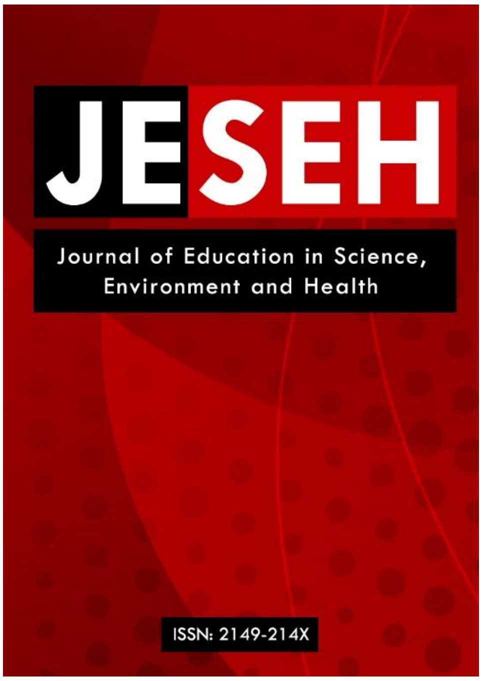

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A Comprehensive Bibliometric Analysis of Artificial Intelligence Research in the Field of Science Education

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A Comprehensive Bibliometric Analysis of Artificial Intelligence Research in the Field of Science Education

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Abstract

Today, the importance of artificial intelligence in science learning and teaching is rapidly increasing. The growing interest in this field and the resulting increase in academic publications on the subject make it challenging to understand its progress and trends on a global scale. Furthermore, a literature review reveals a notable lack of studies that offer a comprehensive perspective, reflecting the current state and research trends in this field. Therefore, this study aims to analyze the current state, evolution, and important research trends in studies on artificial intelligence in science education from 1985 to 2024, utilizing bibliometric methods. To this end, a total of 169 articles were analyzed from the Web of Science database using specific keywords. Analytical tools such as VOSviewer and SciMAT software were used for data visualization. The results indicate that research on artificial intelligence in science education from 1985 to 2024 has developed irregularly, with significant growth occurring in recent years. The country with the highest citation and production levels in this research field is the United States. The most productive journals in the area are the Journal of Science Education and Technology, Frontiers in Education, and the Journal of Research in Science Teaching. The leading authors are Cooper, G., and Zhai, X. Keyword analysis showed that "science education," "computer science education," "machine learning," "artificial intelligence assessment," "ChatGPT," and "learning analytics" are among the most frequently used terms and highlight emerging thematic clusters. Furthermore, this analysis showed that while artificial intelligence research in science education was initially more limited and focused on technology-related themes, it has recently shifted toward a research direction that includes learning analytics, interactive learning environments, computational thinking, and large language models. The results offer a guiding framework and valuable insights for practitioners and education researchers seeking direction in the evolving landscape of artificial intelligence in science education.

Introduction

In an era of rapid advances in information technology, artificial intelligence (AI), although a relatively recent scientific and technological field, has played a significant role in society's increasing digitization due to its rapid development in recent years (Jia et al., 2024). This important role has not only transformed many aspects of our daily lives and professional practices but has also had a comprehensive and profound impact on education (Guo et al., 2024; Song & Wang, 2020).

The integration of AI technologies into educational environments presents significant opportunities to enhance the quality and effectiveness of education in numerous areas, including personalized learning systems, automated assessment and feedback processes, virtual reality, chatbots, facial recognition systems, and innovative classroom systems. It also has the potential to transform and enhance traditional teaching and learning models (Akgun & Greenhow, 2021; Guo et al., 2024, Saydullayeva, 2025).

Science education plays a crucial role in equipping individuals with the skills they need to succeed in an increasingly complex and technology-driven world (Shofiyah et al., 2025). Science education is a practice-oriented learning field that involves abstract concepts, complex or challenging tasks, and requires higher-level cognitive skills. Utilizing AI-driven applications to improve learning outcomes in science education presents promising results for all ages and backgrounds. AI-driven virtual laboratories and simulations allow for safe and controlled execution of experiments that could be dangerous or expensive in a traditional classroom.

These virtual situations provide opportunities for students to explore scientific concepts and apply and develop their scientific skills (Ibáñez & Delgado-Kloos, 2018; Wahyono et al., 2019). AI applications enhance learning effectiveness by offering more comfortable, personalized, and interactive learning experiences tailored to each student's individual needs, skills, and learning preferences (Cooper, 2023; Dolenc & Aberšek, 2015). Furthermore, AI technologies can make science education more enjoyable, accessible, and engaging for students by providing them with interesting and immersive learning content, thereby eliminating the tediousness of teaching (Chen & Chang, 2024; Elkhodr et al., 2023). Additionally, AI-driven tools accelerate the learning process for students by providing detailed and timely feedback, and automated assessments relieve teachers of some of their excessive workload (Maestrales et al., 2021; Zhai et al., 2020). AI-driven tools, such as virtual assistants and chatbots, help students become more cognitively engaged in the learning process and encourage high motivation (Lee et al., 2022; Ng et al., 2024). AI recognizes students' emotional states, performance, and success levels in science classes, offering targeted intervention and support (Almeda & Baker, 2020; Çetinkaya & Baykan, 2020). Additionally, AI applications significantly help develop students' skills in problem solving, computational thinking, creative thinking, collaboration, STEAM literacy, and digital literacy (Irwanto, 2025).

Today, an increasing number of researchers are investigating the impact of incorporating AI technologies into science education on student learning. Evidence shows that AI technologies have noticeable effects and advantages in renewing and supporting the teaching and learning of science content, and improving learning outcomes, (Almasri, 2024; Heeg & Avraamidou, 2023). However, while the integration of AI into education holds tremendous promise, it also raises issues such as algorithmic bias, digital dependency, student competencies, ethical, social, and technical concerns, as well as teacher resistance (Adams et al., 2022; Garzón et al., 2025).

The increasing interest on AI technologies and its potential within science education community necessitates to cast a lens on how use of AI technologies impacts education. Consequently, to capture a complete picture, studies are needed to understand the current state and developments in the field and to identify supporting and guiding trends. However, few studies in the existing literature thoroughly examine the work related to AI in science education within global educational contexts, highlighting the trends, research gaps, and collaboration networks in the field especially from a review and bibliographic analyses perspective. Existing research presents a vague picture of AI use in science education with diverse approaches used on how to approach the problem.

Almasri (2024) conducted a systematic review of 74 empirical studies published between 2014 and 2023, focusing on the effects, perceptions, and challenges encountered in integrating AI into science teaching and learning. His research offers a comprehensive overview of the potential advantages and challenges of applying AI in science education settings. The research findings suggest that incorporating AI into science education has a positive impact on student learning outcomes, fosters participation in the learning process, and enhances student motivation. Heeg and Avraamidou (2023) conducted a systematic literature review to examine the current state of AI use in school science, analyzing 22 studies published in four international databases between 2010 and 2021. Their findings revealed that nine different AI applications were used, with most studies focusing on geoscience and physics, and that these applications were used to support knowledge construction or skill development. Jia et al. (2024) examined 76 articles indexed in the Web of Science (WoS) and Scopus from 2013 to 2023, using bibliometric and content analysis to identify the key role of artificial intelligence in science education at the primary and secondary levels, and to explore research trends. Their research showed that AI in science education has grown a lot in the last ten years. Atmaca-Aksoy and Irmak (2024) analyzed 89 studies retrieved from WoS databases using VOSviewer software in their research-on-research trends of articles on science education and AI, employing bibliometric methods. The study included research on annual publication trends, the most frequently used keywords, the most productive journals, countries, institutions, highly cited authors, and studies. Similarly, Genç and Koçak (2024) conducted a bibliometric study on publications related to AI in science education published in WoS between 2019 and 2023 by analyzing the scientific literature in the same year. Ayuni et al. (2024) conducted a bibliometric review of 146 documents published in Scopus from 1975 to 2024, utilizing the R program and VOSviewer to identify research trends in AI in science education. Akhmadieva et al. (2023) examined 202 publications on AI in science education published in Scopus, using bibliometric analysis to reveal the current state of the research field. Finally, Arıcı (2024) conducted a similar bibliometric analysis to examine trends in 80 articles in the current field listed in WoS.

Previous bibliographic analyses and review studies offer a broad overview of AI research in science education. However, differences in methodology such as literature selection, article inclusion criteria, and software used as well as limited sample sizes and short time frames, expose partial inconsistencies in research trends or limitations on understanding the bigger picture. To address this critical gap in literature, this article aims to conduct a bibliometric analysis to deeply examine the insights of research on AI in science education, thereby revealing the evolution of the field, its current state, and future research directions. To reach this goal, the following research questions were tackled:

1. What is the distribution of AI research in science education over the years, and what are the citation trends?
2. Which countries contribute the most to AI research in science education?
3. What were the productive journals that contribute to publishing research on AI in science education?
4. Who are the leading authors in AI research in science education?
5. What are the key research themes in AI within science education, and how are the related sub-themes shaped?
6. How have the main themes in AI research within science education evolved over time?

