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Research Article

Artificial intelligence in inquiry-based science teaching: A bibliometric study

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ABSTRACT

The integration of artificial intelligence (AI) into science education has accelerated in recent years, raising urgent questions about its role in supporting inquiry-based pedagogies. This study employs a bibliometric methodology to map global research trends, subject areas, geographical distribution and conceptual structures at the intersection of AI and inquiry-based learning. A Scopus query retrieved 26,283 documents, which were analyzed through descriptive statistics and science mapping. Findings reveal a sharp rise in publications since 2017, with notable peaks in 2024 and 2025, reflecting the rapid mainstreaming of AI in science education. Subject area analysis indicates that while research is anchored in the social sciences and computer science, it has progressively diversified to encompass psychology, mathematics, engineering and medicine. Geographically, the USA, China, and the UK dominate output, but growing contributions from Indonesia, India and Malaysia highlight increasing global engagement. Keyword co-occurrence analysis identified five thematic clusters: technological foundations, pedagogical applications, human and social dimensions, learner engagement, and classroom practice. By providing a large-scale bibliometric analysis of research at the intersection of AI and inquiry-based science education, this study establishes a foundation for future scholarship while underscoring unresolved challenges surrounding equity, ethics and collaboration. The findings also provide evidence to inform policy initiatives, teacher training programs and equitable investment in AI-enhanced science education.

Keywords: artificial intelligence, inquiry-based learning, science education, bibliometric analysis

INTRODUCTION

The increasing presence of artificial intelligence (AI) in education has stimulated widespread interest in how emerging technologies are reshaping science teaching and learning. Science education, particularly at the primary and secondary levels, plays a pivotal role in cultivating curiosity, problem-solving skills and scientific literacy for the 21st century. One approach that exemplifies these aims is inquiry-based learning, which positions students as active participants in the practices of science–asking questions, planning and conducting investigations, analyzing and interpreting data and constructing explanations from evidence. Rather than emphasizing memorization, inquiry stresses learning science by doing science (National Research Council [NRC], 2012).

AI integration has been highlighted as a transformative force, enabling personalized learning, enhancing assessment practices and equipping teachers with new tools for addressing misconceptions and diversifying pedagogy (Kotsis, 2024). In science classrooms, applications such as intelligent tutoring systems, adaptive platforms and AI-powered simulations are already redefining traditional instruction, while generative AI and conversational tools like ChatGPT are beginning to support inquiry-based learning, problem-solving and critical thinking. These developments suggest that AI represents not only a technological innovation but also a pedagogical shift aligned with calls for deeper engagement, inquiry and equity in science education (Mustofa et al., 2025).

To capture the scope and direction of this transformation, bibliometric analysis provides a rigorous methodology for mapping knowledge production, identifying influential contributors and uncovering thematic clusters in research (Donthu et al., 2021). Unlike traditional reviews, bibliometric approaches allow researchers to analyze large datasets systematically, revealing publication patterns, collaboration networks and conceptual structures that define the trajectory of a field. Advances in science mapping and performance analysis have made it possible to track the rapid expansion of AI-related research in education, as well as its intersections with inquiry and project-based pedagogies. This study therefore employs bibliometric methods to examine the integration of AI into inquiry-based science education, aiming to provide a structured overview of trends, opportunities and challenges (Donthu et al., 2021; Kotsis, 2024; Mustofa et al., 2025; NRC, 2012).

The need for this study arises from the rapid expansion of AI in contemporary science education and the increasing adoption of inquiry-based pedagogies, even though little is known about how these two domains evolve together on a global scale. As AI tools become more integrated into classroom inquiry–supporting questioning, investigation, data analysis, modelling and evidence-based reasoning–it is essential to understand the broader research landscape in which this integration is taking place. The objective of this study is therefore to provide a large-scale bibliometric mapping of research connecting AI with inquiry-based science teaching, examining publication trends, disciplinary and geographical patterns and conceptual themes. By offering a comprehensive, data-driven overview, such a study can contribute to science education scholarship and supports more informed pedagogical and curricular decisions in the age of AI (Kotsis, 2024; NRC, 2012; Scopus, 2025).

LITERATURE REVIEW

Bibliometric studies provide a systematic means of charting research landscapes, identifying growth patterns and uncovering thematic structures in emerging fields. In education, such studies are particularly valuable for tracing how technological innovations, including AI, are integrated into teaching and learning. Earlier reviews of AI in education examined applications ranging from machine learning to robotics and adaptive platforms, highlighting their pedagogical and policy implications. Yet, despite confirming the rapid rise of AI-related research, relatively few studies have focused specifically on its convergence with inquiry-based approaches in science education–a gap the present study seeks to address (Donthu et al., 2021; Genc & Kocak, 2024; Jia et al., 2024; Kavitha & Joshith, 2024).

Bibliometric Studies Regarding AI in Science Education

Genc and Kocak (2024) analyzed 867 publications on AI in science education from 2019 to 2023 using the Web of Science and VOSviewer, focusing on the introduction of AI in science and the related concerns. Their results revealed a marked rise in output, particularly in 2022 and 2023, with the USA, China, and Australia as leading contributors. Dominant themes included machine learning, AI and learning analytics, reflecting strong interest in adaptive and data-driven approaches. The authors emphasized not only rapid growth but also the need for broader database coverage and more robust international collaboration.

