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Digital and AI-based Learning Environments for Data Literacy Development (2017–2026): A Bibliometric–Systematic Review

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Abstract. Artificial intelligence has transformed the world of educational technology, especially the way data-driven digital learning environments are designed. Data literacy is now considered both a purely statistical ability and a critical-thinking ability in interacting with algorithmic systems. The purpose of this study is to map the development, intellectual structure, and thematic trends of research regarding digital and AI-based learning environments for data literacy development. This study uses a bibliometric and systematic review approach to publications from 2017 to 2026. Data were collected from Scopus using the search terms "AI in education", "digital learning environment", and "data literacy". The analysis was conducted using VOSviewer and Biblioshiny, with support from the PRISMA framework for systematic selection. The analysis includes annual scientific production, author productivity, and geographic distribution as well as mapping of keyword networks and thematic structures. The results of the analysis show a huge increase in recent years. The structure of author productivity and the relatively dispersed geographical distribution suggest that this sector is still in the stage of establishing an epistemic identity. Based on the thematic analysis, artificial intelligence serves as the central theme connecting technology, literacy and education. This leads to an artificial intelligence-driven data literacy paradigm. This research helps to integrate data literacy and artificial intelligence into education, developing a critical pedagogy reflective of data-driven systems.

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Keywords: AI in education; digital learning environment; data literacy; bibliometric analysis; systematic review

1. Introduction

Artificial intelligence in education is being integrated increasingly into teaching and learning practices. Over the past ten years, AI has evolved from an add-on component in digital learning to an integral part of the infrastructure that shapes the learning experience actively. Adaptive learning systems in technology are an innovation integrated into learning models, such as the use of ChatGPT.

A learning environment like this does not only convey the content taught to students but also collects, analyses, and responds to student learning data in real time. The shift in the learning paradigm is evident in data-driven educational trends, such as algorithmic systems that process all student interactions, including clicks, response times, error patterns and material content preferences (Jiménez-Macías et al., 2025; Pogodaev & Galkina, 2025; Sheshadri et al., 2025). This situation requires literacy data from users or learning actors, such as teachers, students and school management. Data literacy includes the ability to read graphs and to understand basic and descriptive statistics.

Moreover, a person with data literacy will be able to interpret data-driven information, evaluate its credibility, understand the logic of algorithmic systems and make wise decisions in a context mediated by artificial intelligence (Kavut, 2025; Liu, 2024; Varga & Koltay, 2025). Digital learning environments and artificial intelligence should not be perceived solely as technological instruments (Bey, 2026; Li & Wong, 2023). They serve as environments where data are produced, analysed, and utilised in educational processes (Kesgin, 2025; Mintii & Semerikov, 2024). In this regard, students learn not only through data-driven systems, but also inside frameworks that influence the interpretation and application of data.

Most bibliometric analyses focus on broad research trends or technological advancements, even though earlier studies have examined artificial intelligence in education (Corzo-Zavaleta et al., 2025; Kesgin, 2025; Ma et al., 2024; Nweke-Love et al., 2025; Turmuzi & Tyaningsih, 2025). The relationship between the development of data literacy and AI-driven digital learning environments has received little attention. Furthermore, current research is unable to provide a longitudinal, integrated mapping linking various domains within a single analytical framework. This suggests that a more targeted bibliometric examination is required that accounts for their interdependence.

Nevertheless, current bibliometric research has afforded very scant focus on the correlation between AI-driven digital learning environments and the advancement of data literacy (Ma et al., 2024; Nweke-Love et al., 2025) based on literacy data in a data framework. Furthermore, these studies focus predominantly on identifying trends and technological advancements, with minimal attention to the significant role of AI-driven digital learning environments in fostering growth in data literacy. This indicates the need for a more focused bibliometric analysis that considers the interrelationship between

AI, digital learning environments and data literacy, particularly in the context of data-driven education.

In addition, there is no mapping of conceptual and structural differences in the literature, nor is there a longitudinal mapping showing the evolution of AI in education. Research on AI in education today focuses more on system effectiveness, algorithm performance, or technical design (Babu et al., 2025; Vasou et al., 2025; Wan Yahaya & Zaini, 2025). However, it does not link the development of data literacy competencies systematically with the transformation of the AI-based learning environment (Olari et al., 2023). The significance of this disparity is that the increasing integration of AI in education is not solely a matter of technological adoption; it also pertains to the development of learners' capacity to interpret and utilise data in a meaningful manner.

This research integrates two areas that have developed significantly in recent years: digital learning environments and AI and data literacy. This integration forms a conceptual bridge linking technological advances to competency strengthening. Furthermore, longitudinal mapping by developmental period was used in this study to identify the emergence, expansion, and acceleration phases in this field. This method provides a systematic overview of the evolution of the paradigm, not just a description of the growth of the publication. Moreover, this study employs a multi-layered bibliometric architecture. This approach includes productivity analysis, citation influence, geographic distribution, collaborative networking as well as theme mapping and co-occurrence analysis. This multidimensional method generates a comprehensive intellectual map, enabling the identification of motor themes, emerging themes, and the conceptual structures of the field.

This research continues the discussion of AI in education, moving beyond the mere effectiveness of technology to its epistemological implications for the formation of theoretical competencies. It also helps to consolidate the conceptual framework linking AI-driven learning environments to the development of data literacy in the data-driven learning ecosystem. The use of the bibliometric–systematic review method in this study is used to understand the structure and dynamics of this rapidly developing interdisciplinary field (Ramya et al., 2025). The analysis model used can be applied to mapping other educational technology domains (İnci & Köse, 2024; Jing et al., 2024).

The results of this study offer an evidence-based foundation for researchers, technology developers, and policymakers to design AI integrations that are technically innovative and useful in improving the data literacy of learners. This study aims to map the research landscape on digital learning environments and AI for the development of data literacy, considering the background, differences and contributions provided. With this conceptual approach, this research does not only map the literature; it also seeks to explain the theoretical foundations of a rapidly evolving, increasingly complex field. Specifically, this investigation aims to find answers to the following questions:

RQ1: How have the results of research evolved on digital learning environments and AI for data literacy?

RQ2: Which authors, institutions, and countries stand out in this field in terms of research productivity and academic influence?

RQ3: What are the dominant research themes, and how are keywords interconnected conceptually in the literature?

2. Methodology

A bibliometric–systematic review methodology is used in this investigation. To identify trends in productivity and collaboration patterns, a quantitative bibliometric analysis was first conducted (Hallinger & Kovačević, 2022; Wang et al., 2023). The PRISMA framework was then used in a qualitative systematic review to interpret conceptual developments and theme structures (Corzo-Zavaleta et al., 2025; R. Kumar, 2025).

In reviewing the literature, inclusion criteria were set, including: (1) peer-reviewed journal articles published from 2017 to February 2026; (2) English-language publications; and (3) focusing on the topics of AI in education, digital learning environment, and data literacy. In accordance with the PRISMA framework, the inclusion and exclusion criteria were delineated to guide the screening process, as outlined in Table 1.

Table 1: Inclusion and exclusion criteria for study selection in the PRISMA-based systematic literature review

Criteria type	Description
Inclusion criteria	Peer-reviewed journal articles published between 2017 and 2026
	Articles written in English
	Studies focusing on AI in education, digital learning environment, and data literacy
Exclusion criteria	Non-English publications
	Open access
	Articles not aligned with the research focus

The data were sourced from the Scopus database, chosen for its comprehensive coverage, stringent indexing criteria, and appropriateness for bibliometric research. Scopus indexes over 25 000 active journals from more than 7000 publishers and exhibits significant overlap with Web of Science, especially in the domains of social sciences and educational technology. Although Google Scholar provides extensive coverage, it incorporates non-curated sources like theses and reports, potentially compromising data consistency in bibliometric analyses. Consequently, Scopus was deemed the most suitable database for guaranteeing data quality and dependability in this research.

