results show substantial expansion in publication output since 2024, concentration of scientific production and international collaboration among a limited number of leading contributors, and a conceptual structure centered on AI literacy. The thematic analyses further identify relationships involving generative AI, teacher development, and critical engagement with AI. These findings characterize the structure and temporal distribution of research within the selected Scopus corpus rather than changes in actual educational practice.

Discussion

The Development of AI Literacy as a Research Domain in Primary Education

The rapid expansion of AI literacy publications in primary education indicates growing scholarly attention to the competencies children need to understand, evaluate, and interact with artificial intelligence. The concentration of 109 publications (88.62%) during 2024–2026 suggests that the field has expanded considerably within a relatively short period. However, publication growth should not be equated with conceptual or methodological maturity. The recent concentration of research may reflect increasing interest in the topic, while the extent to which theoretical frameworks, assessment approaches, and pedagogical practices have become consolidated requires further investigation. The incomplete coverage of 2026 also prevents definitive conclusions about the trajectory of publication growth beyond the last complete calendar year.

This development can be interpreted alongside the expanding educational significance of AI literacy. Long and Magerko (2020) established an influential conceptual foundation by identifying competencies needed to interact with and critically evaluate AI systems. Ng et al. (2021) subsequently organized AI literacy into four dimensions: knowing and understanding, using and applying, evaluating and creating, and ethical issues. These frameworks contributed to conceptualizing AI literacy beyond technical proficiency. Their educational relevance has become increasingly apparent as AI technologies have become more accessible to teachers and students. Nevertheless, the translation of general AI literacy frameworks into primary education requires attention to children's developmental characteristics, learning experiences, and the suitability of instructional approaches.

The development of generative AI provides a plausible explanation for part of the recent research interest, although the bibliometric data cannot establish a causal relationship. Generative AI enables direct interaction through the production of text, images, and other learning materials, raising questions about the evaluation of AI-generated information, responsible use, and the role of human judgment in learning activities. Yim and Su (2025), through a systematic review of 25 empirical studies, demonstrated that AI literacy education in primary schools involves diverse theoretical frameworks, instructional strategies, learning tools, assessment methods, and educational outcomes. Their findings illustrate the breadth of educational questions surrounding AI literacy. The present study complements this evidence by showing how scholarly attention to these questions is distributed and connected within a focused bibliometric corpus.

Citation patterns offer a complementary perspective on the development of the field. Earlier publications remain prominent among the most globally cited documents, despite the considerable increase in recent publication output. This difference may partly reflect the longer citation exposure of older studies rather than their inherently greater methodological quality. Consequently, research productivity, citation accumulation, and conceptual influence should be considered as related but distinct dimensions of scientific development. Compared with Abroto et al. (2026), who mapped 547 Scopus-indexed journal articles addressing AI in primary education more broadly, the present study contributes a more narrowly defined perspective on AI literacy. Its distinctive contribution lies in identifying the publication, collaboration, conceptual, and temporal structures of research

specifically concerned with AI-related understanding, evaluation, and responsible engagement in primary education.

Geographical Concentration and International Research Collaboration

The geographical distribution of research indicates that the expansion of AI literacy scholarship has not been accompanied by an equally distributed pattern of scientific production and international collaboration. The United States, China, and Hong Kong represent the leading publication contributors within the analyzed corpus. However, publication productivity and collaborative connectivity reveal different aspects of their contributions. The United States exhibits the strongest international collaboration links, followed by Hong Kong and China. This distinction is particularly relevant because Hong Kong demonstrates greater collaborative connectivity than China despite contributing slightly fewer publications. Scientific productivity therefore cannot be treated as equivalent to the strength of international research relationships.

The concentration of publication output may be associated with differences in research capacity, institutional networks, educational priorities, and opportunities for international collaboration. However, these potential explanations were not directly examined in the present study. Furthermore, the visualization represents the largest connected component of the country-level co-authorship network rather than all countries or territories represented in the dataset. The relatively concentrated network should therefore be interpreted as a characteristic of the retrieved Scopus corpus, not as evidence that research activity or educational innovation is absent from less-represented geographical contexts.

This distribution has implications for the contextual relevance of AI literacy knowledge. Chiu, Ahmad, et al. (2024) emphasize that AI literacy and competency frameworks for K–12 education need to consider broader dimensions of knowledge application, educational context, and the roles of teachers. Similarly, Yim and Su (2025) demonstrate that primary-school AI literacy education involves different conceptual frameworks, learning designs, and assessment practices. These findings suggest that educational conditions matter when translating AI literacy concepts into instructional practice. Frameworks developed in particular educational systems may require further adaptation and validation before being applied to settings with different curricula, languages, technological resources, and student characteristics.

