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ARTIFICIAL INTELLIGENCE OF HIGHER ORDER THINKING IN SCIENCES EDUCATION: A BIBLIOMETRIC ANALYSIS

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Abstract:

This research demonstrates a bibliometric analysis of research on the integration of Artificial Intelligence (AI) in fostering Higher-Order Thinking (HOT) within science education, an area that has gained significant attention in the context of digital transformation in teaching and learning. Although AI has been widely applied across various disciplines, its role in enhancing critical thinking, problem-solving, and creativity in science education remains underexplored. This raises the need to map the intellectual structure, collaboration patterns, and research trends in this emerging field. Data were collected using the Scopus database through an advanced search strategy with the keywords "sciences," "education," "artificial intelligence," and "higher order thinking," yielding a final dataset of 2,009 publications. The data were cleaned and harmonized using OpenRefine, descriptive statistics and trend analyses were generated with the Scopus Analyzer, and visualization maps were constructed using VOSviewer. The results indicate a steady growth of publications, with a sharp increase from 2019 onward, reflecting the accelerated adoption of AI-driven pedagogical approaches. China, the United States, and the United Kingdom emerged as the most productive and highly collaborative countries, while leading keywords such as "artificial intelligence," "students," "machine learning," and "higher education" demonstrated the thematic concentration of the field. Co-authorship and co-occurrence analyses further revealed eight distinct clusters, highlighting interdisciplinary collaborations that connect traditional science education with generative AI technologies. This study contributes to the body of knowledge by providing a systematic overview of how AI applications are shaping HOT in science education, identifying current research hotspots, and offering insights into potential directions for future pedagogical innovation and international collaboration.

Keywords:

Sciences, Education, Artificial Intelligence, Higher Order Thinking

Introduction

Artificial Intelligence (AI) has become apparent as a transformative force across various sectors, including education. Its integration into higher education, particularly within science education, holds the potential to revolutionize conventional teaching and learning approaches. AI-driven tools provide personalized support, enabling students to better understand study materials, visualize complex concepts, and engage in interactive problem-solving Mnguni (2025); Stuchlikova & Weis (2024). However, the role of AI in education is multifaceted, presenting potential and obstacles. While AI can improve student engagement and learning efficiency, it also raises concerns concerning overreliance, potential biases, and the need for critical thinking skills Stuchlikova & Weis (2024; Al Ka'bi (2023). This research aims to describe the influence of AI on Higher-Order Thinking (HOT) in science education through a bibliometric analysis, providing insights into current trends, practices, and outcomes Zhao & Fu (2025).

Literature Review

The implementation of AI in education has been widely explored, particularly with an emphasis on its potential to foster HOT skills. HOT, which includes analysis, evaluation, and creation, is crucial for students to navigate complex problems and develop critical thinking abilities. AI-assisted teaching has been shown to significantly enhance these skills, providing a theoretical and empirical basis for its effective integration in education (Mnguni, 2025; Herath & Mittal, 2022). For instance, AI tools can offer personalized and adaptive learning experiences, facilitating immersive and interactive exploration of scientific concepts Mnguni (2025). These tools support the development of HOT skills and improve student engagement, as well as motivation.

Despite the promising potential of AI in education, several constraints and challenges need to be tackled. Here, one major concern is the superficial nature of AI-generated explanations, which may overwhelm students with information without promoting deep understanding Michel-Villarreal et al. (2023). Additionally, excessive reliance on AI tools may hinder students' creativity and critical thinking, as they might begin to replicate the AI's reasoning patterns instead of cultivating their own Mnguni (2025); Michel-Villarreal et al., (2023). Ethical considerations, for instance, ensuring the fairness and accuracy regarding AI algorithms and protecting student data privacy, are also critical issues that need to be determined (Javaid & Haleem, 2020); Cui et al., 2021). Furthermore, the effectiveness of AI in education may be impacted by a variety of factors, including the instructional settings, the type of AI tools used, and the specific educational context Babu et al. (2025).

International Journal of Modern Education
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Recent studies have emphasized the significance of fostering HOT skills in students through the AI integration in education. In this context, AI-enabled learning environments can encourage the development regarding critical thinking and problem-solving skills by offering real-time feedback and personalized learning pathways Babu et al. (2025). AI in assessment has also been explored, with tools like ChatGPT offering interactive and customized evaluation opportunities that promote authentic scientific inquiry and critical thinking Javaid & Haleem (2020). However, the successful AI integration in education demands careful consideration of teacher preparedness, curriculum development, and resource disparities Mnguni (2025).