Building on this, Kavitha and Joshith (2024) conducted bibliometric mapping and a systematic review of 20 Scopus-indexed studies published between 2013 and 2023 on AI in K-12 science education. They found that robotics, chatbots and machine learning were frequently applied to inquiry-based, project-based, blended and cooperative pedagogies, with outcomes linked to greater engagement, scientific literacy and inquiry skills. While high school contexts were well represented, the study pointed to major gaps at the elementary and middle school levels, underscoring the need for more diversified research.

Similarly, Jia et al. (2024), in a ten-year bibliometric review of 1,338 publications, documented accelerating growth in AI-related science education research after 2019. Their analysis highlighted the USA, China, and Singapore as leading contributors, with strong patterns of international collaboration. Keyword mapping revealed four thematic clusters–machine learning, robotics, learning analytics and inquiry-based/adaptive learning–demonstrating that AI-supported inquiry and robotics-enhanced teaching are among the most prominent emerging directions.

Generative AI has also received increasing attention. Festiyed et al. (2024) analyzed 115 Scopus-indexed publications on ChatGPT in science education between 2022 and mid-2024. Their results showed a sharp

Table 1. Overview of previous bibliometric studies related to AI and science–STEM education

Authors	Database	Focus of study	Key findings
Festiyed et al. (2024)	Scopus	ChatGPT in science education	Sharp increase in publications after 2023; main contributors include USA, Germany, and Canada; themes include classroom application, teacher perception, engagement, and ethical concerns.
Genc and Kocak (2024)	Web of Science	AI in science education	Rapid growth in AI-related science education research; major contributing countries include USA, China, Australia; dominant themes include machine learning and learning analytics.
Jantakun et al. (2024)	Dimensions	AI in STEM education	Steep increase in 2024; USA and China as main contributors; research focuses on personalized learning, mixed-reality systems, analytics, and instructional automation.
Jia et al. (2024)	Web of Science	AI in science education (2013-2023)	Strong expansion after 2019; leading countries USA, China, Singapore; four thematic clusters including robotics, data mining, learning analytics, and adaptive inquiry learning.
Kavitha and Joshith (2024)	Scopus	AI in K-12 science education	Use of robotics, chatbots, machine learning; positive effects on engagement and inquiry skills; need for research in primary/middle school contexts.

surge in output beginning in 2023, with the USA, Germany, Canada, and the Netherlands emerging as key contributors. Keyword clusters highlighted themes such as classroom application, teacher perspectives, collaborative learning and student engagement, alongside growing concerns about ethics and pedagogy. The study concluded that ChatGPT-related research is expanding rapidly worldwide, though unresolved questions remain about integrity, overreliance and long-term impacts on inquiry and critical thinking.

Expanding beyond specific tools, Almasri (2024) conducted a systematic review of 74 empirical studies published between 2014 and 2023 that examined AI integration in science education. Following PRISMA protocols, the review explored impacts about learning outcomes, adoption contexts, perceptions of students and teachers and pedagogical challenges. Results showed that AI tools improved outcomes by fostering engagement, motivation, problem-solving and personalized feedback. Adoption was concentrated in the USA and Germany, with physics, biology and general science as the most frequently addressed subjects. While students and teachers expressed generally positive perceptions, concerns about adaptability, subject-specific accuracy and ethical implications persisted. The study concluded that equity, contextualization and responsible use remain central challenges.

In a complementary analysis, Jantakun et al. (2024) examined 35 publications on AI in STEM education using the Dimensions database. Their study reported a steep increase in research activity in 2024, with the USA leading in productivity and impact, followed by China. The analysis underscored AI's growing role in personalized learning, advanced analytics and instructional automation, while also noting challenges around ethical use, AI literacy and student engagement.

Taken together, these studies, as displayed in **Table 1**, paint a consistent picture of rapidly expanding application of AI in research on science and STEM education, with both opportunities and risks. Across datasets and timeframes, all analyses highlight sharp growth in publications after 2019, with the USA consistently emerging as the most prolific and influential contributor, followed closely by China and active regions such as Australia, Singapore, and Europe (Genc & Kocak, 2024; Jantakun et al., 2024; Jia et al., 2024). Common themes include the integration of machine learning, robotics, chatbots, learning analytics and, more recently, ChatGPT, within inquiry-based and project-based pedagogies (Festiyed et al., 2024; Kavitha & Joshith, 2024). Outcomes consistently highlight improvements in engagement, motivation, literacy and inquiry skills. At the same time, the literature underscores ongoing challenges, including ethical concerns, academic integrity, equitable access and the urgent need for professional development and AI literacy (Festiyed et al., 2024; Jantakun et al., 2024; Kavitha & Joshith, 2024). Collectively, this body of evidence affirms the transformative potential of AI in fostering personalized, data-driven and inquiry-oriented science education while also emphasizing the necessity of addressing its long-term implications for pedagogy, critical thinking and educational equity (Festiyed et al., 2024; Genc & Kocak, 2024; Jantakun et al., 2024; Jia et al., 2024).

Bibliometric Studies in Inquiry-Based Learning

In terms of bibliometric studies on inquiry-based learning in science, Awinda et al. (2024) examined the integration of inquiry-based learning with digital and AI-supported approaches in science education. Their findings emphasized that inquiry fosters critical thinking, problem-solving and collaboration, while digital tools enhance engagement and accessibility. The study underscored the importance of aligning inquiry pedagogy with emerging technologies to maintain its effectiveness in diverse classroom contexts.

Similarly, Lismaya et al. (2024), in their analysis of inquiry-based strategies, explored how technology-enhanced inquiry promotes student-centered learning in science. They reported that integrating inquiry with digital platforms supports deeper understanding of scientific concepts while fostering creativity and reflection. Their study concluded that inquiry-based teaching remains essential for 21st century education, especially when combined with tools that enable adaptive and collaborative learning.