Bibliometric analysis was carried out using VOSviewer and Biblioshiny software to visualise bibliographic data, analyse citation networks, author collaborations, conceptual structures, and the co-emergence of keywords, uncovering intellectual concepts, thematic patterns, and the position of AI in education, digital learning

environment, and data literacy. The combination of bibliometric analysis and systematic review assists researchers in synthesising empirical findings and mapping the landscape of research activities, including identifying key contributors and emerging trends (Akinlar, 2025; Hidayat et al., 2025; López-Chila et al., 2024). The integration of these two methodologies provides a thorough picture of the development, previous time, and future path of the topic, making it highly beneficial for multidisciplinary studies to obtain deeper insights (De la Vega Hernández et al., 2023; Mayes-Ramírez et al., 2023). Bibliometric analysis is frequently used in scientific publications to assess scientific journals according to their economic weight (Gardazi et al., 2023).

The initial stage of this study involved selecting keywords using a macro (top-down) approach, starting with a broad search and narrowing it down to more specific studies and topics. Based on the evaluation of previous research and the limited number of studies that discuss AI specifically in education, the digital environment, and data literacy, these were integrated jointly into a single learning experience. The keywords used in this study are "AI in education", "digital environment", AND "data literacy". The search query is TITLE-ABS-KEY ("AI in education") AND TITLE-ABS-KEY ("digital learning environment") AND TITLE-ABS-KEY ("data literacy").

The Scopus database was chosen because it is used widely for research purposes, including conducting literature reviews, identifying experts in specific fields, and monitoring research trends. What follows in Figure 1 is a flow diagram of the database selection that was reviewed in this study.

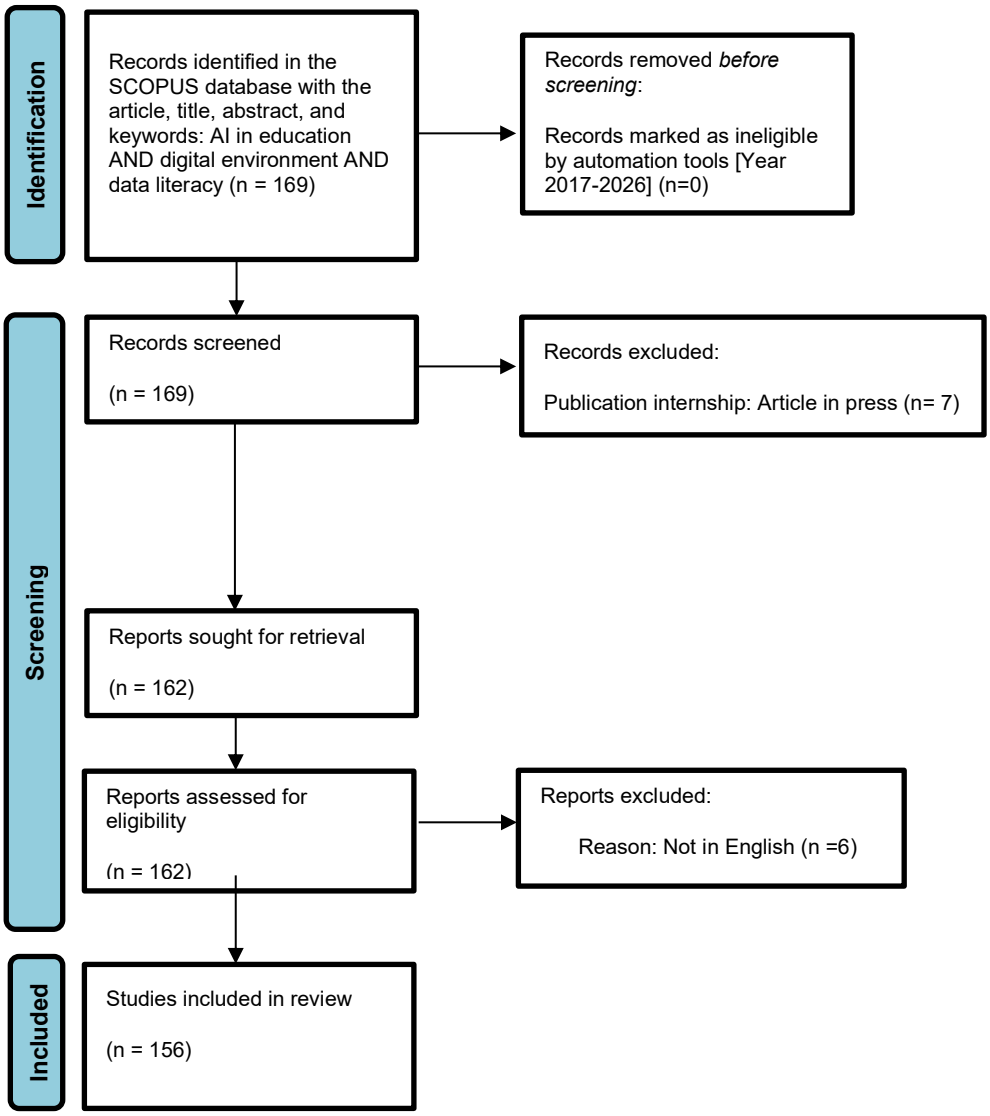

Figure 1: Document selection process flow diagram using the PRISMA protocol

Based on a search of the Scopus database in February 2026, 169 documents were retrieved. Furthermore, the screening process was carried out based on the final state of the literature to be reviewed. The data selection process involved several stages. First, irrelevant articles were excluded during title and abstract screening, focusing on relevance to artificial intelligence, digital learning environments, and data literacy. Second, duplicate records were removed during the data cleaning process to ensure data accuracy.

For data analysis, bibliometric mapping was conducted using VOSviewer and Biblioshiny to identify keyword co-occurrence and thematic clusters. Thematic interpretation was then carried out by examining the relationships among clusters and identifying patterns relevant to data literacy development in AI-driven learning environments. Seven research results were issued, along with related documents (see Figure 1). After that, the articles obtained were again filtered

based on the language of instruction in each article. Six documents were eliminated, so 156 documents were reviewed.

3. Results

3.1 Research Output and Publication Distribution

The analysis of research output and publication distribution was carried out by quantifying research results and the dissemination of publications during the observation period, namely 2017 to 2026. The growth pattern and acceleration of research related to data literacy, AI in education, and the digital environment are evident in scientific production each year. From this growth pattern, it is possible to identify different phases of development, such as emergence, expansion, and acceleration. In addition, the dissemination of publications based on academic sources or venues reflects the degree of consolidation of the field, the concentration of discussion in the core journal, and the position of this field in educational technology and artificial intelligence in education. Therefore, the analysis in this section reveals the structural dynamics that indicate the maturity and development of the field, as well as the number of publications. Figure 2 shows scientific production from 2017 to 2025.