Method

Bibliometric analysis is a quantitative methodology used to analyze the information structure of publications in a specific research field, providing a comprehensive and global overview of the existing literature (Guo et al., 2024; Ulukök Yıldırım & Sönmez, 2024). Bibliometric studies provide a quantitative, measurable, and unbiased method to assess a study's contribution to the advancement of knowledge (Panday et al., 2025). This study employed bibliometric analysis to identify dominant trends, recent developments, and emerging themes from 1985 to 2024 aiming to deepen the understanding of research on artificial intelligence in science education. By examining an extensive time span, it provides a comprehensive overview of the field's evolutionary process and transformations in research topics.

Data Collection

A thorough online search was performed using the WoS database to gather relevant literature. The WoS database was chosen as it provides a comprehensive and reliable range of bibliometric data worldwide and is often used as the main data source in many bibliometric studies in the literature (Tonbuloğlu & Tonbuloğlu, 2023; Ulukök, 2022). To conduct a comprehensive literature search and ensure its accuracy, previous studies were reviewed, and research-specific keywords were identified (Heeg & Avraamidou, 2023; Jia et al., 2024). A search query was performed using the following search string (see Table 1) in the topic field based on the identified keywords. Following the final search conducted in September 2025, 1168 documents were initially retrieved. Following the filtering of the initial search results based on the categories including "Education and Educational Research," "Education Scientific Disciplines," "Education Special," and "Psychology Educational," the dataset was narrowed down to 741 publications. Articles published in 2025 were excluded from the study as they do not represent the whole year and the total number of articles was reduced to 642.

Article type was used as a second filter and non-article types, including conference papers, books and book chapters and editorial letters, were excluded, narrowing the selection to 296 articles. Language and citation index were other filters used to select articles. Non-English publications were removed, leaving a dataset of 287 articles. Only the articles indexed in ESCI, SSCI, SCI-Expanded, and A&HCI were included, resulting in a total of 284 articles. Finally, a manual review of the database-identified documents was conducted. Articles from disciplines unrelated to the topic, such as medical education, engineering education, and information science, were excluded. Ultimately, 169 articles published in English relevant to the study were included in the final dataset. The selected articles were downloaded in "plain text" format for processing with the tools used in this study. Details of the search strings are presented in Table 1.

Table 1. The search string for the research

Search within	Search string
Title, Abstract, and Keywords	Search within: Title, Abstract, and Keywords Search Keywords: ("artificial intelligence" OR "AI" OR "AIED" OR "machine learning" OR "intelligent tutoring system" OR "expert system" OR "recommended system" OR "recommendation system" OR "feedback system" OR "personalized learning" OR "adaptive learning" OR "prediction system" OR "student model" OR "learner model" OR "data mining" OR "learning analytics" OR "prediction model" OR "automated evaluation" OR "automated assessment" OR "robot" OR "natural language processing" OR "virtual agent" OR "algorithm" OR "machine intelligence" OR "intelligent support" OR "intelligent system" OR "deep learning" OR "AI education") AND ("science educat*")

Data Analysis

This study used a combination of open-source SciMAT v1.1.06 and VOSviewer version 1.6.20 software for bibliometric analysis and visualization. The reasons for choosing VOSviewer and SciMAT software are that they offer comprehensive analysis capabilities, provide professional-level data visualization, and are freely accessible. The VOSviewer software, developed by Van Eck and Waltman (2010) for the creation and visualization of bibliometric networks, utilizes a distance-based mapping technique to display elements. The program enables text mining based on keywords and terms in abstracts, citation and co-citation analyses, as well as overlaying, cluster density, and visualization of network maps (Van Eck & Waltman, 2020). Additionally, SciMAT, a powerful scientific mapping and data analysis software, allows for visualization of scientific fields over time through co-word analysis, allows detailed insights into research themes within a specific domain, and enables tracking the development of these themes across different periods (Liu et al., 2024).

VOSViewer software was used to perform citation analysis based on countries, journals, and authors, to conduct keyword analysis, and to create visual representations. In this way, the most productive journals, the most frequently used keywords, the countries that contributed the most, and the leading authors were identified. Detailed keyword analyses of the included publications were conducted and visualized using SciMAT software. For each study period, a graphical representation of the themes in the strategic diagrams and cluster networks was created, showing the thematic evolution of the research field over time. Figure 1 provides an example of such representations.

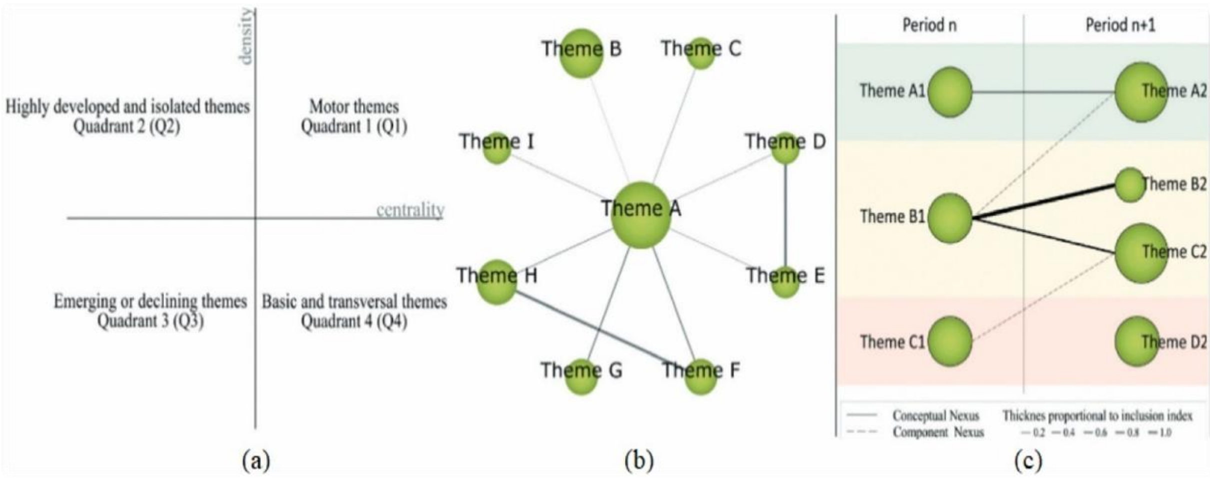

Figure 1. Example of a strategic diagram (a), example of a thematic network (b), and example of a thematic evolution map (c) (adapted from Viedma et al., 2020)

The strategic diagram (Figure 1(a)), a two-dimensional map divided into four quadrants, is created by considering two parameters: centrality, shown on the horizontal axis, which measures the level of interaction of one network with others, and density, shown on the vertical axis, which indicates the internal strength of the network (Cobo et al., 2011). In the strategic diagram (Figure 1(a)), the themes in the upper right quadrant are considered the motor themes of the field. These represent the most important and highly debated topics, characterized by high centrality and density. The upper left quadrant contains highly developed and isolated themes, characterized by low centrality and high-density values. Although these themes are highly specialized, they are not important for the field. The lower left quadrant contains themes that are emerging or declining over time. With low centrality and density values, these themes are considered weakly developed and marginal. Finally, the bottom right quadrant contains basic and transversal themes with low density and high centrality values. Despite their limited development, these themes are highly relevant to the research field (Özköse, 2023). This diagram clusters themes for each analysis period, helping to determine the significance of different themes (Jiménez et al., 2024).

Thematic networks (Figure 1(b)) illustrate the cohesion among research themes and emphasize the strength of the relationships between these themes (Severo et al., 2021). The change in themes over time is shown using a thematic evolution map (Figure 1(c)). In this thematic evolution map, the size of the green circles indicates the number of documents associated with each theme. Continuous lines between clusters represent themes sharing the same keywords as the theme itself, while dashed lines represent themes sharing common keywords other than the theme itself. The thickness of these lines indicates the inclusion index and shows the strength of the connection between two themes (Karakose et al., 2024; Liu et al., 2024).

Results

Annual Scientific Production

Figure 2 illustrates the yearly scientific output and citation distribution of publications related to AI in science education from 1985 to 2024.

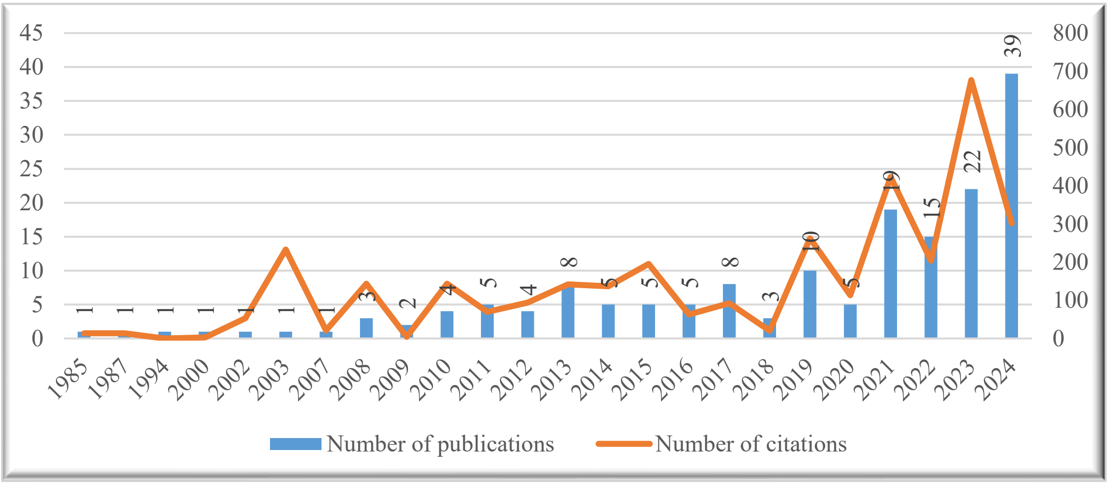

Figure 2. Distribution of publications and citations over the years

As shown in Figure 2 the first publication in this research area appeared in 1985. From that year until 2009, the number of publications remained low, with only a few articles published each year. Between 2010 and 2018, annual publication rates increased slightly, varying between 4 and 8 publications per year. In 2019, the number of publications reached double digits for the first time. Although a slight decline was observed in 2020, a general upward trend in AI-related science education research has continued since then. The highest number of publications was recorded in 2024, with a total of 39 articles published during that year. Overall, data reveal a fluctuating trend, yet upward trend characterized by periodic increases and decreases in publication numbers. This observed pattern reflects the growing interest in AI within science education, notable expansion of research activity, and the dynamic evolution of the field. Regarding the annual citations counts, citation trends have also risen in recent years, peaking in 2023 with 677 citations. The second-highest citations count occurred in 2021, with 423 citations.