Zulkarnaen et al. (2025) also highlighted the importance of inquiry-based learning for developing higher-order thinking skills in science education. Their study noted that when supported by AI and digital applications, inquiry can extend beyond traditional classroom practices, offering personalized and data-driven pathways for exploration. These findings reinforce the view that inquiry remains a central pedagogical model, capable of adapting to technological advancements while supporting equity in diverse educational contexts.

Likewise, Arifin et al. (2025) investigated the impact of inquiry-based learning on students' critical thinking skills in science classes. They found that inquiry-oriented teaching significantly enhanced students' ability to analyze, evaluate and synthesize information, with technology integration further amplifying these effects. The study highlighted the potential of inquiry approaches to cultivate essential competencies for scientific literacy in an AI-driven educational environment.

Putri (2025) examined the role of inquiry-based instruction in fostering scientific reasoning and problem-solving in primary education. The study stressed that inquiry encourages curiosity, experimentation and reflective learning and that combining it with AI and digital tools enhances motivation and accessibility. These findings suggest that inquiry-based models are highly adaptable to technological change and remain fundamental for building strong foundations in science learning.

Collectively, the reviewed bibliometric studies affirm that inquiry-based and project-based approaches are central to strengthening critical thinking in science education. Research indicates that inquiry-based learning in elementary science has grown steadily–though unevenly across regions–and is increasingly associated with digital and collaborative strategies. Online and blended inquiry models in biology are strongly linked to higher-order thinking skills, particularly when supported by interactive technologies. Project-based learning has also experienced a marked rise in publications, especially in relation to STEM integration and the use of digital tools in hybrid environments. Meta-analytic evidence further confirms that inquiry-based learning significantly enhances critical thinking across educational levels, with guided and open inquiry proving most effective. Guided inquiry, in particular, remains a widely adopted and flexible model that supports structured problem-solving and reflective thinking. Together, these studies highlight the transformative potential of inquiry- and project-based pedagogies, while also underscoring the importance of digital integration, contextual diversity and continuous refinement for sustainable educational impact (Arifin et al., 2025; Awinda et al., 2024; Lismaya et al., 2024; Putri, 2025; Zulkarnaen et al., 2025).

METHODOLOGY

Building on prior bibliometric studies in science education that have mapped research landscapes and identified thematic clusters in AI and inquiry-based learning, the present study adopts a bibliometric methodology to provide a comprehensive overview of this emerging field. Earlier reviews demonstrated the value of large-scale data analysis in tracing research growth, identifying leading contributors and mapping conceptual structures. However, no study has systematically examined the intersection of AI and inquiry-based pedagogies. This gap provides both the context and the rationale for the current methodological design (Almasri, 2024; Festiyed et al., 2024; Genc & Kocak, 2024; Jia et al., 2024; Kavitha & Joshith, 2024).

Data source and search strategy. Consistent with established bibliometric practices in educational research, Scopus was selected as the primary database due to its extensive coverage of education, science and technology. It provides broader coverage in education and technology-related fields, while offering detailed metadata that supports bibliometric mapping. Scopus was selected as the data source, instead of other relevant platforms, because its advanced keyword indexing and subject classification functions align closely with the study's research questions, particularly the identification of thematic clusters and conceptual structures. The following query was applied: ALL ('inquiry AND based AND learning' OR 'inquiry AND based AND instruction' OR 'inquiry AND based AND teaching') AND ALL ('artificial AND intelligence' OR 'AI').

This search retrieved 26,283 documents. The dataset included bibliographic records such as titles, abstracts, author names, affiliations, keywords, document types, years, source titles and citation counts (Donthu et al., 2021; Scopus, 2025).

Research questions. In line with comparable bibliometric analyses, this study addressed four key questions:

1. What are the annual publication rates of studies on AI in science education and how have these evolved over time?
2. Which thematic areas and pedagogical contexts are most frequently represented in the literature?
3. Which countries and institutions contribute most prominently and what patterns of international collaboration can be identified?
4. What are the most frequently occurring keywords and how do their co-occurrence patterns reflect the conceptual and thematic structure of the field? (Genc & Kocak, 2024; Jia et al., 2024).

The dataset was cleaned by removing duplicates and standardizing author and institutional names, as recommended in earlier studies. No restrictions were placed on language or year, enabling a longitudinal perspective on research development. Descriptive analyses of publication output, subject areas, document types and geographical distribution were performed directly in Scopus analyze. For science mapping, VOSviewer was used to visualize co-authorship networks, country collaborations and keyword co-occurrence clusters, applying association-strength normalization and default thresholds. This combination of descriptive and network-based methods aligns with best practices in bibliometric research in education (Donthu et al., 2021; Kavitha & Joshith, 2024; Lismaya et al., 2024; Scopus, 2025; van Eck & Waltman, 2010).

Bibliometric analysis was selected for this study because it enables the examination of large research corpora and the identification of publication trends, disciplinary patterns, geographical distributions and conceptual structures that cannot be captured through traditional systematic review approaches. Given the scale of the dataset retrieved from Scopus, bibliometric methods provide an efficient and reliable means of mapping the evolution and thematic organization of the field. Unlike systematic reviews, which require manual screening and are designed for in-depth analysis of smaller bodies of literature, bibliometric analysis allows for a macro-level exploration of thousands of documents, making it particularly well-suited to the aims of the present study (Donthu et al., 2021)

No language restrictions were imposed in this study. All documents retrieved by Scopus using the search query were included in the dataset, and the linguistic composition of the results reflects the indexing practices of the database rather than author-imposed criteria. Because bibliometric analysis focuses on the complete set of records returned by the database, no manual screening or exclusion based on language or country of origin was carried out. The dataset therefore represents the full scope of publications identified by Scopus under the chosen search parameters (Scopus, 2025).