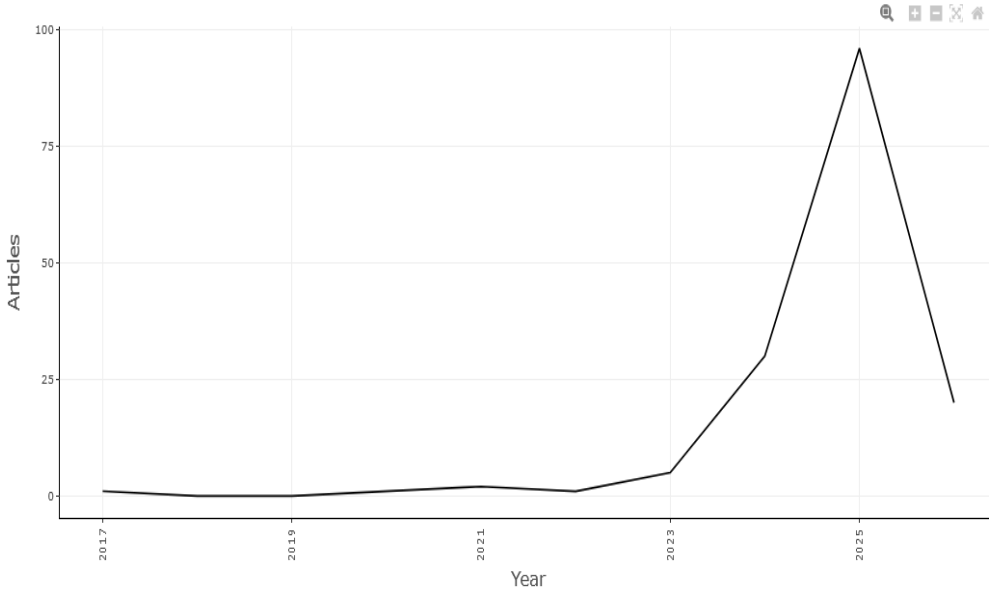

Figure 2: Number of articles published annually from 2017 to 2025

The growth pattern and rate of studies related to data literacy, as well as annual scientific production in digital and artificial intelligence-based learning environments, are shown in Figure 2. Broadly speaking, growth patterns exhibit non-linear features with three clearly known developmental phases. The number of publications from 2017 to 2022 remains very limited and has changed little. Scientific production ranges from zero to two articles per year, with a slight change each year. At this stage, the topic is still exploratory and has not yet become an established research domain, so it cannot be classified as an emerging phase. The low output at this stage suggests that the educational literature has not prioritised the use of AI in developing literacy data.

In 2023, the publication increased to about five articles, which shows a major change. This increase, although still relatively small in absolute terms, marks a phase of growth. In this phase, academic attention begins to develop more systematically. By 2024, there should be an increase of more than 50%, with about 30 publications. The growing adoption of generative AI in education and the rising conversation about data literacy in the data-driven learning ecosystem may have contributed to this growth, suggesting a strong research interest in this area. Scientific production was expected to triple from 2024 to 2025. When this improvement occurred, the field of research began to grow exponentially, and the scientific community showed signs of consolidation.

The very rapid growth rate between 2023 and 2025 shows that incorporating AI into learning and literacy data development has become part of mainstream research in educational technology and AI in learning. Interestingly, about 20 publications will be reduced by 2026. Since this decline is most likely due to limitations in indexation or partial data for the current year rather than reflecting a decline in research interest. It should be interpreted with caution. Data that have not yet been collected fully are often reflected in fluctuations in bibliometric data from the previous year. Furthermore, the distribution of publications by source is shown in Figure 3, indicating that research in this field is concentrated in journals focused on educational technology and AI in education. The sources with the highest contributions indicate that this discourse develops in the realm of methodologically and empirically robust educational technology.

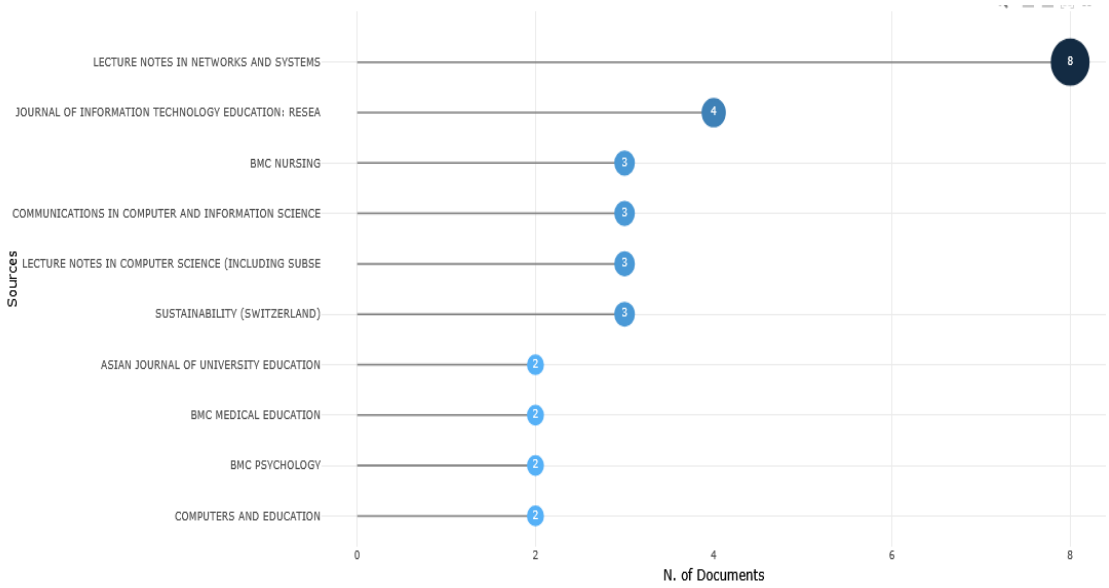

Figure 3: Distribution of publications on AI in education, data literacy, and the digital environment by source (2017–2026)

Publications on artificial intelligence in education, data literacy, and the digital environment span 2017 to 2026, based on the publication sources, as shown in Figure 3. There are 10 primary sources with 32 documents found in this group. Publication contributions are uneven, with one source contributing significantly more than another. *Lecture Notes in Networks and Systems* is the source with the

most publications, with eight papers (25% of the total), and *Journal of Information Technology Education: Research* is the second source with four papers (12.5%). Four other sources each contributed three documents, namely *Sustainability, BMC Nursing, Communications in Computer and Information Science*, and *Lecture Notes in Computer Science*. In addition, four other journals, the *Asian Journal of University Education, BMC Medical Education, BMC Psychology*, and *Computers & Education,* each published two papers, amounting to 6.25% of the total.

The majority of sources (80%) produce only two to three publications, while one source (10%) produces more than five publications. These results show that research on artificial intelligence in education, data literacy, and the digital environment is still being conducted in many scientific institutions and is not concentrated in a single journal. In addition, the dominance of proceedings-based publications and lecture notes series shows that the conference-based research community and technology influence the development of this topic strongly. However, journals in education, health, psychology, and sustainability demonstrate that this field of research is multidisciplinary.

3.2 Influential Authors, Institutions, and Countries

The next analysis examines the social and geographical structures of knowledge production. Mapping of scientific actors at both the individual and state levels is an important indicator in bibliometric studies to understand productivity concentrations, the distribution of citation influences, and patterns of international collaboration. Therefore, two main aspects are discussed in this section: the productivity and consistency of the authors' contributions over time; and geographic distribution and cross-national academic influence. In research on digital learning environments and AI for the development of data literacy, this analysis enables the identification of centres of intellectual dominance, the level of consolidation in the research community, and the dynamics of globalisation. Figure 4 shows the most relevant authors who published their research internationally.