Analysis of Country/Region Distribution

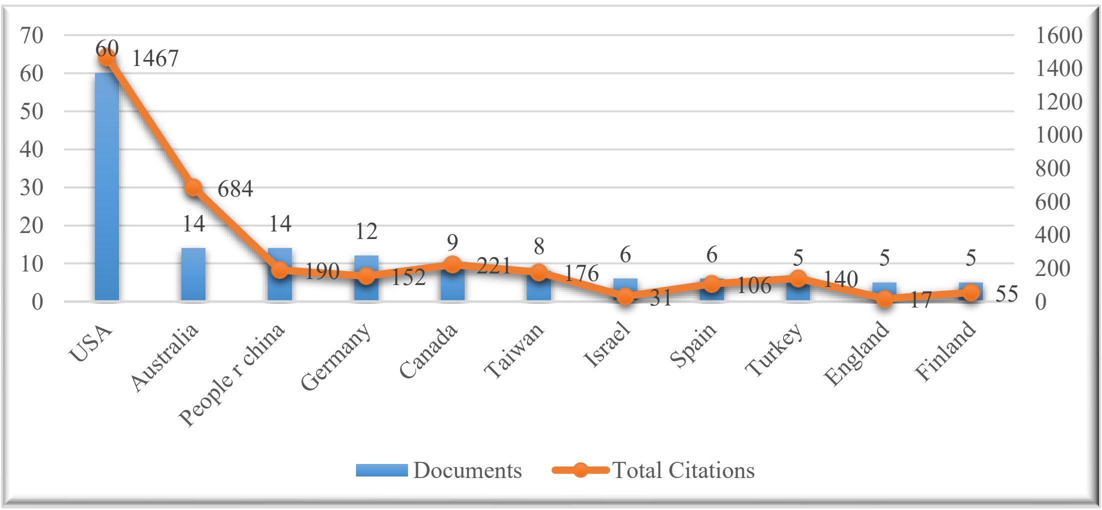

Figure 3. Distribution of citations and publications by country

VOSviewer analyses of scientific articles published in the field of AI in science education between 1985 and 2024 revealed that 37 countries have contributed to this area. Figure 3 presents detailed information on the top 11 countries that published the highest number of articles and received the greatest number of citations. As shown in Figure 3, the United States stands out as the most productive country with 60 publications, demonstrating the dominant position of its research in the field. Australia (14), the People's Republic of China (14), Germany (12), Canada (9), and Taiwan (8) follow. Israel and Spain each have six publications, while Turkey, England, and Finland also show significant participation. When it comes to the countries with the most citations, the United States clearly leads with 1,467 citations, while Australia and Canada rank in the top three with 684 and 221 citations, respectively. Turkey, in particular, has made significant contributions to this research by generating a notable citation impact with five articles, despite its low publication volume. Meanwhile, the co-authorship network between countries created using VOSviewer is shown in Figure 4. At least three documents per country were identified in the analysis. It is evident that the 19 countries meeting this criterion actively engage in related research and contribute significantly to the advancement of the field.

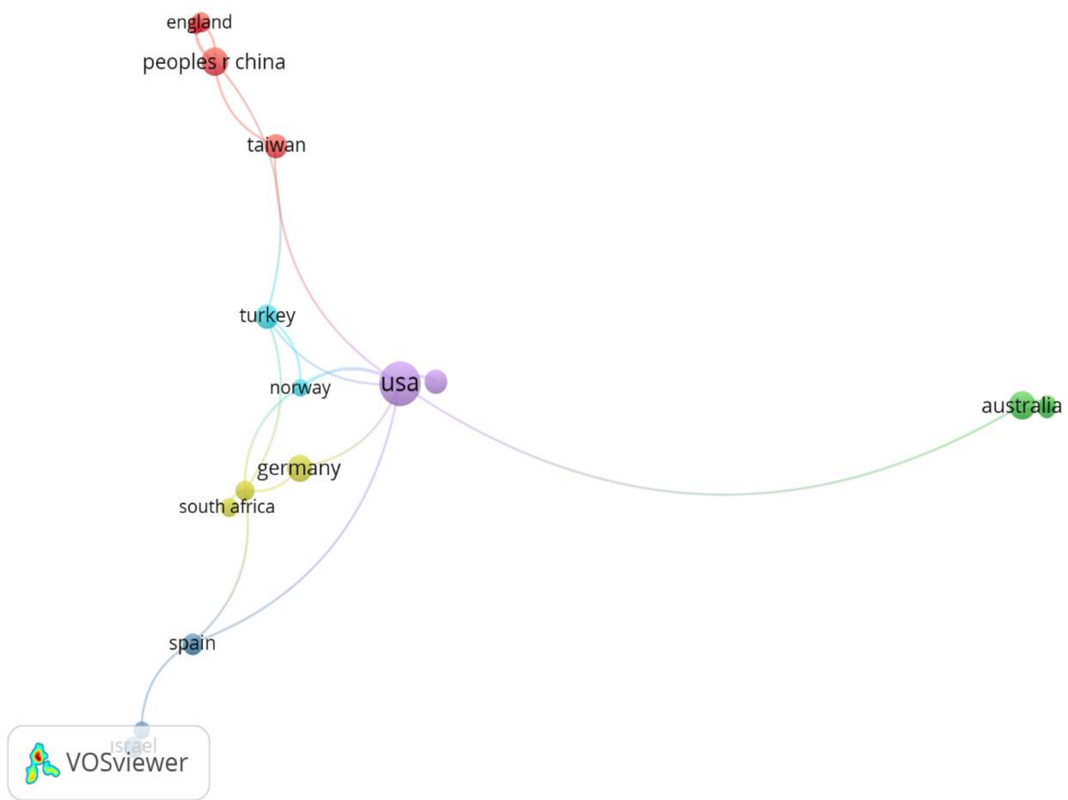

Figure 4. Co-authorship networks of countries

As shown in Figure 4, six distinct clusters were formed. The United States, which interacts with all clusters with a total link strength (TLS) of 9, emerges as the most collaborative country. Following the United States, Finland and China with a TLS of 5 each, and Norway and Turkey each with a TLS of 4, are among the other prominent contributing countries in this field. In contrast, countries such as the United Kingdom and Israel are represented by only one TLS each within the network, demonstrating a very limited level of collaboration.

Productive Journals

Figure 5 presents data on the most productive journals publishing scientific articles in the field of artificial intelligence in science education, along with the number of articles published in each. The Journal *of Science Education and Technology* ranks first with 18 articles published with a focus on AI in science education. *Frontiers in Education, Journal of Research in Science Teaching, Research in Science Education,* and *Education Sciences* have also made significant contributions to literature in this field. Overall, research on this topic has been published in a range of journals encompassing diverse thematic areas, including educational technology, science education, and interdisciplinary studies.

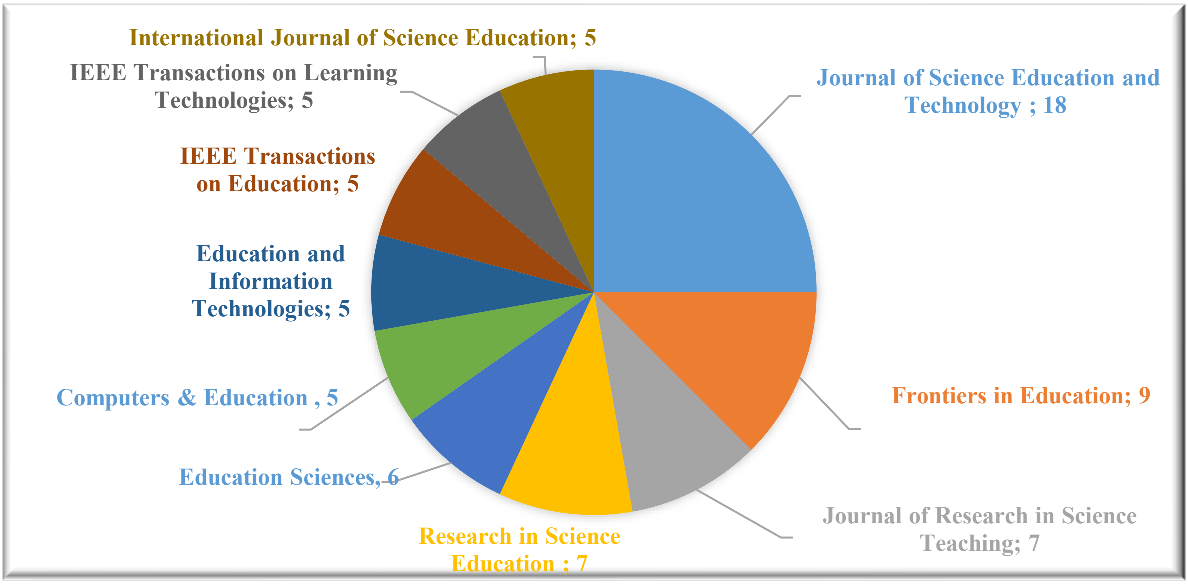

Figure 5. Most productive journals

Leading Authors in Terms of Productivity and Citations

In the citation analysis, which included authors with at least two publications, 27 authors met the criteria. Table 2 presents the number of articles and citations for 10 authors who have contributed to research on AI in science education.