By aligning its design with previous bibliometric reviews while extending the focus to the intersection of AI and inquiry-based learning, this study ensures comparability with earlier findings while generating new insights into a rapidly expanding research domain (Festiyed et al., 2024; Genc & Kocak, 2024; Jia et al., 2024).

FINDINGS

For the first research question, the Scopus query yielded 26,283 documents related to AI and inquiry-based learning. Analysis of annual publication output showed relatively low and fluctuating growth until the

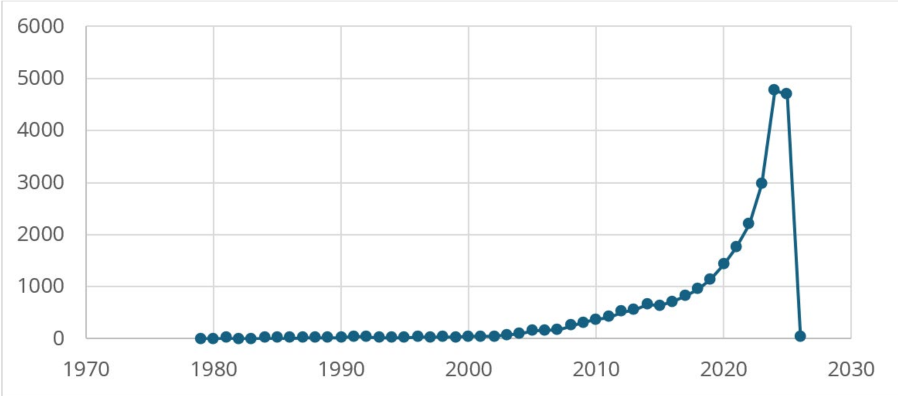

Figure 1. Number of publications per year (Scopus, 2025)

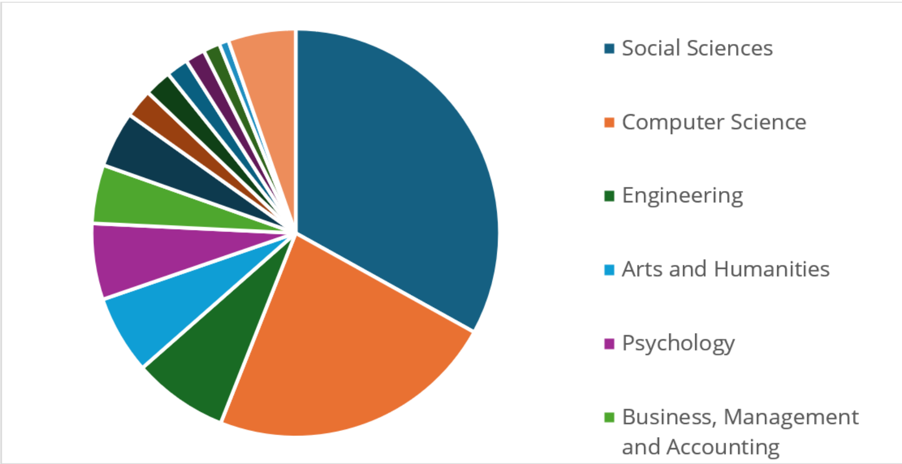

Figure 2. Subject areas (Scopus, 2025)

mid-2000s, followed by steady increases beginning in 2017 and a sharp acceleration in recent years (**Figure 1**). Publications peaked in 2024 with 4,770 documents, while 2025 maintained similarly high output with 4,688 documents. The dataset for 2026 includes only 34 documents, reflecting incomplete indexing for the current year. These results confirm the rapid expansion of research at the intersection of AI and inquiry-based pedagogies, particularly between 2022 and 2025, underscoring growing scholarly interest in the integration of emerging technologies in science education (Almasri, 2024; Genc & Kocak, 2024; Jia et al., 2024; Scopus, 2025).

For the second research question, subject area analysis revealed that research on AI and inquiry-based learning spans a wide range of disciplines (**Figure 2**). The largest share of publications was in the social sciences (16,031 documents), followed by computer science (11,121), reflecting the pedagogical and technological foundations of the field. Additional contributors included engineering (3,654), arts and humanities (3,008), and psychology (2,923), while domain-specific areas such as mathematics (2,149), medicine (1,036), environmental science (641) and physics and astronomy (445) also played significant roles. Categories such as decision sciences, health professions and neuroscience further underscore the interdisciplinary character of this research landscape. Overall, the findings suggest that while the field is grounded in education and social sciences, it increasingly integrates perspectives from technological and scientific domains, demonstrating the convergence of AI, pedagogy and STEM-related areas (Jia et al., 2024; Kavitha & Joshith, 2024; Scopus, 2025).