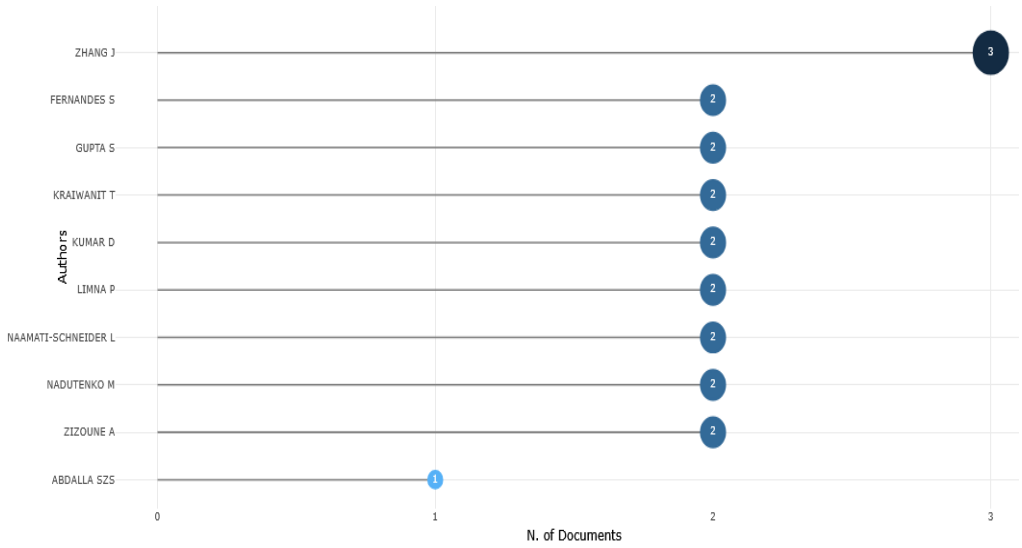

Figure 4: Most relevant author in the literature studied

Figure 4 shows the most relevant authors based on the number of publications published in digital and artificial intelligence-based learning spaces for data literacy advancement from 2017 to 2026. As the visualisation shows, Zhang J is the most prolific writer with three documents. Meanwhile, Abdalla SZS donated one document, while Fernandes S, Gupta S, Kraiwainit T, Kumar D, Limna P, Naamati-Schneider L, Nadutenko M and Zizoune A contributed two documents each. The relatively small productivity range (one to three papers) suggests that there has not been significant dominance by one or two researchers in this field.

In mature research areas, publications and citations are usually concentrated on a small number of authors, who serve as centres of intellectual influence. This condition indicates that this field is interdisciplinary, combining educational technology, artificial intelligence in education, learning analytics, and data literacy. Contributions from various researchers show that progress in this field is driven by relatively open and diverse academic participation, rather than by a single stream of thought (Meng et al., 2025; Thalji & Alkhasawneh, 2025; Wu et al., 2024). Next, Figure 5 shows the dynamics of authors' scientific production over time, as well as the consistency of publications during the period 2015–2026 from several authors. Meanwhile, other writers acted as new contributors in the acceleration phase.

Figure 5: Production of the authors' scientific work from time to time

Figure 5 shows the evolution of the authors' scientific production from 2017 to 2026 in the fields of data literacy, digital learning, and artificial intelligence in education. Each author is linked to their publication year to show productivity patterns over time. The diagram shows that most publications are concentrated in recent years (around 2023–2025), as indicated by a larger bubble, reflecting a significant increase in research activity. Some authors make ongoing contributions over several years, while others appear only at certain points, showing a mix of ongoing engagement and targeted contributions.

In other words, the intellectual network in this field is still in its growth stage and has not yet become an established centre of scientific influence. This is in line with the results in the previous section, which showed that publications are increasing rapidly from 2023 to 2025. This increase appears to be driven more by the growing number of contributing researchers than by the intensification of publication output from a small group of dominant authors. Furthermore, the distribution of research results published from 2015 to 2026 shows the productivity of research across countries and is concentrated in countries with established research and technology infrastructure. This can be seen from Figure 6.

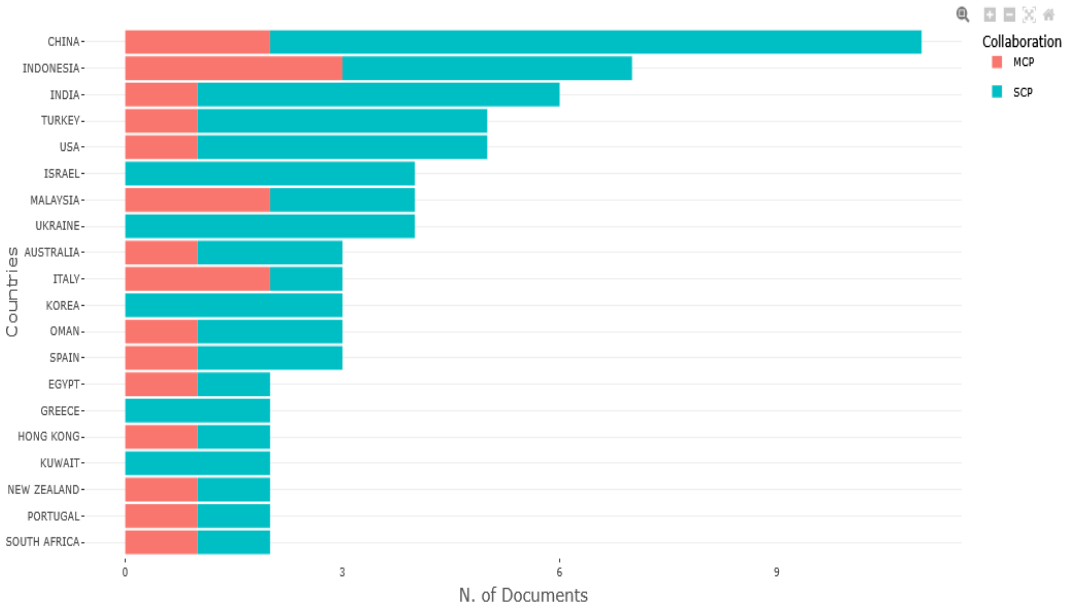

Figure 6: Most influential countries

Figure 6 shows the most influential countries in research on digital learning environments, artificial intelligence in education, and data literacy from 2017 to 2026. It distinguishes between a single-country publication (CP) and a multi-country publication (MCP). China has the highest number of publications, mostly dominated by domestic output (SCP) but also involving international collaboration. Indonesia and India have significant productivity, and Turkey and the US show a combination of national and collaborative contributions.

More moderate contributions include countries like Israel, Malaysia, Ukraine, Australia and Italy. While the presence of SCPs in most countries indicates that research is still largely conducted nationally, MCP later shows that global research networks are expanding gradually, suggesting that the field is emerging internationally with varying degrees of collaboration. A global research network, accompanied by an established research and technology infrastructure in a country, does not only show high productivity, but also a significant global citation rate (Frenken et al., 2005). This can be seen from the research findings presented in Figure 7, indicating a strong academic influence in shaping the direction of discourse.