Table 2. Leading authors in AI research in science education

Author	Documents	Citations
Zhai, X.	7	170
Nehm, R. H.	4	117
Huang, X.	3	35
Xie, C.	3	35
Cooper, G.	3	529
Tang, K.	3	46
Boone, W. J.	2	128
Chin, D. B.	2	86
Dohmen, I. M.	2	86
Schwartz, D. L.	2	86

As shown in Table 2, Zhai, X., Nehm, R. H., Huang, X., Xie, C., and Cooper, G. stand out as prolific authors who have made significant contributions to the knowledge base in this field. Cooper, G., in particular, is the most cited researcher with 529 citations across three articles. Zhai, X., Boone, W. J., Nehm, R. H., Chin, D. B., Dohmen, I. M., and Schwartz, D. L. are among the other most cited researchers in the field.

Keyword Analysis

Author keywords from the WoS dataset were analyzed using VOSviewer, and the resulting co-occurrence network is shown in Figure 6. Keywords that appeared at least twice were included to create a co-occurrence network. Out of 575 keywords, 24 met this criteria. Network analysis indicating the most frequently used keywords as “science education” (Occurrences: 46; TLS: 41), “computer science education” (21; 19), “machine learning” (19; 20), “artificial intelligence” (14; 19), “assessment” (10; 11), ‘chatgpt’ (9; 11), and “learning analytics” (9; 10). Figure 6 shows that the author's keyword network analysis reveals a structure made up of five clusters, each representing a different research theme. Cluster 1 (7 items, red) includes keywords such as computational thinking, computer science education, STEM education, engineering education, and educational technology.

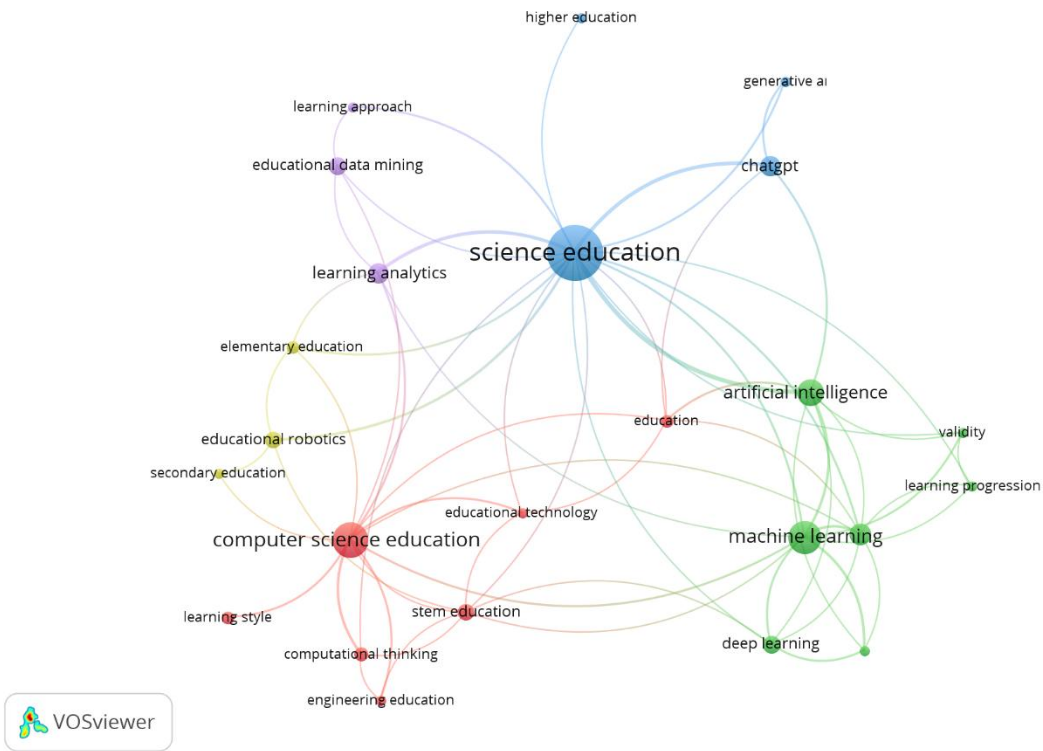

Figure 6. Co-occurrence network of the author's keywords

This cluster concentrates on incorporating AI-related tools into STEM and computer science education, with a special focus on developing students' computational thinking skills. Cluster 2 (7 items, green) features keywords such as artificial intelligence, machine learning, deep learning, natural language processing, assessment, learning progression, and validity. It emphasizes research on measurement, evaluation, and learning analysis in science education using AI. Cluster 3 (4 items, dark blue) contains keywords ChatGPT, generative AI, higher education, and science education, indicating that new technologies, including generative AI and large language models, are being integrated into science education, especially at the higher education level. Cluster 4 (3 items, yellow) mainly centers on AI in science education for early age groups and robotic applications, with keywords including educational robotics, elementary education, and secondary education. Finally, Cluster 5 (3 items, purple) includes keywords such as learning analytics, educational data mining, and learning approach. This cluster encompasses studies in science education that utilize AI to monitor learning processes, conduct data-driven analysis, and evaluate learning approaches.

Structural and Thematic Development

The evolution of keywords for each specified analysis period provides information about the overlap level of keywords. An upward slanted arrow indicates keywords eliminated in the next period; a downward slanted arrow shows keywords included in the new period; the horizontal arrow pointing to the right signifies keywords overlapping between periods. The circles represent the keywords of a period. Figure 7 shows the evolution of keywords across different time periods. The time periods were determined based on the number of published articles and the developmental stages of the research field. Three distinct periods were examined: 1985–2010, 2011–2018, and 2019–2024.

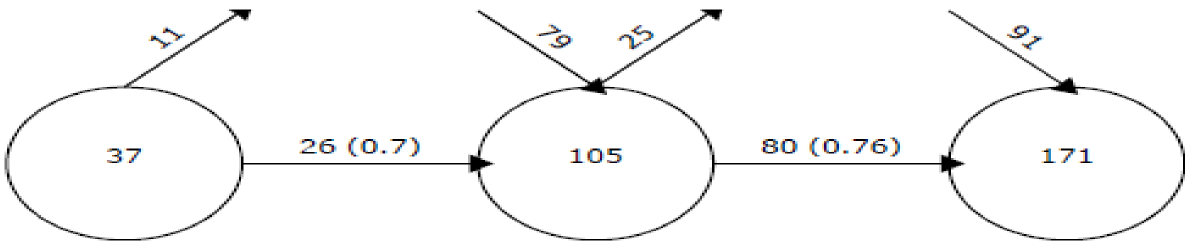

Figure 7. Continuity of keywords between intervals

As shown in Figure 7, the overlap level of keywords between periods is above 70%. These data highlight the thematic consistency of artificial intelligence research in science education across successive periods, while also indicating a dynamic change in terminology, particularly in the most recent period. The themes for each sub-period have been visualized using strategic diagrams to reveal changes in trends related to AI research in science education over time.

Period 1 (1985-2010)

The 16 articles published in first period between the years 1985 and 2010 were examined, and the analysis identified five key strategic themes. Details about these themes are provided in Figure 8.