For the third research question, country-level analysis showed that research on AI and inquiry-based learning is concentrated in several leading regions (**Figure 3**). The USA dominates with 7,023 publications, followed by China (2,753), and the UK (2,289). Other major contributors include Australia (1,332), Germany (1,301), and Canada (1,185), highlighting the strong influence of Western nations. Within Europe, Spain (1,043) is notable, while in Asia, contributions from Indonesia (860), India (855), Malaysia (793), and Taiwan (782)

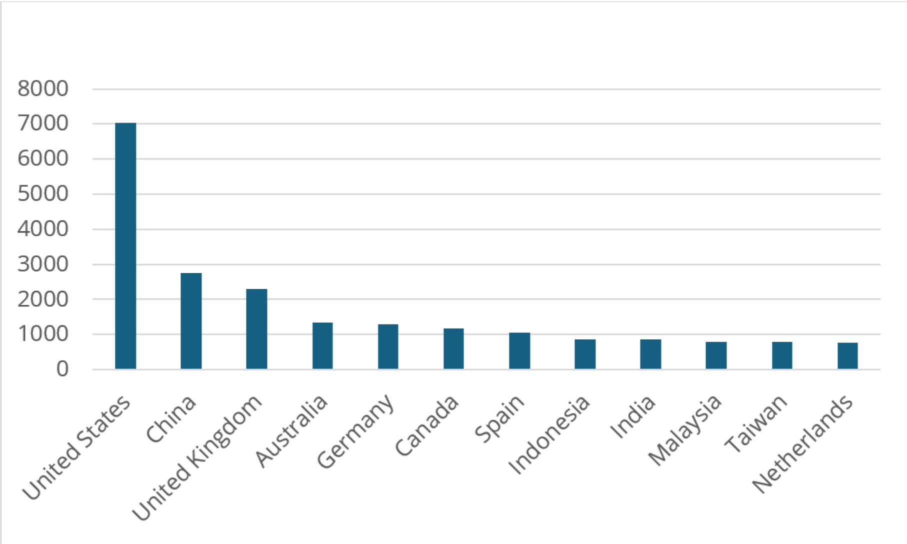

Figure 3. Publications by country (Scopus, 2025)

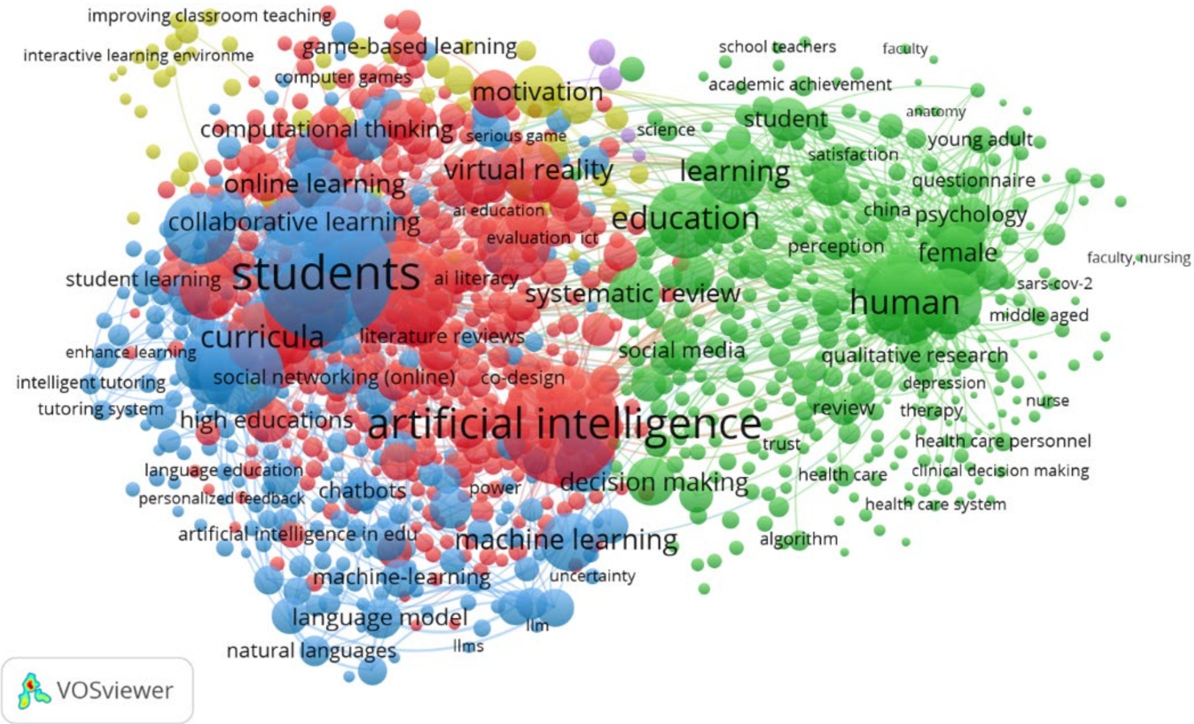

Figure 4. Keyword co-occurrences (van Eck & Waltman, 2010)

indicate growing activity in emerging contexts. The Netherlands (777) further illustrates Europe's active engagement. These results show that although technologically advanced countries continue to dominate, developing and middle-income countries are increasingly contributing, pointing to a gradual global diversification of research activity (Festiyed et al., 2024; Jantakun et al., 2024; Scopus, 2025).

For the fourth research question, keyword co-occurrence analysis identified five distinct clusters, displayed in **Figure 4** and **Table 2**, that illustrate the thematic structure of research connecting AI with inquiry-based education.