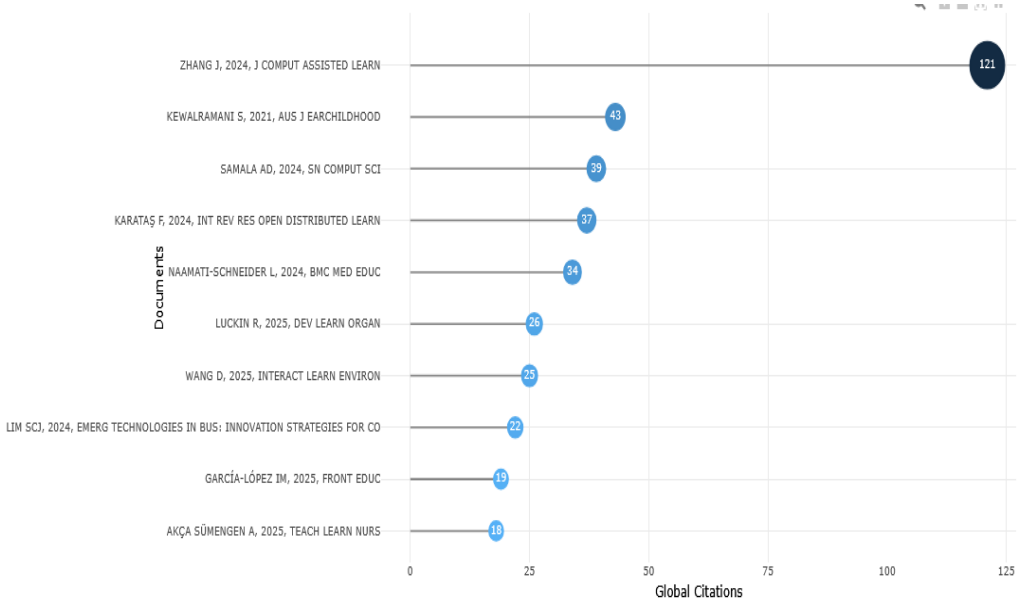

Figure 7: Most cited documents globally

Figure 7 depicts the most cited documents globally related to research on digital learning environments, AI in education, and data literacy from 2017–2026. The X axis on the graph shows the total citations and the Y axis lists the details of the article (author, year, and journal). Based on the research findings presented in the graph, Zhang J (2024), who published his research results in *the Journal of Computer Assisted Learning*, ranked first with 121 citations and showed a much stronger academic impact than other documents. Furthermore, it is followed by Kewalramani S (2021) with 43 citations, Samala AD (2024) with 39 citations, and Karatas F (2024) with 37 citations, while other articles range from 18–34 citations.

The high number of citations demonstrates a substantial conceptual and empirical contribution to the development of AI integration in digital learning and data literacy environments. This contribution reflects a situation in which research on this subject is advancing so quickly that even relatively recent publications can achieve considerable global impact in a short time. The author and their country of origin become an inseparable attachment as an identity of published research results. In addition, there are keywords that show a pattern of collaboration and interconnectedness in this study globally. Then, the interaction between actors, geographical location, and thematic focus shows that this field has a global character with a certain regional concentration. This can be seen in Figure 8.

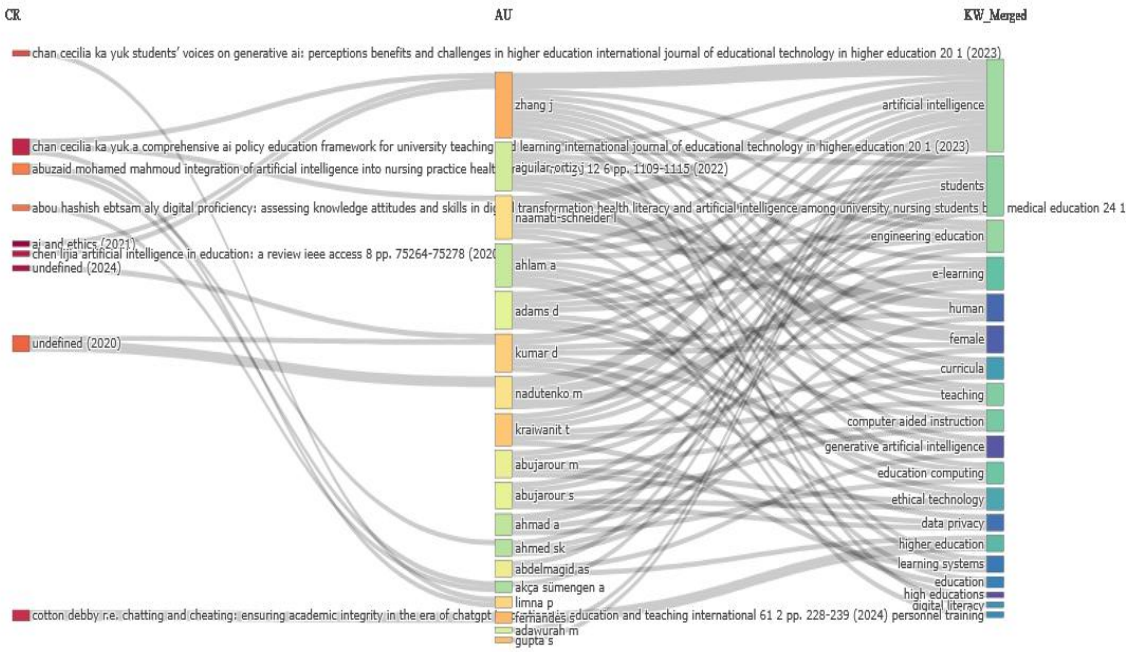

Figure 8: Three plot fields that connect countries, authors, and keywords in digital environmental research, AI in education, and data literacy (2017–2025)

The plot in Figure 8 shows the relationship between cited references (CR), authors (AU), and merged keywords (KW_Merged) in research on digital learning environments, artificial intelligence in education, and data literacy. On the left side, the most frequently cited references are about students' perceptions of generative AI, academic integrity in the ChatGPT era, and AI-based educational policy frameworks. The central column shows a network of interconnected and productive authors, reflecting increasing academic collaboration across disciplines and education.

Prominent keywords on the right side include artificial intelligence, students, higher education, e-learning, generative artificial intelligence, data privacy, ethical technology, and digital literacy. This suggests that research is emphasising the incorporation of AI in the digital education environment as well as growing concerns about morality, data protection, and the development of data literacy. The flows of the three fields show that this research area is very connected. They connect theoretical foundations, key contributors, and dominant research themes into a coherent knowledge structure. This means that research on digital learning environments driven by artificial intelligence and data literacy has many aspects and benefits.

In addition, this emphasises the importance of determining the changes of modern education. The relationship between the author and the globally cited document is inseparable from the keywords used in the publication of published research results. The keyword tree map (Figure 9) and the visualisation of the word cloud (Figure 10) show the dominance of the use of terms as keywords. Figures 9 and 10 are presented next.

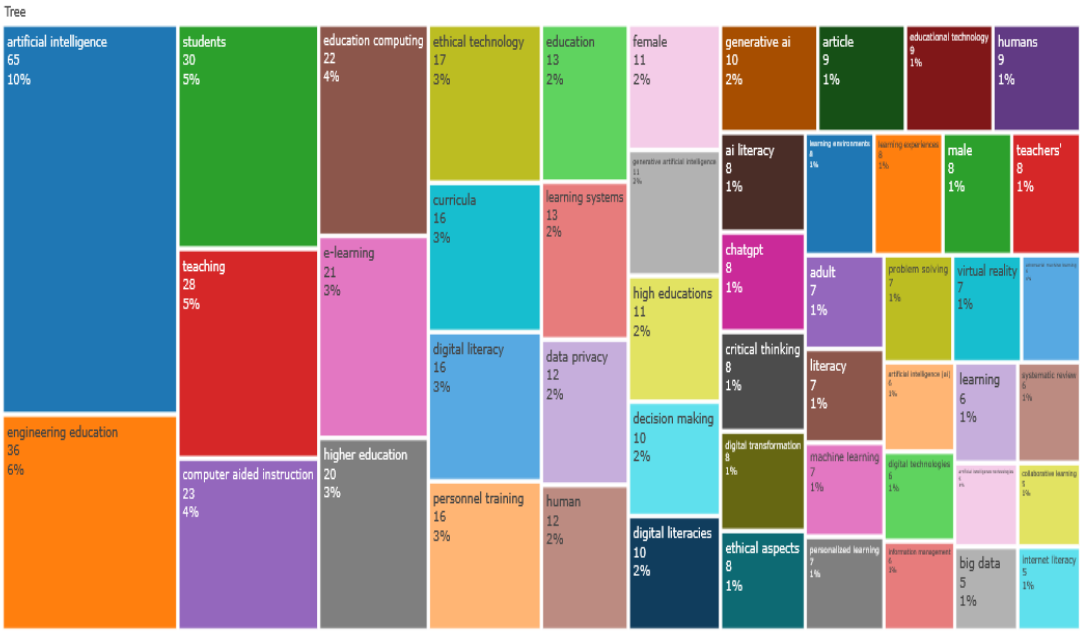

Figure 9: Authors' keyword tree map

Figure 9 shows the authors' keyword-related tree map to illustrate the distribution and frequency of keywords in digital learning environment research, AI in education, and data literacy from 2017–2026. The size of each rectangle represents the frequency of occurrence, while the percentage indicates its proportion in the entire dataset. The keyword artificial intelligence was the most dominant with 65 instances (10%), followed by engineering education with 36 (6%), students with 30 (5%), and teaching with 28 (5%). Other high-frequency keywords included computer-aided instruction (23; 4%), educational computing (22; 4%), e-learning (21; 3%), higher education (20; 3%), and curriculum, digital literacy, and personnel training (16; 3% each).