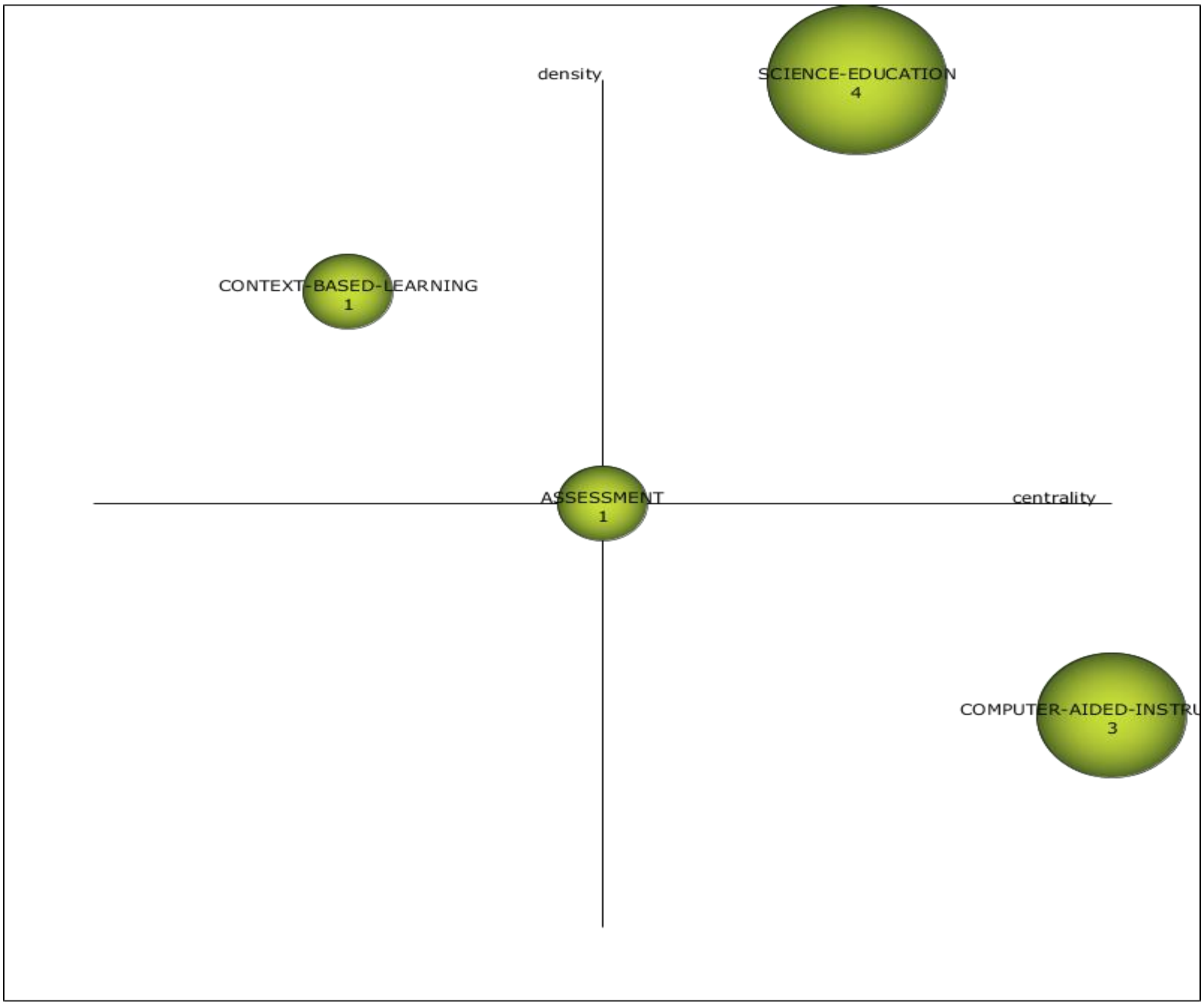

Figure 8. Period 1 (1985–2010) strategic diagram (h-index)

As shown in Figure 8, the theme with the highest bibliometric value is “science education,” followed by the theme “computer-aided instruction.” Since the “science education” theme is located in the upper right quadrant, it stands out as the primary driving or pioneering theme of the period. “Context-based learning” appears as a highly developed and isolated theme, whereas “computer-aided instruction” is a basic and transversal theme. Moreover, the “assessment” theme suggests that measurement and evaluation applications in AI-supported learning environments were also addressed during this period. A comprehensive analysis of the “science education” motor theme and related sub-themes are presented in the thematic network structure in Figure 9.

As shown in Figure 9, the cluster network of the “science education” theme is connected to the sub-themes “ability,” “achievement,” “self-efficacy,” “classroom,” “instruction,” “instructional-design,” “inquiry,” “motivation,” “perceptions,” “personalized-learning,” “machine learning,” and “automated-assessment." Therefore, it can be concluded that research on AI in science education during this period mainly focused on the technological aspects, assessment systems, and the integration of various pedagogical processes.

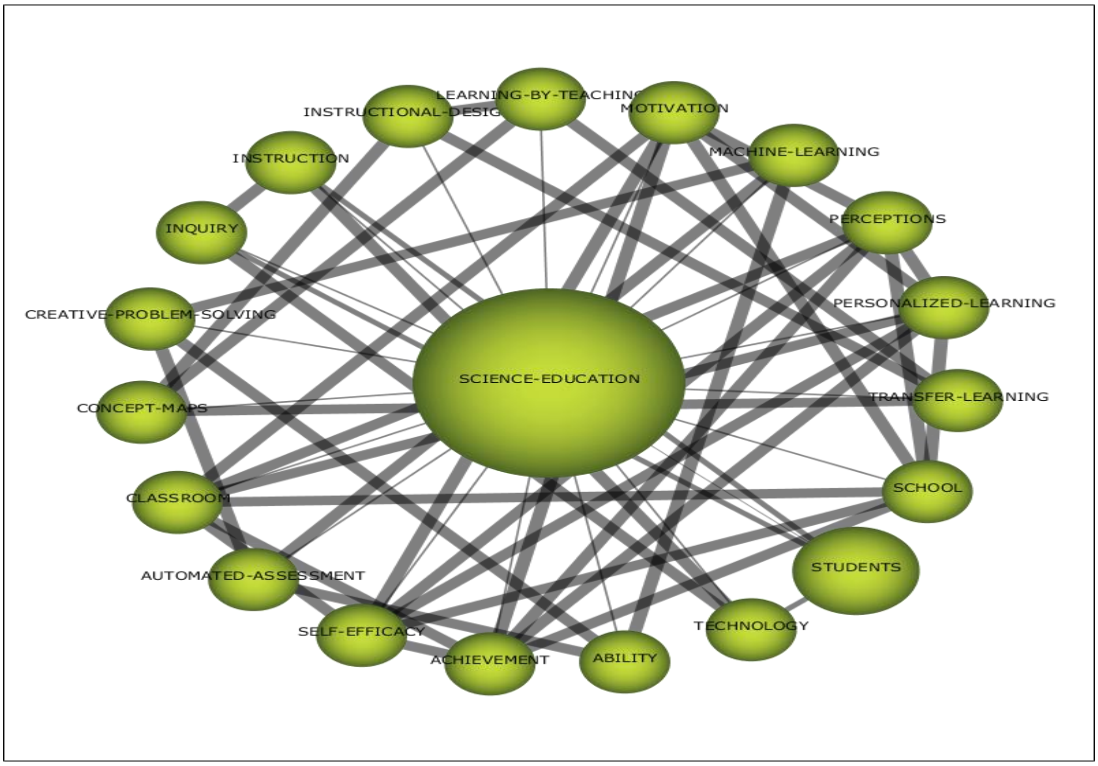

Figure 9. Thematic network structure of the motor theme in Period 1

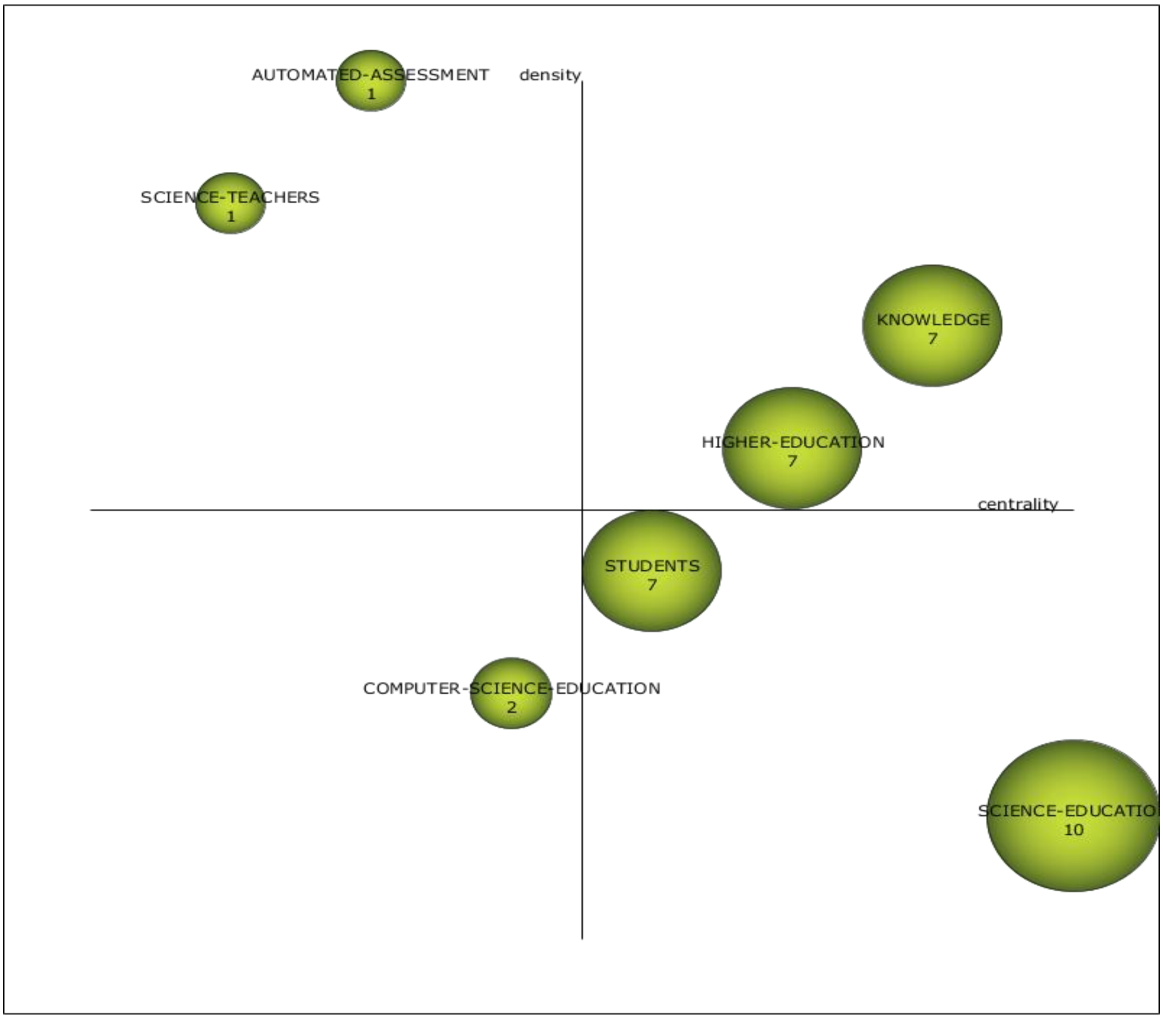

Figure 10. Period 2 (2011-2018) strategic diagram (h-index)