The first cluster represents the technological foundation of the field, with terms such as *AI*, *machine learning*, *decision making*, and *virtual reality*. The second highlights pedagogical applications, including keywords like *students*, *curricula*, *collaborative learning*, *online learning*, and *chatbots*. The third emphasizes the human and social dimension, with terms such as *education*, *psychology*, *female*, *health care personnel*, and

Table 2. Keyword clusters identified in the co-occurrence analysis and their educational implications

Cluster	Main keywords	Educational implications
Cluster 1. AI & data analytics	Artificial intelligence, machine learning, deep learning, neural networks, & data mining	Indicates a strong technological foundation underpinning AI-supported inquiry. Emphasizes the need for educators to understand how predictive analytics, intelligent systems, and automated feedback can enhance data interpretation and modelling within inquiry-based learning.
Cluster 2. Teaching, learning, & digital pedagogies	Teaching, learning, pedagogy, digital learning, & instruction	Suggests that AI is increasingly embedded in pedagogical design, supporting inquiry tasks by providing scaffolding, personalized guidance, and adaptive learning environments. Highlights opportunities for integrating AI tools to enhance the inquiry cycle.
Cluster 3. Students, social interaction, & human factors	Students, collaboration, motivation, engagement, & attitudes	Reflects the human-AI dimension in classrooms. Points to the importance of designing AI-supported inquiry activities that promote student agency, motivation, collaboration, and equitable participation.
Cluster 4. Education, adoption, & implementation	Education, integration, adoption, teacher training, & challenges	Shows that institutional and implementation factors influence how AI is incorporated into inquiry practices. Highlights the need for teacher professional development, infrastructure support, and attention to ethical and contextual considerations when deploying AI tools.
Cluster 5. Classroom practice, & learning activities	Inquiry, experiment, classroom, assessment, science & activities	Demonstrates that AI is being used to support hands-on inquiry practices such as experimentation, investigation, and formative assessment. Highlight opportunities for designing AI-enhanced inquiry tasks that strengthen scientific reasoning and data-driven exploration.

qualitative research. The fourth reflects engagement and innovation, with terms like *game-based learning*, *serious games*, *motivation*, and *computational thinking*. Finally, the fifth relates to classroom practice and outcomes, including *schoolteachers* and *academic achievement*. Collectively, these clusters indicate that research on AI in inquiry-based science education is strongly grounded in technological developments, pedagogically diverse, and increasingly oriented toward human-centered, learner-focused, and classroom-based applications, reflecting a growing emphasis on both instructional design and student engagement (Genc & Kocak, 2024; Jia et al., 2024; Kavitha & Joshith, 2024; Festiyed et al., 2024).

Thus, the findings highlight clear growth in publication output, strong representation across both pedagogical and technological subject areas, dominance of a few leading countries alongside increasing global participation and the emergence of five thematic keyword clusters that capture the multidimensional character of the field. These results confirm the rapid expansion and diversification of research on AI in inquiry-based science education, while also revealing distinctive patterns of concentration and thematic development. To interpret these outcomes more fully, it is necessary to relate them to insights from earlier bibliometric studies and to consider their implications for the future of science education. The subsequent section situates the present findings within the broader literature, drawing connections to previous reviews and outlining the challenges and opportunities that accompany the integration of AI into inquiry-based pedagogies (Festiyed et al., 2024; Genc & Kocak, 2024; Jia et al., 2024; Kavitha & Joshith, 2024).

DISCUSSION

The analysis of annual publication output provides important insights into the evolution of research at the intersection of AI and inquiry-based education. While early contributions were sparse, the period after 2017 marked a turning point, with steady increases giving way to rapid expansion between 2022 and 2025. This trajectory reflects the recognition of AI not only as a technological innovation but also as a pedagogical catalyst for inquiry-oriented approaches to teaching and learning. The sharp rise in publications during this period indicates that the field is entering a phase of consolidation, in which AI is no longer peripheral but an integral component of mainstream educational research agendas. This trend also demonstrates the responsiveness of the research community to global educational priorities, particularly the emphasis on digital transformation and the development of 21st century skills (Almasri, 2024; Genc & Kocak, 2024; Jia et al., 2024).

Beyond simple growth patterns, these trends underscore the dynamic interplay between technological breakthroughs and scholarly inquiry. The surge in output after 2022 closely corresponds to the widespread adoption of generative AI tools such as ChatGPT, which quickly stimulated debate, experimentation and empirical investigation in science education. This alignment illustrates how advances in AI capabilities create new opportunities for rethinking inquiry, assessment and pedagogy. Moreover, the consistently high publication levels across consecutive years suggest that research in this area is building long-term momentum rather than responding to short-lived novelty. The accumulation of thousands of studies within a few years points to the establishment of a critical mass of knowledge capable of supporting sustained collaboration, theoretical refinement and methodological diversity. Publication trends, therefore, not only confirm the rapid expansion of the field but also highlight its growing influence on the broader trajectory of science education research (Festiyed et al., 2024; Scopus, 2025).

The subject area analysis confirms that research on AI and inquiry-based education is not confined to a single discipline but spans a wide range of fields. The dominance of social sciences and computer science reflects the dual orientation of the topic: addressing educational and pedagogical questions while simultaneously drawing on technological innovations in AI. This interdisciplinary distribution echoes earlier bibliometric studies that emphasized the centrality of learning sciences, data science and computational methods in shaping AI-related educational research (Genc & Kocak, 2024; Jia et al., 2024). Contributions from psychology and mathematics highlight the integration of cognitive and analytical dimensions into science learning (NRC, 2012), while involvement from medicine, environmental science and physics reflects a tendency for AI in education to extend into applied contexts beyond the classroom (Kavitha & Joshith, 2024).