Supporting themes such as learning systems, data privacy, ethical technology, digital literacy, and decision-making are also evident, along with more specific emerging topics such as ChatGPT, generative AI, virtual reality, and big data, each contributing about 1%. The dominance of the core keywords indicates that the research focuses primarily on integrating artificial intelligence into engineering and educational contexts, emphasising digital literacy, learning systems, and ethics and data privacy considerations. Based on the thematic structure of the tree map, the research focus centres on AI as a core concept, intertwined with the pedagogical, technological, and data literacy dimensions in a multidisciplinary framework. Next, the relationship between AI and data literacy can be seen as a strong, interconnected thematic structure, as shown in Figure 10.

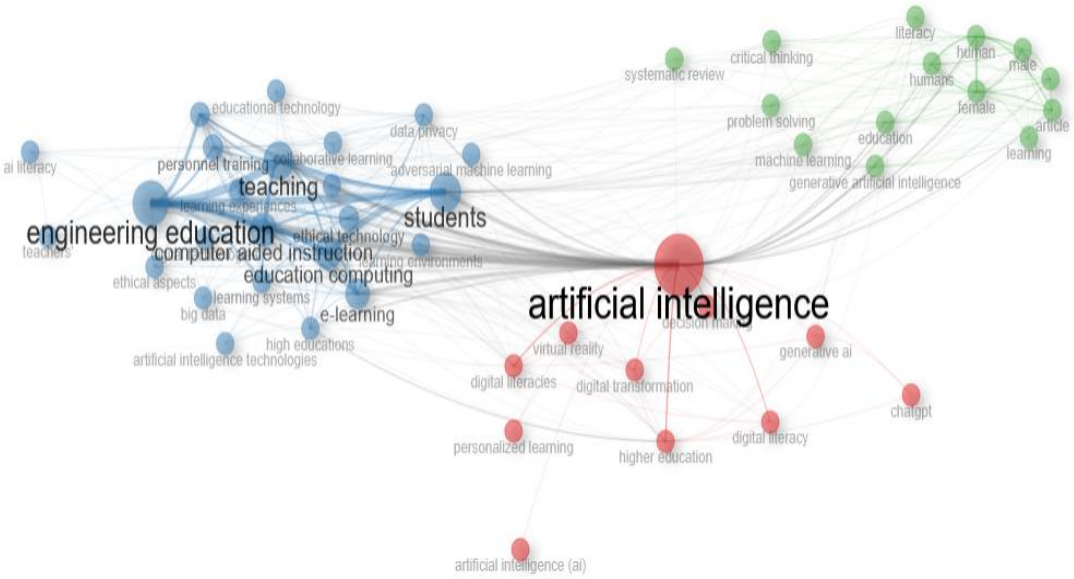

Figure 10: Co-occurrence network

The interconnected network of keywords forming groups together illustrates the interconnectedness between terms in the literature reviewed on AI in education, data literacy, and digital learning environments, where each node represents a keyword; the size of the node reflects the frequency; the connecting line indicates the strength of the relationship; and the colour indicates a thematic cluster. The term artificial intelligence emerged as the largest and most central node, affirming its role as a core concept connecting themes such as digital literacy, higher education, digital transformation, decision-making, generative AI, and ChatGPT. Furthermore, other clusters dominated by engineering education, teaching, students, computer-aided instruction, educational computing, and e-learning highlight the context of pedagogical and instructional implementation.

Moreover, there are clusters that include literacy, critical thinking, problem-solving, and machine learning, reflecting their relationship to cognitive skill development. The dense interconnection shows that the field is highly interdisciplinary and integrated, with AI serving as a central hub that connects the technological, pedagogical, and literacy dimensions simultaneously. Then, the initial focus of the research is seen to be more related to adaptive systems and e-learning (Alghamdi et al., 2025), while the latest period shows an increase in attention to generative AI, ethical issues, and data-driven decision-making, as shown in the graph in Figure 11.

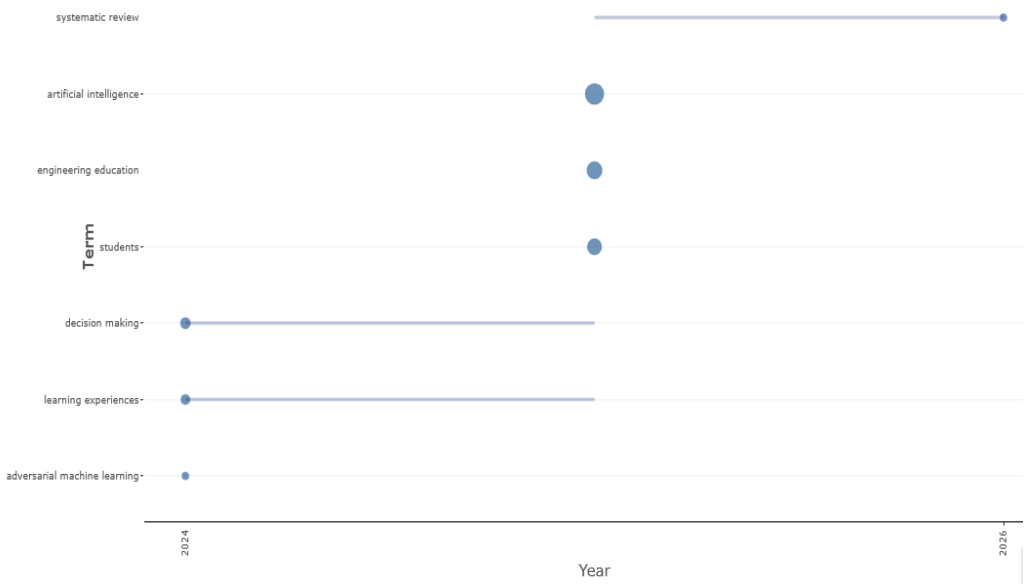

Figure 11: Trend topics related to AI research in education, data literacy, and digital environment

Figure 11 presents the evolution of research topics on AI in education, data literacy, and digital learning environments between 2024 and 2026, where the horizontal axis indicates the year, the vertical axis expresses key terms, the bubble size indicates the frequency, and the horizontal line reflects the duration of the topic's relevance. The topic of systematic review spans the longest period until 2026, indicating that systematic review methodology is increasingly important for examining the development of AI in education.