Period 2 (2011-2018)

The second period encompasses 43 articles published between 2011 and 2018, and the analysis identified seven strategic themes. Details about these themes are shown in Figure 10. In the second period (2011–2018), the theme with the highest bibliometric value is again "science education." This is followed by the themes "students," "knowledge," and "higher education." The motor themes of this period are "knowledge" and "higher education." "Automated assessment" and "science teachers" are highly developed and isolated themes. "Science education" and "students" are basic and transversal themes. Studies conducted in the field of science education on AI during this time period indicate that higher education is the educational level most strongly influenced by this technology. The thematic network structures of the two motor themes identified in Period 2 are presented in Figure 11.

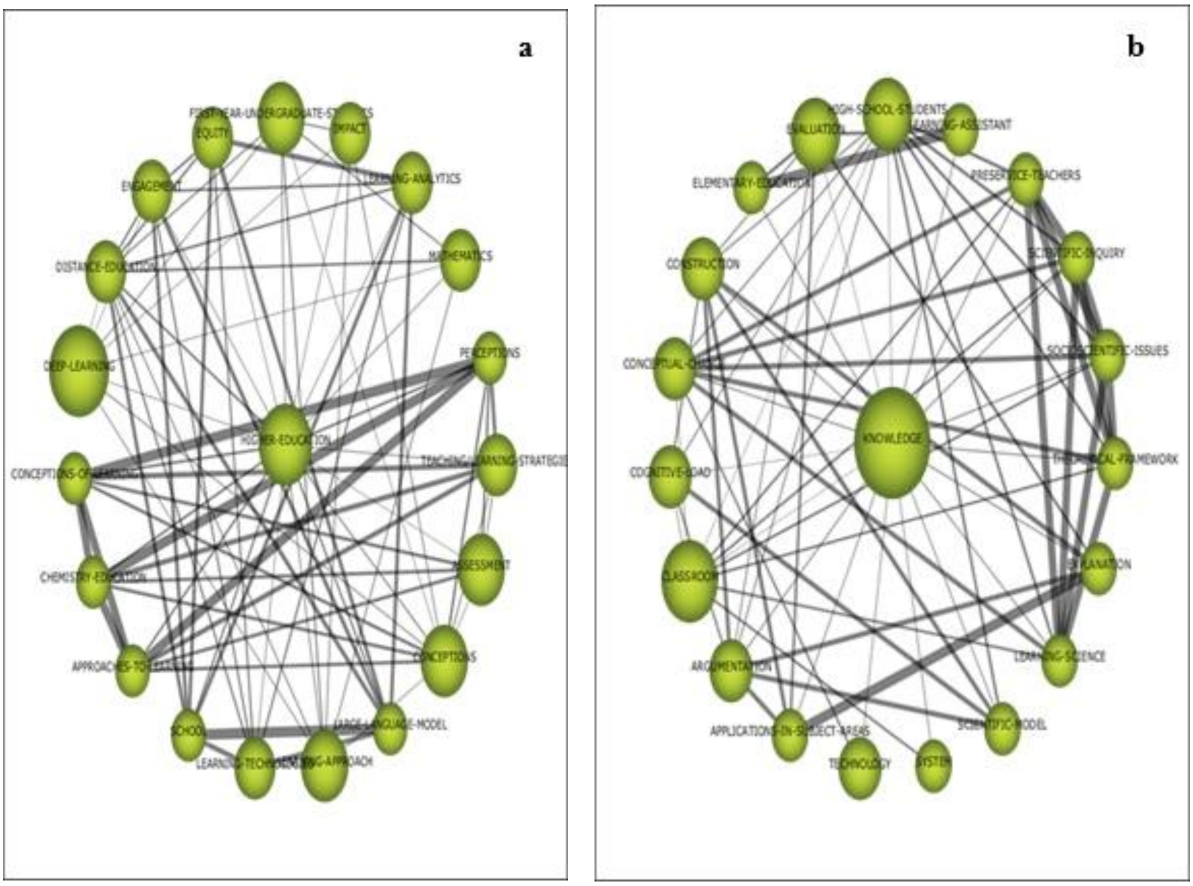

Figure 11. Thematic network structures of period 2 motor themes; (a) higher education and (b) knowledge

When examining the cluster network in Figure 11, it can be seen that the theme of "higher education" is associated to "impact," "learning analytics," "mathematics," "perceptions," "teaching/learning strategies," "assessment," "conceptions," "approaches to learning," "large language model," "learning technologies," "school," "distance education," "equality," "participation," "learning concepts," and "chemistry education." The theme of ''knowledge'' is associated to "learning assistant," "teacher candidates," "scientific inquiry," "socio-scientific issues," "theoretical framework," "explanation," "applications in subject areas," "argument," "construction," "learning science," "scientific model," "technology," "classroom," "system," and "primary education." During this period, research primarily focused on integrating AI into higher education for knowledge building, automatic assessment, smart/interactive learning environments, and personalized learning.

Period 3 (2019-2024)

In the third period, from 2020 to 2024, the number of articles published increased to 110, and analysis of the metadata identified 10 themes. Details on these themes are shown in Figure 12. In the third and final period, the theme found to have the highest bibliometric value was "learning analytics," followed by ''students'' and "science education." The motor themes contributing to the development of the research field in this final period were "computational thinking (CT)," "classroom," "knowledge," and "model." The themes "cognitive load" and "learning style" are found to be highly developed and isolated themes. The themes "students" and "learning analytics" were among the basic and transversal themes. These themes are not yet sufficiently developed, indicating potential for growth in the coming periods and a broad scope for improvement. Finally, themes such as "ChatGPT" and "science education" are emerging and declining themes suggesting either an increasing attention from academic circles or areas that have not yet been sufficiently developed. The thematic network structures of the four motor themes identified in Period 3 are presented in Figure 11.