Equally important, these disciplinary patterns reveal the conceptual foundations of inquiry-based learning in the digital age. The clustering of publications around social sciences and STEM fields mirrors theoretical perspectives that view inquiry as both a pedagogical method and a vehicle for fostering disciplinary thinking (Arifin et al., 2025; Putri, 2025). Integrating AI into these domains reinforces the argument that technology mediates inquiry processes by supporting questioning, data analysis and reflection in ways consistent with inquiry-based frameworks (Almasri, 2024; Awinda et al., 2024; Lismaya et al., 2024). At the same time, the breadth of subject areas suggests that AI is increasingly positioned as a cross-cutting tool, enabling new forms of collaboration and problem-solving across disciplines (Zulkarnaen et al., 2025). These findings point to a deeper theoretical alignment between inquiry as a teaching method and AI as a catalyst for innovation in science education (Donthu et al., 2021).

The analysis of country-level contributions shows that the field is led by technologically advanced nations such as the USA, China, and the UK, consistent with earlier bibliometric reviews in science and STEM education (Genc & Kocak, 2024; Jantakun et al., 2024; Jia et al., 2024). These countries not only dominate publication output but also possess robust research infrastructures and funding systems that support large-scale AI integration in education. The concentration of output underscores the link between technological innovation, investment in research and global visibility in scholarly publishing. Prominent institutions such as Carnegie Mellon University and Curtin University have emerged as central nodes in international collaboration networks, reflecting how leadership in AI development translates into leadership in research on AI pedagogy and inquiry (Festiyed et al., 2024; Jantakun et al., 2024).

At the same time, the growing engagement of emerging regions–particularly in Asia–signals an important diversification. Increasing contributions from Indonesia, India, Malaysia and Taiwan suggest that AI-supported inquiry-based learning is no longer confined to the Global North but is gradually extending into middle-income contexts. This trend aligns with evidence on the value of inquiry-based and project-based pedagogies in fostering critical thinking and higher-order skills across diverse cultural and educational environments (Awinda et al., 2024; Lismaya et al., 2024; Putri, 2025). The rise of these countries illustrates how global adoption of AI tools is accompanied by local adaptation to pedagogical needs, thereby advancing both theory and practice in inquiry-based education. These developments confirm that while global leadership remains concentrated, contributions are diversifying, pointing toward a more inclusive and collaborative research landscape. At the same time, the predominance of English-language publishing may limit the visibility of scholarship from emerging regions, suggesting that the diversification observed here could in fact be broader than bibliometric data alone reveal (Almasri, 2024; NRC, 2012; Zulkarnaen et al., 2025).

The country-level analysis also highlights significant disparities in global research participation, with a number of regions contributing minimally to the field. Expanding research capacity in these contexts will require sustained international collaboration, including joint projects, cross-institutional mentoring networks, and access to shared research infrastructures. Increasing availability of open-source AI tools, training programs for science teachers, and targeted funding initiatives could further support researchers in low-involvement countries. Strengthening institutional support mechanisms, promoting multilingual dissemination and fostering regional research communities may also help broaden global engagement with AI-supported inquiry-based science education. Such efforts are essential for ensuring that innovation in this field develops equitably and reflects diverse educational contexts (Awinda et al., 2024; Zulkarnaen et al., 2025).

The keyword co-occurrence analysis provides further insight into the conceptual organization of research on AI and inquiry-based education. The five clusters demonstrate how the field is structured around technological, pedagogical, social, motivational and classroom-oriented dimensions. The first cluster, centered on AI, machine learning and virtual reality, reflects the technological foundation of the field and aligns with previous bibliometric reviews emphasizing learning analytics, robotics and adaptive platforms (Genc & Kocak, 2024; Jia et al., 2024). The second cluster, focused on students, curricula, chatbots and online learning, resonates with studies showing how AI is increasingly embedded in instructional design and assessment (Kavitha & Joshith, 2024; Mustofa et al., 2025). These clusters confirm that technological innovation and pedagogical integration remain central drivers of research development, highlighting AI's dual role as both a technical and educational phenomenon (Donthu et al., 2021).

Equally significant are the remaining clusters, which highlight the human and social dimensions of AI-supported inquiry. The third cluster, featuring terms such as psychology, female and health care personnel, illustrates intersections between AI-enhanced education and broader concerns with human learning and equity, extending beyond classroom contexts (Awinda et al., 2024; Lismaya et al., 2024). The fourth cluster, with keywords such as game-based learning, motivation and computational thinking, reflects growing interest in engagement strategies, aligning with studies that emphasize creativity, problem-solving and higher-order thinking as outcomes of inquiry-based pedagogy (Arifin et al., 2025; Putri, 2025). Finally, the fifth cluster, with terms like schoolteachers and academic achievement, underscores the importance of classroom practice and the central role of teachers in implementing AI-supported inquiry, echoing findings from studies on project-based and guided inquiry (Festiyed et al., 2024; Zulkarnaen et al., 2025). Taken together, the clusters reveal a field that is conceptually diverse but converges on integrating AI with inquiry to enhance learning, motivation and classroom outcomes (Genc & Kocak, 2024; Jia et al., 2024; Scopus, 2025; van Eck & Waltman, 2010).

The findings of this study also carry significant pedagogical implications for teachers, curriculum designers, and science education researchers. For teachers, the thematic patterns identified in the literature demonstrate the growing potential of AI tools to support core inquiry processes such as questioning, modelling, data analysis, and evidence-based explanation. This underscores the importance of selecting AI applications that align with inquiry principles and promote active engagement rather than passive consumption. For curriculum designers, the emergence of clusters related to adaptive learning, feedback systems, and digital investigation suggests opportunities to embed AI-mediated inquiry activities within science curricula in ways that strengthen conceptual understanding and analytical reasoning. For researchers, the identified clusters highlight productive avenues for future investigation, particularly regarding how AI can best scaffold learner autonomy, facilitate collaborative inquiry, and address issues of equity and accessibility in diverse classroom contexts (Donthu et al., 2021; NRC, 2012).