The contribution of the present mapping is to distinguish geographical research productivity from the structure of international knowledge collaboration. This distinction extends beyond identifying leading countries by revealing differences in their connectivity within the research network. For future research, the results support greater attention to cross-contextual comparisons and collaborative investigations involving educational systems that are less prominently represented in the retrieved literature. In Indonesia, such investigations could examine the relevance of existing AI literacy frameworks to elementary schools and *madrasah ibtidaiyah.* These directions represent opportunities for further research rather than conclusions about the current quality or availability of AI literacy education in Indonesian schools.

AI Literacy as an Interconnected Conceptual and Pedagogical Research Domain

The keyword co-occurrence structure suggests that AI literacy in primary education is discussed in connection with technological concepts, educational approaches, teacher preparation,

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and ethical considerations. This configuration indicates that the scholarly discourse is broader than the acquisition of technical knowledge alone. However, the prominence of AI literacy and primary education is partly influenced by the search strategy used to define the corpus. More meaningful conceptual insights therefore arise from examining their associations with other terms, including generative AI, machine learning, project-based learning, teacher education, and AI ethics. These associations indicate areas of scholarly co-discussion without demonstrating that the corresponding elements have been integrated into a unified educational model.

This interpretation is consistent with the multidimensional conceptualization proposed by Long and Magerko (2020) and Ng et al. (2021). AI literacy includes the capacity to understand AI-related concepts, use and evaluate AI systems, and recognize their ethical implications. The contribution of keyword mapping is to reveal how these dimensions are situated within the wider research discourse on primary education. The relationships among technological and pedagogical terms suggest that researchers are examining AI literacy through multiple educational perspectives rather than treating it exclusively as a computer science topic.

Previous empirical research illustrates the educational possibilities associated with these conceptual relationships. Ng et al. (2022) examined digital story writing as an instructional approach for developing AI literacy among primary students, demonstrating how AI learning can be incorporated into a broader educational activity. Dai (2024) investigated a dual-contrast pedagogy for upper elementary students that used comparisons between human and artificial intelligence to support conceptual understanding. More recently, Cheng et al. (2025) developed and validated an AI literacy questionnaire for fifth-grade students and examined a learning approach integrating STEAM, project-based learning, and artificial intelligence of things. Kahila et al. (2024) also examined participatory AI learning and curriculum co-design in Finnish K–12 classrooms, illustrating how educational activities can be designed to foster students' data agency, creativity, and understanding of AI concepts. These studies provide empirical examples of pedagogical design and assessment in primary education. Nevertheless, their findings should be distinguished from the present bibliometric results, which identify conceptual associations rather than evaluate the effectiveness of particular instructional strategies.

The ethical and critical dimensions of AI literacy add further complexity to this research structure. Atias and Mawasi (2025) found that AI literacy educational programs for children and young people have tended to emphasize operational dimensions, while sociocultural and critical dimensions remain comparatively underdeveloped. Ma et al. (2025) similarly identified gaps in the integration and assessment of responsible AI principles within K–12 education. These findings suggest that the presence of ethical terminology in a bibliometric network does not necessarily indicate adequate attention to ethical learning outcomes in educational practice. The distinction is particularly important when interpreting relationships involving AI ethics and critical AI literacy.

The present study contributes a field-level perspective by identifying the relationships among technological understanding, pedagogical approaches, teacher-related concepts, and ethical concerns. These relationships provide a basis for developing research questions about how AI literacy dimensions may be integrated within age-appropriate learning environments. Rather than establishing the existence of a fully developed pedagogical ecosystem, the mapping identifies

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interconnected research areas whose theoretical coherence and educational effectiveness require further empirical investigation.

Thematic Diversification: Generative AI, Teacher Preparation, and Critical AI Literacy

The thematic analyses indicate continuity in the foundational concepts of AI literacy alongside the appearance of more specialized research themes. AI literacy, artificial intelligence, and artificial intelligence in education remain represented across successive periods, while the later thematic structures include generative AI, teacher professional development, pre-service teachers, and critical AI literacy. This pattern is more appropriately understood as thematic diversification than as a complete transformation of the research field. The unequal number of publications across periods, especially the limited earlier corpus and incomplete 2026 data, also requires caution when interpreting changes in thematic prominence.