Core themes such as artificial intelligence, engineering education, and students emerged consistently with high intensity, confirming that research remains focused on integrating AI into engineering education and student learning contexts. Emerging topics such as decision-making and learning experiences show increased attention since 2024, reflecting interest in the impact of AI on cognitive processes and learning quality, while more specific themes such as hostile machine learning are emerging with lower frequency and shorter time spans, suggesting that they are still a niche area, and overall, the numbers indicate a shift from broad conceptual discussions to more specific and methodological explorations, signalling the maturation and diversification of research. Next is the division of themes into motor themes, niche themes, emerging/declining themes, and basic themes, as presented in Figure 12.

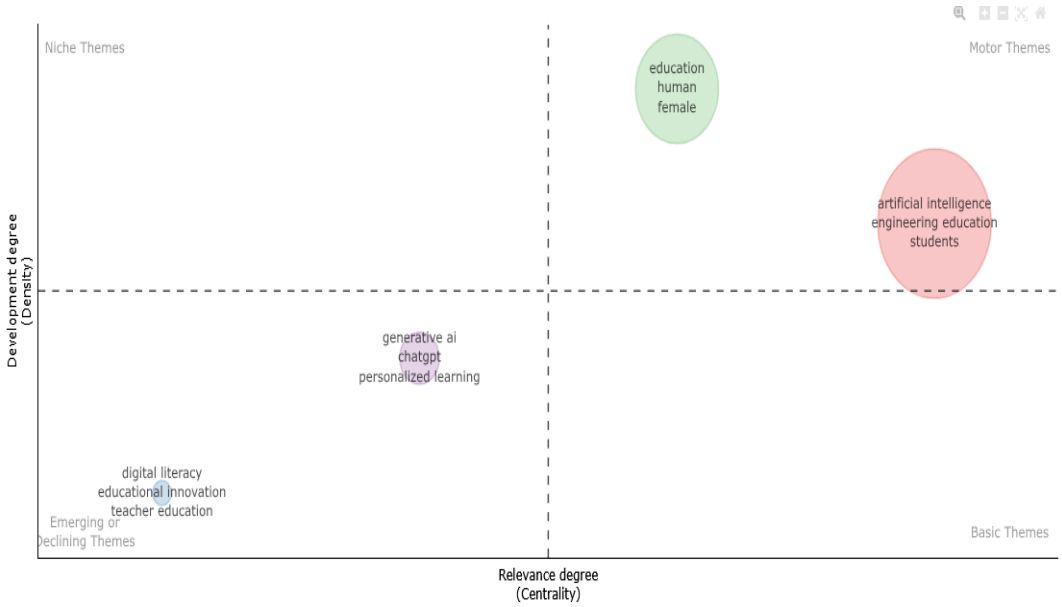

Figure 12: Thematic map

The thematic mapping presented in Figure 12 illustrates the structure and maturity of research themes in AI in education, data literacy, and digital learning environments, based on two main dimensions: the level of relevance (centrality) on the horizontal axis and the level of development (density) on the vertical axis. The theme map produced by bibliometric analysis was examined subsequently using a systematic review method to provide a more in-depth conceptual explanation of the detected clusters.

Figure 12 is divided into four quadrants, namely motor themes, basic themes, niche themes, and emerging or declining themes. Theme categories are determined based on the size of the bubble representing the thematic contribution in the dataset. The largest clusters in the motor themes quadrant include artificial intelligence, engineering education, and students, demonstrating high relevance and development, and positioning them as the main drivers of research fields. Moreover, this theme focuses primarily on using artificial intelligence to enhance data literacy through adaptive, data-driven learning experiences. A closer look at the selected works reveals that these themes are linked strongly to personalised learning systems, learning analytics, and intelligent tutoring systems, indicating a mature and well-developed line of research.

Conversely, the emerging and niche themes indicate areas still in development, including the ethical implications of AI, the importance of critical data literacy, and the role of digital environments in cultivating higher order thinking skills. The systematic review of these clusters underscores that, despite the increasing attention these topics receive, their empirical validation and theoretical foundation remain inadequate. Moreover, the basic themes illustrate fundamental research that links digital learning environments to advances in data literacy, frequently emphasising conceptual frameworks and pedagogical models. The comprehensive analysis of this research indicates that, although the technological

aspect of AI is well-defined, the pedagogical integration and its effects on the critical data skills of learners require further investigation.

The personalised ones occupy transitional areas, suggesting that growth could become a central theme in the future. This mapping confirms that the integration of AI into engineering education and student learning is at the core of the research landscape, with new technology-oriented themes gaining momentum amid digital transformation in education. Furthermore, the analysis of the theme can be seen as its factorisation, revealing a relatively consolidated intellectual structure with several main clusters that reflect the meeting between technology, pedagogy, and data literacy, as shown in Figure 13.

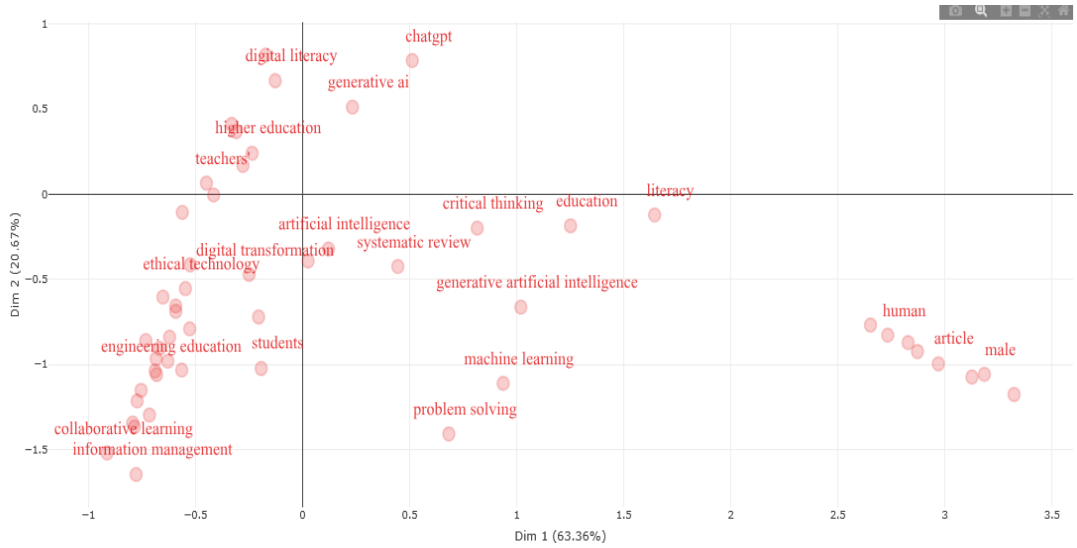

Figure 13: Factorial analysis

The factorial analysis presented in Figure 13 maps the conceptual structure of research keywords in AI in education, data literacy, and digital learning environments into two main dimensions, Dimension 1 (63.36%) and Dimension 2 (20.67%), which account for the largest variance in the dataset, where the distance between keywords reflects thematic differentiation. On the right side (positive Dimension 1), keywords such as human, article, and male imply a research orientation that prioritises study subjects, demographic features, and empirical reporting rather than pedagogical or technological dimensions. Their separation from themes such as collaborative learning and engineering education suggests that Dimension 1 distinguishes between participant-oriented empirical studies and education-focused conceptual or instructional research.

In contrast, the middle right area includes literacy, education, critical thinking, machine learning, and solving problems, which reflect the integration of cognitive competencies and AI technologies in the context of education; on the left side (negative Dimension 1), themes such as engineering education, students, collaborative learning, information management, and ethical technology emphasise pedagogical context and ethical considerations. Along Dimension 2 (vertical axis), the upper region highlights innovative topics such as ChatGPT,

generative AI, digital literacy, and higher education. In contrast, the lower region emphasises more technical and application-oriented themes such as machine learning and problem-solving.