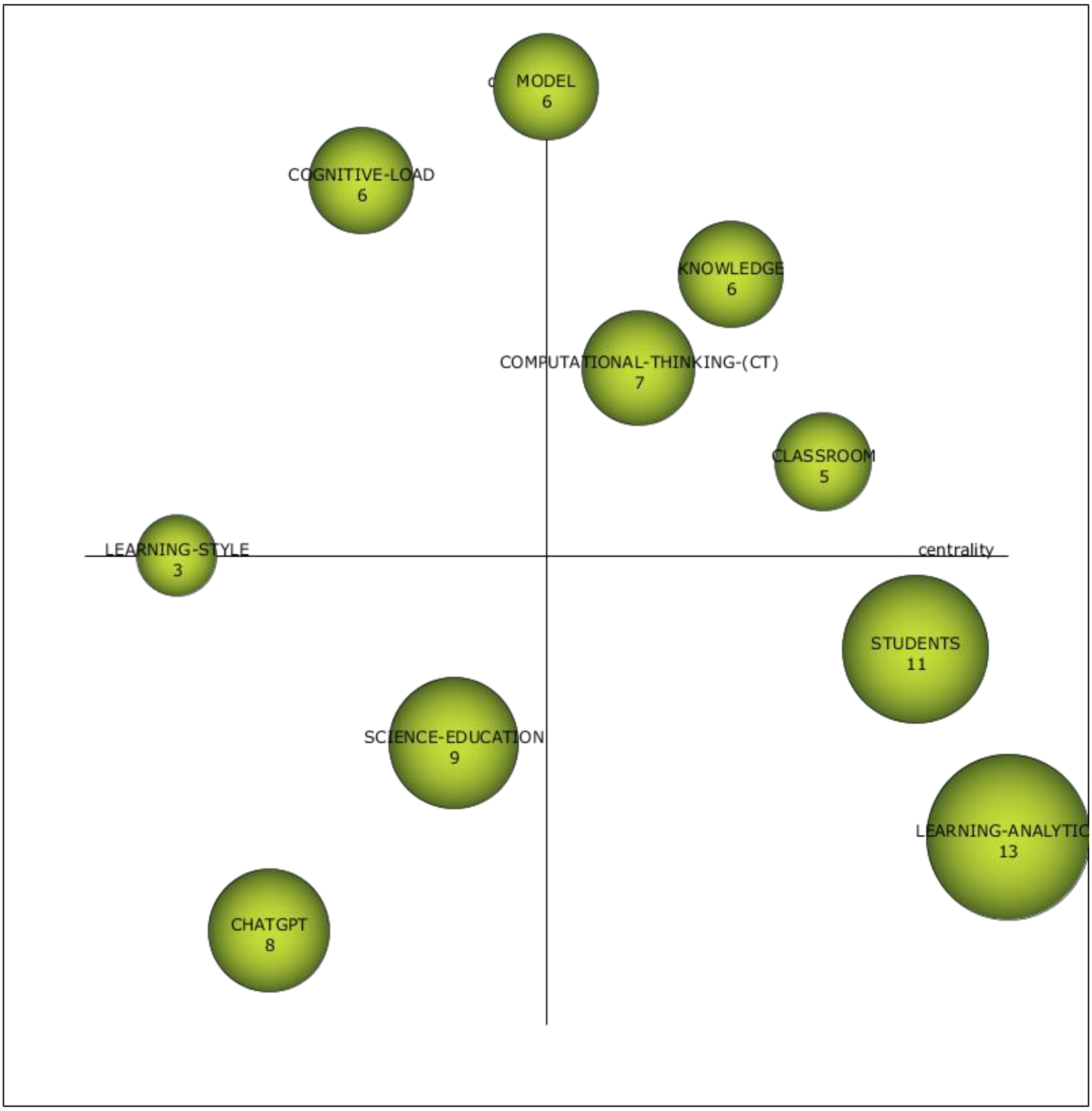

Figure 12. Period 2 (2018-2024) strategic diagram (h-index)

As shown in Figure 13, the "classroom" theme relates to sub-themes such as "school," "ethical AI," "learning outcomes," "engagement," "feedback," "interest," "online learning," "personalized learning," "algorithms," "cultural," and "children." These theme-subtheme connections demonstrates that the main application of AI in science education is within the classroom setting, where it is examined alongside pedagogical, technological, socio-cultural, and ethical aspects. The "knowledge" theme connects to sub-themes such as "meaningful assessment," "reflective assessment," "language processing," "deep learning," "video," "perceptions," "scientific inquiry," "scientific model," "professional vision," and "teachers' reflections." These data highlight that the "knowledge" theme is closely associated with AI assessment techniques, teacher development, and technological tools. The "model" theme is associated with "system," "technology," "abductive reasoning," "anatomy education," "argumentation," "attitudes," "digital education," "formative assessment," "improve," "information," "learning management system," "scaffolding," "technology acceptance model (TAM)," "undergraduate biology," "virtual reality," and "user acceptance.'' This theme- subtheme network shows that artificial intelligence research in science education enhances modeling.

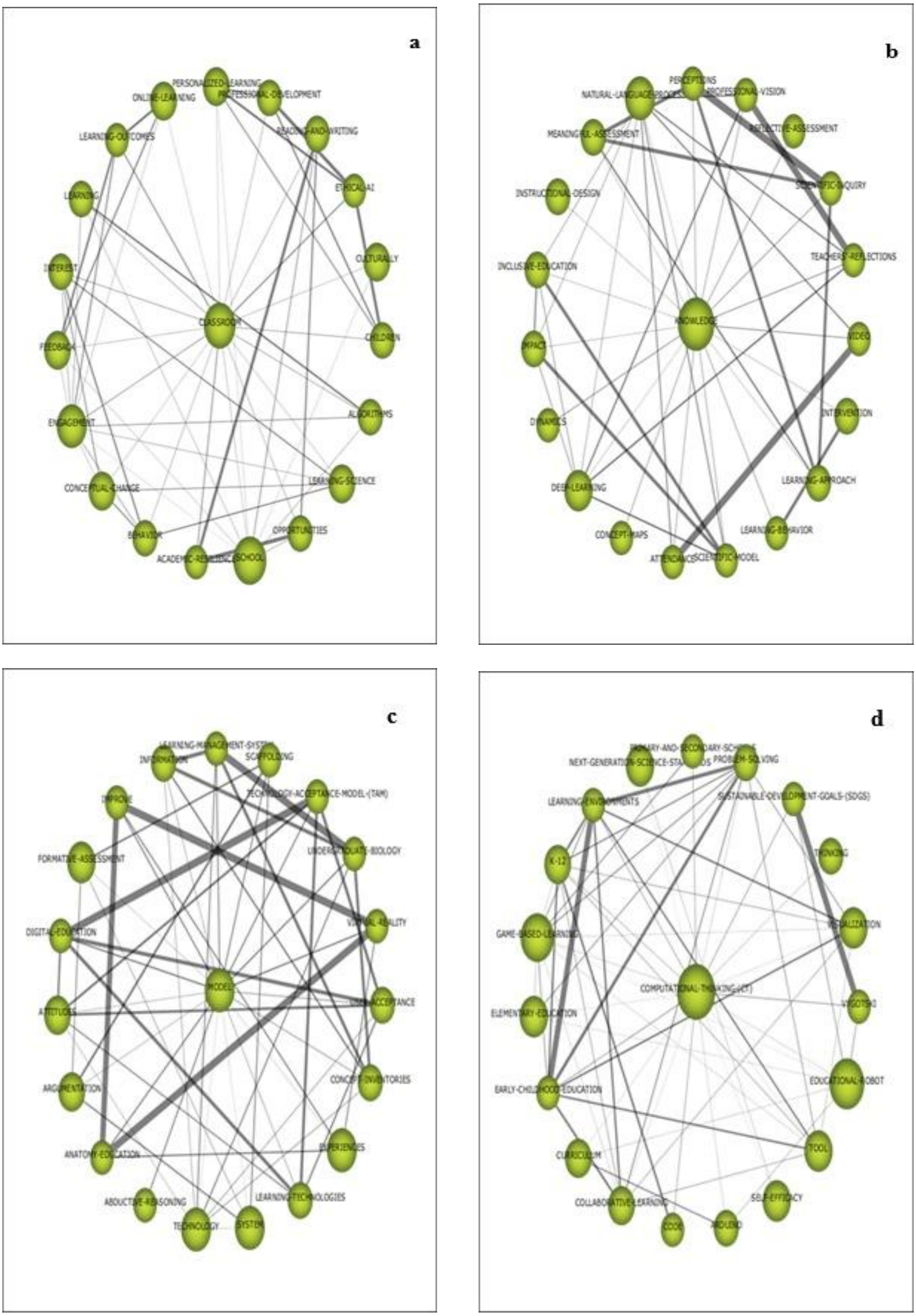

Figure 13. Thematic network structures of Period 3 motor themes; (a) classroom, (b) knowledge, (c) model, and (d) computational-thinking-(ct)

The "computational thinking (CT)" theme relates to "educational robot," "code," "game-based learning," "tool," "collaborative learning," and "problem solving." This shows that computational thinking is reinforced through practical applications. The theme is also connected to "primary and secondary schools," "K-12," and "early-childhood education," indicating that computational thinking is being explored across various educational levels.

Thematic Evolution Analysis

The thematic evolution map, created to examine all three analysis periods as a whole and to see their evolution over time more clearly, is presented in Figure 14.