The results of this study also carry meaningful implications for policymakers who guide the integration of emerging technologies into science education systems. The geographical trends identified in the bibliometric analysis, together with evidence from earlier research showing strong concentration of AI-related work in a small number of countries (Genc & Kocak, 2024; Jia et al., 2024), suggest the need for policies that support more equitable access to AI tools and research participation worldwide. Findings from school-based studies indicate that effective use of AI in inquiry-focused science classrooms requires not only digital infrastructure but also structured guidance, teacher support, and clear implementation frameworks (Kavitha & Joshith, 2024). Policymakers can therefore strengthen system-level readiness by providing professional development, enabling cross-institutional collaboration, and establishing ethical guidelines addressing issues such as transparency, privacy, and responsible use of generative AI. Supporting long-term investment in these areas is essential for ensuring that AI-enhanced inquiry-based science education develops in ways that are sustainable, inclusive, and aligned with national priorities (Almasri, 2024; Festiyed et al., 2024).

In short, the findings demonstrate that research on AI in inquiry-based education has shifted from a peripheral concern to a rapidly expanding and thematically diverse field. Publication trends reveal sharp growth after 2017, culminating in peaks in 2024 and 2025, confirming the accelerated integration of AI into science education. Subject area distributions show that while the field is grounded in the social sciences and education, it is increasingly shaped by technological and STEM-related contributions, reflecting its interdisciplinary nature. The geographical analysis highlights the continued dominance of technologically advanced countries while also emphasizing the growing participation of emerging Asian contexts, pointing to a gradual diversification of global contributions. Finally, the keyword clusters illustrate the conceptual complexity of the field, where technological innovation, pedagogical design, human and social dimensions, learner engagement and classroom practice converge to define the research landscape. Collectively, these results provide a comprehensive picture of the state of the field and establish a foundation for identifying both opportunities and challenges for future inquiry-based science education in the era of AI (Festiyed et al., 2024; Genc & Kocak, 2024; Jia et al., 2024; Kavitha & Joshith, 2024; Scopus, 2025).

CONCLUSIONS

This study provides a comprehensive bibliometric overview of research on AI in inquiry-based education, drawing on 26,283 Scopus-indexed publications. The findings demonstrate rapid growth in output–particularly between 2022 and 2025–confirming the accelerating integration of AI into educational research. Subject-area distributions highlight the dual role of pedagogy and technology, while geographical analysis reveals both the dominance of technologically advanced nations and the growing contributions of emerging contexts. Identification of five keyword clusters further illustrates the field's conceptual diversity, spanning technological innovation, pedagogical integration, human and social dimensions, learner engagement and classroom practice. Collectively, these results position AI-supported inquiry as an increasingly mainstream area of science education research, reflecting global priorities and sustained interdisciplinary engagement (Festiyed et al., 2024; Genc & Kocak, 2024; Jia et al., 2024; Kavitha & Joshith, 2024).

The implications of these findings are significant for both researchers and practitioners. For research, the results offer benchmarks on productivity, collaboration and conceptual structuring that support comparative and longitudinal analyses. For practice, they highlight the potential of AI to enhance inquiry by enabling personalization, timely feedback and innovative forms of engagement, while also underscoring the need for teacher support and context-sensitive implementation. These conclusions echo theoretical frameworks that position inquiry as a driver of scientific literacy (NRC, 2012) and align with empirical evidence that AI can foster critical thinking, collaboration and higher-order skills (Arifin et al., 2025; Kotsis, 2024; Putri, 2025). Future work should therefore deepen examination of how AI-enabled inquiry translates into classroom practice and how it can be adapted across diverse educational systems (Awinda et al., 2024; Lismaya et al., 2024; Zulkarnaen et al., 2025). In addition, bibliometric insights can inform teacher professional development, curriculum innovation and equity-focused AI initiatives, ensuring that technological advances translate into inclusive and sustainable educational practices (Donthu et al., 2021; Mustofa et al, 2025).

The findings of this bibliometric analysis have important implications for science education practice in the age of AI. The thematic clusters identified in the keyword network suggest that AI is increasingly used to support core elements of inquiry-based learning, including questioning, investigation, data interpretation, and evidence-based reasoning. For science teachers, this highlights the need to integrate AI tools in ways that enhance–not replace–students' engagement with authentic inquiry processes. For curriculum designers, the results point to opportunities for embedding AI-enhanced investigative tasks and adaptive learning pathways within science curricula to promote higher-order thinking. These trends also underscore the importance of preparing teachers to evaluate AI tools critically, ensuring their use aligns with inquiry principles and remains pedagogically meaningful (Arifin et al., 2025; NRC, 2012).

Before generalizing these conclusions, several limitations merit emphasis. The findings are shaped by the coverage and indexing practices of Scopus, which may exclude relevant literature captured in other databases such as Web of Science, Dimensions, or Google Scholar. The analysis also relies on quantitative indicators that reveal structural patterns but cannot fully capture the depth of pedagogical design or classroom implementation. Moreover, keyword co-occurrence maps, while valuable for conceptual visualization, may underrepresent nuanced theoretical connections. Addressing these constraints will require complementary systematic reviews, case studies and cross-database analyses to triangulate results and enrich understanding of how AI and inquiry-based pedagogies interact in practice (Donthu et al., 2021; Scopus, 2025).

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