Generative AI introduces additional educational questions concerning the reliability of generated information, human–AI interaction, instructional design, and responsible technology use. Its position within the motor themes quadrant indicates relatively strong centrality and internal development in the generated thematic map. However, this position alone does not establish that generative AI has become the dominant focus of AI literacy education in primary schools. Cheah et al. (2025), in a study involving 89 K–12 teachers in the United States, found that participants were generally underprepared to integrate generative AI and frequently used it for lesson preparation, assessment, and administrative activities rather than direct classroom instruction. Their findings help explain why questions of teacher preparedness and pedagogical judgment remain relevant when considering the educational use of generative AI. Importantly, these empirical observations provide contextual evidence rather than causal explanations established by the present bibliometric analysis.

The representation of teacher education and professional development highlights another important dimension of the research agenda. Sperling et al. (2024) found that AI literacy in teacher education remained insufficiently developed, particularly concerning teachers' practical knowledge and professional judgment. Prilop et al. (2025) further identified AI literacy, AI didactics, and AI assessment as interconnected dimensions in the context of generative AI and teacher education. Celik et al. (2022) identified the opportunities and challenges associated with teachers' use of AI, while Celik (2023) extended the technological pedagogical content knowledge framework by incorporating ethical considerations into teachers' AI-related professional knowledge. Together, these studies suggest that preparing teachers to engage with AI requires more than familiarity with technological applications. Pedagogical decision-making, critical evaluation of AI outputs, assessment competence, and ethical responsibilities also warrant attention. The present thematic structure identifies teacher-related concepts within the research landscape, while previous empirical and review studies clarify why these concepts are educationally significant.

Critical AI literacy provides a further perspective on the development of the field. In the thematic map, critical AI literacy is positioned within the emerging-or-declining quadrant, indicating relatively limited centrality and internal development. Its representation in the most recent thematic period demonstrates its presence in contemporary research, but does not establish a sustained increase in scholarly attention. Veldhuis et al. (2025), through a scoping review and framework synthesis, highlight the importance of enabling children to engage critically with AI

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rather than merely understand or operate AI systems. Their work provides a conceptual basis for examining children's awareness of algorithmic decisions, social consequences, and their own agency when interacting with AI.

The significance of this critical dimension is also supported by research on ethical competencies. Tagare et al. (2025) identified interconnected dimensions of ethical knowledge, skills, and dispositions relevant to K–12 teachers, including awareness of AI limitations, critical analysis, transparency, and culturally responsive pedagogical judgment. Lin and Dai (2025) demonstrated how constructionist learning activities could support upper primary students in examining AI-related ethical issues such as fairness, bias, and transparency. For younger learners, Wong (2026) proposed an integrated ethical framework emphasizing privacy protection, algorithmic bias, developmental well-being, and shared responsibilities in early childhood and early primary education. These studies indicate that critical and ethical AI literacy can be investigated through pedagogical and assessment approaches suited to younger learners. However, the present thematic map cannot establish the prevalence or effectiveness of such approaches across primary schools.

Taken together, the thematic analyses identify three complementary areas of research attention: interactions with generative AI, the preparation of educators, and critical engagement with AI systems. Their relationships suggest opportunities to connect technological understanding with instructional decisions and ethical learning objectives. The contribution of this study is to identify these areas within the temporal and conceptual structure of the literature while maintaining a distinction between bibliometric evidence, theoretical interpretation, and empirical findings reported by previous studies.

Research Implications for Primary Education and Madrasah Ibtidaiyah

The findings provide a basis for developing a more focused research agenda in primary education, particularly in contexts where existing AI literacy frameworks have not been sufficiently evaluated. The first priority concerns the development and contextual validation of AI literacy assessment instruments for elementary school students. Such instruments should consider age-appropriate dimensions of AI knowledge, application, critical evaluation, and ethical reasoning. Cheng et al. (2025) provide an empirical example of questionnaire validation among fifth-grade students, demonstrating the importance of examining measurement quality and student characteristics. Complementary measurement approaches include objective AI literacy assessments (Chiu, Chen, et al., 2024), multidimensional questionnaires (Ng et al., 2024), and self-assessment instruments developed for upper primary school students (Thianwan & Srikoon, 2026). Future investigations in Indonesian elementary schools and madrasah ibtidaiyah could assess whether existing instruments demonstrate appropriate content validity, reliability, and measurement equivalence across grades, languages, and educational contexts. Their suitability should be established empirically rather than assumed from validation studies conducted elsewhere.

The second priority concerns teacher readiness and professional development. The representation of teacher education and professional development within the conceptual and thematic analyses suggests that educators constitute an important focus of AI literacy scholarship. Building on Sperling et al. (2024) and Prilop et al. (2025), future studies could investigate how

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teachers' AI knowledge, pedagogical judgment, assessment practices, and ethical awareness relate to their readiness to design age-appropriate AI literacy learning activities. In the context of madrasah ibtidaiyah, comparative or mixed-methods investigations could examine how teacher preparation interacts with institutional conditions, curriculum requirements, and access to educational technology. These relationships remain questions for empirical examination rather than established findings of the bibliometric analysis.