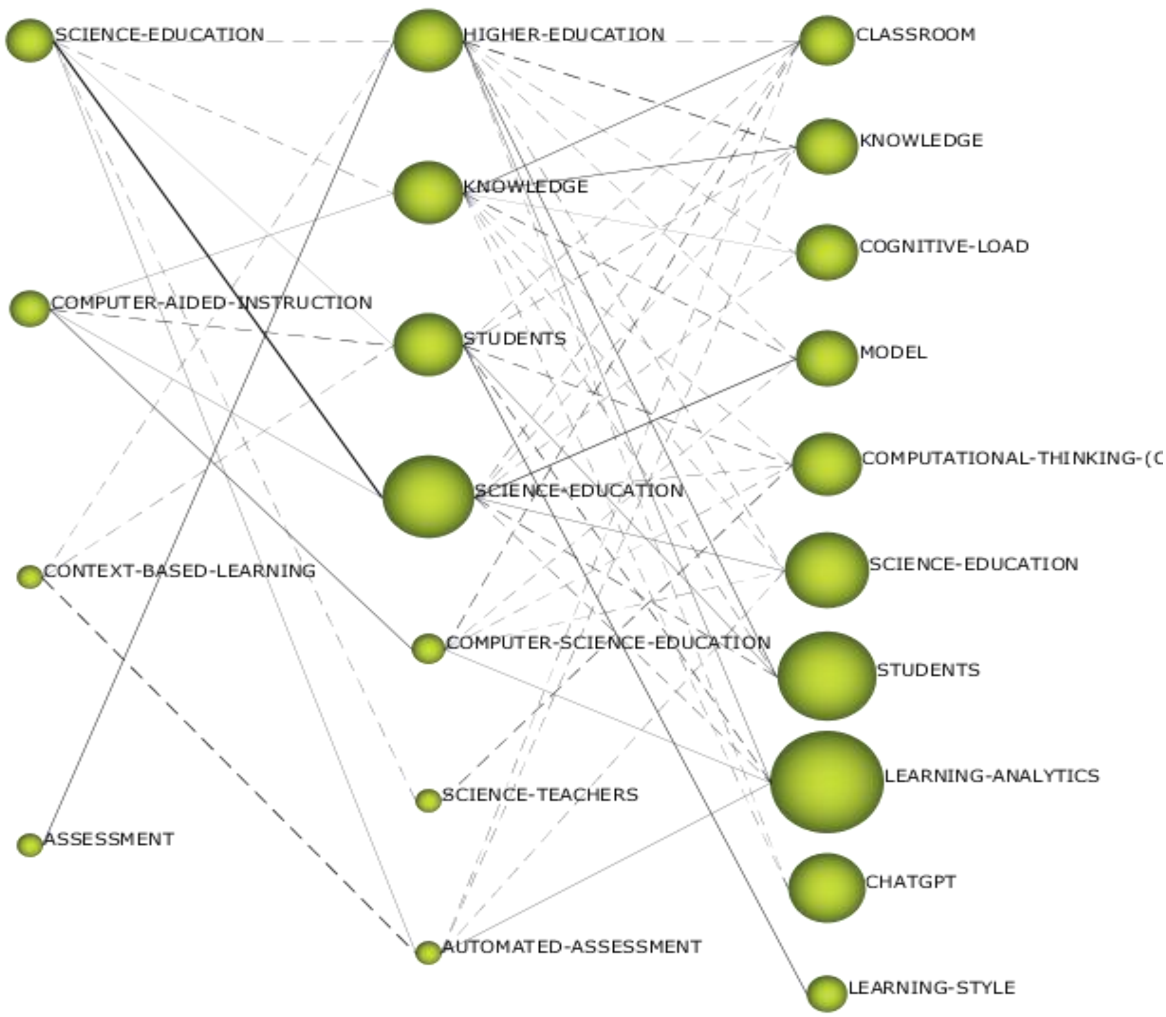

Figure 14 Thematic evolution by h-index

As shown in Figure 14, four themes emerged during the first period. While the theme "science education" was present across all three time periods, the other three themes, computer- aided instruction, context-based learning and assessment were seen to evolve into different themes in subsequent periods. The theme "computer-aided instruction" was also found to be related to "knowledge," "computer science education," "students," and "science education" during the second period. Similarly, "context-based learning" was associated with "higher education," "students," and "automated assessment" during the second period. The ''assessment'' theme was likewise linked to the "higher education" at this stage. New themes appeared in the second period, and the themes of "science education," "students," and "knowledge" persisted into the third period, while the remaining themes evolved into others. During this period, "higher education" was connected to "students," "learning analytics," and ''ChatGPT," whereas ''knowledge'' theme was associated with "classroom," "cognitive load," "model," and "ChatGPT" in the third period. The "students" theme was closely linked to "learning-style," "learning-analytics," and "classroom," whereas the "computer science education" theme relates to "learning-analytics" and "model." The "science-teachers" theme demonstrated a relationship with "computational-thinking," while the "automated-assessment" theme is connected to "learning-analytics" and "science-education" during the third period. The "science-education" theme maintained its continuity in the third period and was linked to themes such as "model," "classroom," "learning analytics," and "knowledge." This stage represents the point at which AI research in science education become most diversified with ten themes emerging. In the final period, research interest shifted toward a data-driven, competency-based approach that included "learning analytics," "cognitive load," "model," "computational thinking (CT)," and "ChatGPT.''

Conclusion, Discussion, and Recommendations

Recent technological innovations have become an integral part of today's social life and are having a global impact, particularly in the fields of economics, health, and education. AI technologies, with a growing interest, have become one of these innovations being incorporated into teaching and learning processes. This article provides a comprehensive overview of research on AI in science education. For this purpose, 169 English-language articles published between 1985 and 2025 in the WoS database were analyzed.

An examination of publication trends shows that scientific output on AI in science education began in 1985 and has since exhibited irregular growth. Three time periods were observed based on the trends of publications. From 1985 to 2009, publication levels remained low and between 2010 and 2018, scientific production stayed relatively stagnant. However, after 2019, a notable increase was observed, reaching its peak in 2024. This pattern suggests a growing interest in this field in recent years. Similarly, the rise in the citations counts also reflects this growing interest. This upwards trend can be attributed to the rapid advancement of AI technologies, their improved accessibility, the expansion of potential application areas in science education, and growing interest and investment in AI-driven educational technologies. The COVID-19 pandemic, which began in late 2019, also appears to have accelerated this process (Ayuni et al., 2024; Heeg & Avraamidou, 2023).

Regarding countries, the United States stands out as the leading contributer to research in this field which is consistent with findings of previous bibliometric studies on AI research in science education (Akhmadieva et al., 2023; Ayuni et al., 2024). Australia, China, and Germany were the other countries following the United States with their significant contribution to the research. Policies promoting the integration of technology in educational settings, different levels of research infrastructure, and substantial funding sources may be responsible for the observed increase in the numbers of publications in these countries (Arıcı, 2024; Ekin et al., 2025). The analysis of international collaboration reveals that the United States has the highest frequency of cooperation, while the participation of developing countries is limited. This finding illuminates the need to support for the integration of AI in science education settings in low-income/disadvantaged communities and countries as well research and strengthening international cooperation

The distribution of publications across journals indicates that research on AI in science education has primarily been published in the Journal of Science Education and Technology, Frontiers in Education, and the Journal of Research in Science Teaching. This finding suggests that the current body of research is predominantly published in multidisciplinary journals that address topics at the intersection of science education and technology. These journals offer academics and practitioners involved in AI in science education opportunities to access research findings and explore emerging trends.

In terms of autorship, Zhai, X., and Nehm, R. H., stand out as the most prolific authors. Additionally, Cooper, G., and Zhai, X. are among the leading authors. These researchers play a significant role in mentorship and collaboration, guiding and shaping AI-related research within the field of science education. The findings of the current study agree with those of Atmaca Aksoy and Irmak (2024), who identify Zhai, X., as the most prolific author in artificial intelligence research in science education.

The keyword network analysis revealed that the most frequently occurring keywords were "science education," "computer science education," "machine learning," "artificial intelligence,'' ''assessment," "ChatGPT," and "learning analytics." Similarly, the bibliometric study conducted by Atmaca Aksoy and Irmak's (2024) identified these keywords as the most significant ones in AI-related science education research.

Regarding the evolution of keywords, it has been found that there is a high level of overlap between adjacent periods, indicating an agreement on the established line of research on this subject. In terms of thematic performance, it is evident that the number of studies and themes was quite limited in the first period from 1985 to 2010 which was a limitation. The theme of "science education" is at the forefront during this period. Research conducted during this period indicates that the integration of AI into science education has primarily progressed through the theme of "computer-aided instruction." The focus of studies was observed to broaden in the second period, covering years between 2011 and 2018. "Knowledge" and "higher education" were the motor themes of this period, and the focus was on integrating AI into higher education to support knowledge building, automatic assessment, innovative and interactive learning environments, and personalization. Indeed, Moreno-Guerrero et al. (2020) also stated that AI applications were most commonly used in higher education among all levels. Subsequently, related studies have become increasingly diverse between 2018 and 2024. The motor themes of this third period include ''computational thinking (CT),'' ''classroom,'' ''knowledge,'' and ''model.'' Additionally, the presence of themes such as "learning analytics" and ''ChatGPT'' suggests that this field of study is still in its early stages of exploration. This indicates that current research trajectories are being shaped around the development of students' computational thinking skills, the rising applications of ChatGPT and generative AI, learning analytics, personalization, cognitive design, and knowledge construction and learning. These findings are also supported by studies conducted by Jia et al. (2024) and Arıcı (2024). Furthermore, AI applications in teacher education, potential risks, as well as ethical and practical implications of AI integration in science education are areas that have not yet been sufficiently explored in existing studies. Future research could focus on teacher training, large language models, the ethical and theoretical foundations for advancing AI in science education, and the long-term impacts of AI technologies on learning and teaching processes in actual Keard–12 classroom settings.

In terms of thematic evolution based on the specified time periods, a conceptual progression was observed even though different themes emerged in each period. This is primarily due to the persistent presence of the theme "science education" throughout all three periods. Research on AI in science education, which initially conducted at an experimental and conceptual level, has recently evolved into a more interactive and data-driven framework that addresses students' changing needs, fosters computational thinking, and transforms the learning experience.
In conclusion, this comprehensive bibliometric analysis provides both theoretical and practical insights into AI-supported science education and to the evolving research landscape. It reveals clear evidence that interest in this subject has grown significantly, particularly since 2019. Advancing the field of AI in science education requires interdisciplinary collaboration among stakeholders, including computer scientists, educators, researchers, funders, and policymakers. Such collaboration is essential to fostering innovation, addressing the challenges of AI integration into contemporary teaching practices, and meeting the demands of an increasingly dynamic technological environment in education.

Limitations

Like any research study, this research has certain limitations. The most evident limitation is that it only includes studies published in English and indexed in the WoS database. A second limitation of this study is the exclusion of studies published in 2025, as the calender year has not yet concluded. Given the growing interest in AI-related research within science education, this exclusion may prevent the identification of emerging publication trends. Finally, although the time periods were determined based on the number of articles and the developmental trajectory of the field, the selection of specific intervals of time periods may also represent a limitation limitation.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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