4. Discussion

The developments found in this study are not only those related to the research focus on AI in education, but also those that facilitate data literacy and teach how to understand it. At the beginning of its emergence, AI was used as a tool to support the learning process; of late, AI is being used to provide learning experiences that leverage AI (M. Kumar, 2025; Limame et al., 2026; Wollweber, 2024).

In other words, artificial intelligence is turning into an interactive environment that enables data-driven thinking (Monika Singh et al., 2024), analysis, and decision-making processes, rather than additional tools that help students to make sense of data (Seremeti & Anastasiadis, 2025; Seremeti & Anastasiadou, 2025). In addition, these findings suggest that the formation of a robust conceptual framework has not kept pace with the acceleration of scientific production. Many studies still focus on the application of technology without explicitly building an integrative pedagogical model (Alavi et al., 2009; Čubela et al., 2023; Elsayary, 2023). Therefore, the field is evolving constantly and still requires a deeper theoretical understanding.

The field is still in the stage of epistemic identity formation, as indicated by the authors' productivity structure and relatively dispersed geographical distribution (Carvalho & Batty, 2006). The interdisciplinary nature and conceptual fragmentation is demonstrated by the absence of a strong intellectual figure or centre (Osbeck & Nersessian, 2024; Özbay et al., 2025). These findings suggest that cross-disciplinary theoretical cooperation is needed (Osbeck & Nersessian, 2017). Educational technology and AI in education cannot run simultaneously without a sustainable pedagogical foundation (Avalekar et al., 2025; Danday, 2019; Yunusaliyev et al., 2024). Otherwise, research can be stuck on short-term technical solutions without a sustainable pedagogical foundation. As thematic analysis shows, artificial intelligence serves as a key conceptual focus. However, the meaning is much broader than just keyword dominance.

Data literacy in the AI era requires a reflective aspect, namely understanding how the system deals with biases, decisions and recommendations (Passas, 2024). These results reinforce the argument that data literacy should be defined as an evolving ability in human–machine relationships. This research contributes to strengthening the data literacy framework driven by artificial intelligence, an approach that views data literacy as a capability built through active interaction with intelligent systems. The framework expands on traditional data literacy theories rooted in statistics and numeracy, incorporating ethical, distributed cognition and algorithmic dimensions (Schüller, 2022; Tran et al., 2023). There is also a need to combine critical literacy theory, digital constructivism, and cognitive pressure in the context of AI (Mahala & Chauhan, 2025). AI, as part of emerging learning ecosystems, is discussed in the literature as having the

potential to influence metacognitive processes, the distribution of knowledge authority, and aspects of cognitive control. In this context, learning theory may need to be examined further in relation to AI-supported pedagogical practices.

Furthermore, the systemic bibliometric approach that has been carried out has found the evolution of a rapidly evolving field (Che Ghazali et al., 2025; Guo et al., 2024; Jaleniauskienė et al., 2023; Pinheiro & Azevedo, 2026). However, in the future, research should go beyond descriptive mapping to include more in-depth longitudinal analyses, such as network centrality, theme evolution across time periods, and burst citation analysis. In addition, a mixed-methods research design is required. It should combine a qualitative exploration of AI implementation practices in the classroom with a quantitative analysis of the network. Without methodological triangulation, our understanding of AI integration and data literacy will remain at the surface level.

The use of AI in learning is not limited to tool use; teachers can create learning scenarios that allow students to interpret carefully the data generated by the artificial intelligence system, understand the basic logic of the algorithm, and identify potential biases (Ajani et al., 2025; Bedoya-Cano et al., 2025; Yadav, 2024). In addition, it can develop the ability to make careful data-driven decisions. Therefore, artificial intelligence-based pedagogy must change from being an instructional approach to a more constructive and reflective approach. Teachers do not only help students to use technology but also serve as epistemic mediators, helping them to understand how data and algorithms shape knowledge. In addition, it is necessary to develop a curriculum that integrates data literacy and artificial intelligence literacy explicitly. Without a systematic curriculum design, the use of AI may become too simple and will not help to improve competence in the 21st century.

5. Conclusion

This study aims to examine the mapping and trends of research in digital learning environments and artificial intelligence for data literacy. This is accomplished by a bibliometric and systematic review methodology. The results of the study indicate that the field is experiencing substantial advancement. This process involves conceptual and structural dynamics that could create new paradigms in educational technology and artificial intelligence in education.

The results indicate that the increase in publications in recent years has been abrupt rather than incremental. This acceleration signifies a transition from simple technology integration to a pedagogical transformation propelled by artificial intelligence. Digital learning environments are viewed increasingly as dynamic ecosystems in which students interact with data and algorithmic systems, rather than simply as platforms for the dissemination of material. The geographical distribution of authors and production trends indicates that this topic is widely dispersed and is not yet dominated by a single intellectual hub, implying that theoretical consolidation is still underway. Despite the rise in international participation, there is a necessity for more robust collaborative

research networks to establish a more cohesive and durable knowledge framework.

Thematic analysis finds artificial intelligence as the primary conceptual node connecting literacy, technology and pedagogy. The significance of AI-related data literacy has evolved beyond traditional data interpretation to encompass the ability to engage with, comprehend and assess algorithmic systems. This study reveals a paradigm shift in data literacy, conceptualising it as an evolving capacity arising from dynamic interactions between humans and intelligent systems. In summary, three principal findings are emphasised: (1) a temporal transition towards the acceleration and consolidation of the field; (2) a nascent yet globally expanding scientific framework; and (3) a conceptual evolution that positions artificial intelligence as an ecosystem influencing data literacy. These findings suggest that the area is in a pivotal developmental phase, characterised by a more defined yet still progressing epistemic trajectory.

This study contributes theoretically to the establishment of a conceptual framework that unifies digital learning environments, AI systems, and data literacy into a cohesive paradigm. It emphasises the necessity of redefining data literacy, not as a fixed skill but as a contextual and dynamic construct shaped by algorithmic mediation and socio-technical interactions. This synthesis suggests that AI-driven educational environments play an important role in shaping knowledge construction processes. The findings present significant implications for educators and policymakers from a practical standpoint.

The findings indicate that educators should reform instructional methods to transcend mere technical proficiency with digital tools, aiming instead to cultivate critical engagement with AI systems, including enhancing the algorithmic awareness of students, their reflective thinking and ethical understanding of data use. The study underscores the necessity for policymakers to develop educational policies and curricular frameworks that incorporate AI literacy and data literacy as essential competencies, while also fostering institutional capacity for AI-informed pedagogy. Moreover, policies that promote cross-institutional and international collaboration are vital for enhancing research networks in this swiftly advancing domain.

Nonetheless, some limits must be recognised. Initially, reliance on bibliometric data leads to the exclusion of papers not indexed in the chosen database from the analysis. Second, metadata-driven methodologies may capture the conceptual intricacies of individual studies insufficiently, necessitating interpretative prudence in thematic analysis. Third, the swift advancement of artificial intelligence, especially generative AI, may transform the research field quickly. This analysis is based solely on a single database (Scopus), which, while comprehensive and high-quality, does not encompass all pertinent publications found in other databases such as Web of Science or Google Scholar.

Given these constraints, subsequent research should employ multi-database methodologies to improve comprehensiveness and robustness. Theoretical progress is required to include data literacy, AI literacy, and intelligent systems-based teaching explicitly into a cohesive framework. It is advisable to conduct empirical studies utilising design-based research methodologies to investigate the cognitive, metacognitive, and ethical effects of AI-driven learning environments. Moreover, cross-cultural and international collaborative research is vital to understanding contextual disparities in AI applications in education. Future investigations must also examine ethical concerns rigorously, including algorithmic bias and the enduring effects of generative AI on the epistemic agency of learners.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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