The third priority involves the development and assessment of critical and ethical AI literacy for younger learners. Rather than evaluating students exclusively through their ability to identify or operate AI applications, future research could examine their ability to recognize unreliable AI-generated information, identify potentially unfair outcomes, understand appropriate human oversight, and consider privacy and responsible use. The frameworks and empirical investigations reported by Lin and Dai (2025), Ma et al. (2025), and Veldhuis et al. (2025) provide relevant foundations for developing such research. In Indonesian primary education, these approaches would require age-appropriate instructional tasks, culturally and linguistically suitable assessment instruments, and careful attention to children's digital experiences.

Overall, the distinctive contribution of this study is its focused mapping of AI literacy research in primary education through the integration of scientific performance, international collaboration, keyword relationships, and thematic development. It complements systematic reviews that examine educational frameworks and interventions by identifying the distribution and relationships of research activity at the field level. The findings provide a structured basis for future investigations of student assessment, teacher readiness, and ethical AI literacy without assuming that global bibliometric patterns directly represent educational conditions or instructional effectiveness in Indonesian primary schools.

Limitations and Future Research

This study has several limitations that should be considered when interpreting its findings. First, the analysis was restricted to 123 English-language, Scopus-indexed publications retrieved on September 20, 2026. Consequently, relevant studies published in other languages or indexed in other databases may not have been captured. The inclusion of AI competency terminology in the search strategy also required relevance screening to distinguish AI literacy research from broader studies of AI applications. Furthermore, keyword normalization, minimum occurrence thresholds, and clustering procedures may have influenced the resulting conceptual and thematic structures.

Second, bibliometric analysis identifies patterns of scientific production, citation impact, collaboration, and conceptual relationships but cannot directly establish the effectiveness of AI literacy instruction or explain how educational practices are implemented in primary schools. Citation indicators may also favor older publications because they have had more time to accumulate citations. Additionally, the 2026 data represent an incomplete publication year. The position of critical AI literacy within the emerging-or-declining quadrant should therefore not be interpreted as definitive evidence of thematic growth or decline.

Future research should integrate bibliometric mapping with systematic reviews, qualitative investigations, and empirical educational studies to examine how AI literacy frameworks are translated into instructional practices and assessment. Comparative and longitudinal studies could

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provide stronger evidence regarding changes in research priorities and the applicability of AI literacy approaches across educational contexts. In Indonesia, further investigations are particularly needed to validate age-appropriate AI literacy instruments, examine teacher readiness in elementary schools and madrasah ibtidaiyah, and develop assessment approaches addressing critical and ethical engagement with AI. These priorities require contextual validation to ensure that findings from international research can be meaningfully examined within local educational settings.

CONCLUSION

This study mapped the development and knowledge structure of AI literacy research in primary education through bibliometric analysis and science mapping of 123 Scopus-indexed publications. The findings reveal substantial growth in research output since 2024, with 109 publications (88.62%) appearing during 2024–2026, although the 2026 data represent an incomplete publication year. Scientific production was concentrated primarily in the United States, China, and Hong Kong, while international collaboration exhibited a more limited and unevenly connected geographical structure. Citation patterns further indicate the continuing scholarly prominence of earlier publications despite the rapid expansion of recent research.

Conceptually, AI literacy occupies a central position within a network connecting technological, pedagogical, teacher-related, and ethical research themes. Thematic analyses demonstrate continuity in foundational AI literacy concepts alongside diversification toward generative AI, teacher professional development, and critical AI literacy. However, these patterns represent relationships and thematic developments within the scientific literature rather than direct evidence of educational implementation or effectiveness. The principal contribution of this study lies in providing an integrated, literacy-specific mapping of scientific productivity, international collaboration, conceptual relationships, and thematic development in primary education, complementing previous reviews and broader bibliometric studies of artificial intelligence in education.

The findings provide a basis for future research on age-appropriate AI literacy assessment, teacher readiness, and critical and ethical engagement with AI in primary education. For Indonesian elementary schools and madrasah ibtidaiyah, these priorities require contextual investigation and empirical validation rather than direct adoption of international research patterns. Given the study's reliance on a single bibliographic database and its incomplete coverage of 2026, the conclusions remain specific to the analyzed Scopus corpus. Future investigations involving more diverse educational contexts and empirical approaches are needed to strengthen the understanding of AI literacy development among primary-school learners.

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