In conclusion, AI integration in higher education, particularly in science education, holds substantial potential for enhancing HOT skills. AI-powered tools can allow personalized and adaptive learning experiences, support the development of critical thinking and problem-solving skills, and promote student engagement and motivation. However, addressing the challenges and limitations related to AI in education is crucial for its effective and sustainable implementation. Future research should concentrate on expanding the sample range, conducting long-term studies, and exploring the ethical implications with respect to AI in education to maximize its benefits and minimize potential risks Ilgun Dibek et al., (2025)

The concept paper on *Artificial Intelligence in Higher Order Thinking in Science Education: A Bibliometric Analysis* underscores the growing role of AI in transforming educational practices and advancing research. As illustrated in Figure 1, the topic branches into three main domains: **technological integration**, **research trends**, and **applications in education**. Technological integration emphasizes how AI tools merge with educational technology to enhance learning environments. Research trends focus on scientific production and bibliometric analysis, showcasing how scholarly work maps the evolution of AI in HOT. Meanwhile, applications in education underline the potential of AI in fostering critical thinking and supporting personalized learning experiences tailored to individual student needs. Together, these areas reflect how AI supports innovation in teaching and learning, as well as drives academic research output and educational reforms Ilgun Dibek et al. (2025). In conclusion, the bibliometric approach offers valuable insights into the impact and trajectory of AI in science education, reinforcing its importance in developing critical and adaptive learners prepared for future challenges.

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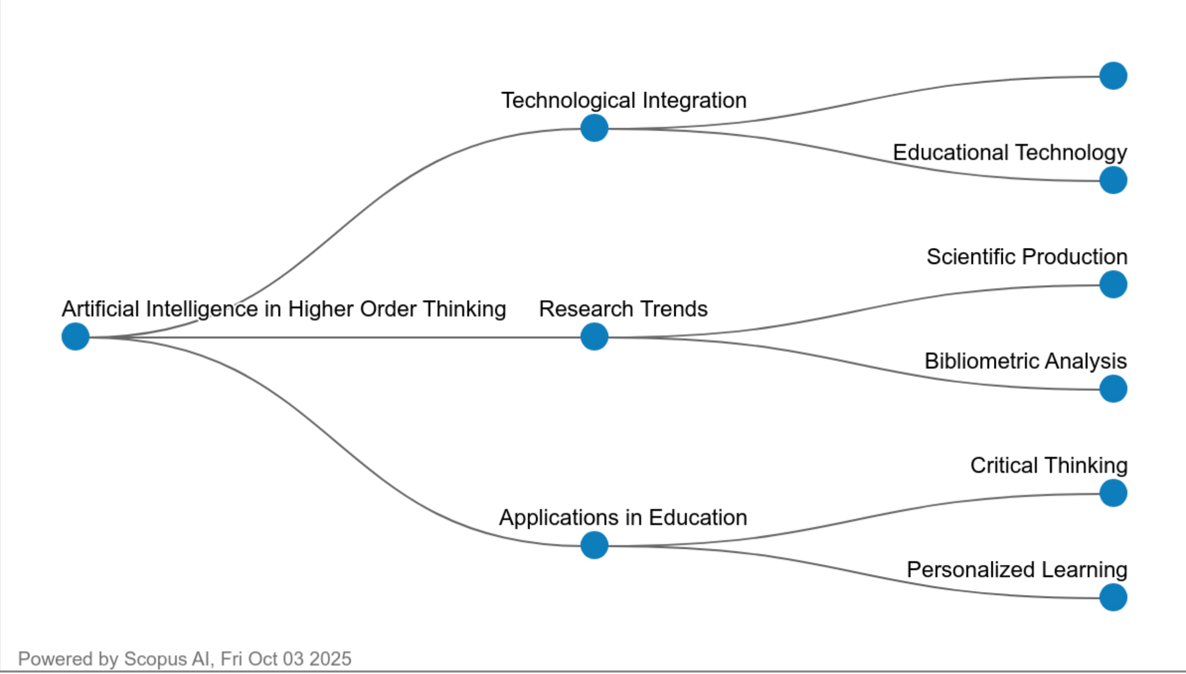

Figure 1: The Topic Branches Into Three Main Domains: Technological Integration, Research Trends, And Applications In Education

Methodology

Bibliometric analysis was employed as the core methodological approach, encompassing the systematic collection, organization, and evaluation of bibliographic data derived from scientific publications Passas (2024) Gan, Y., et al. (2022). Beyond descriptive statistics, for instance, the identification of core journals, temporal publication patterns, and influential authors Maria A Agunti & Manuel Orta Perez (2022); C Wang, X Chen, T Yu, Y Liu, Y Jing (2024), the method incorporated advanced techniques, including document co-citation analysis, to uncover intellectual structures within the field. Conducting a rigorous literature review required an iterative process of keyword selection, database searching, and critical examination to ensure the comprehensiveness and reliability of results N Shaheen, A Shaheen, A Ramadan; UE Chigbu, SO Atiku, CC Du Plessis (2023). Special emphasis was given to high-impact publications, as they provide deeper insights into the theoretical foundations and knowledge trajectories that shape the research domain. To enhance validity and consistency, **Elsevier's Scopus database,** known for its broad and authoritative coverage, was designated as the primary source for data retrieval VK Singh, P Singh, M Karmakar, J Leta, P Mayr , 2021; P Singh, VK Singh, R Piryani; S Yubo, T Ramayah, L Hongmei, Z Yifan, W Wenhui – Heliyon (2023). To preserve scholarly rigor, only peer-reviewed journal articles were incorporated, with books, conference proceedings, and lecture notes intentionally omitted (MJ Piran, NH Tran, 2024). The dataset comprised publications spanning January 2020 to October 2025, offering a contemporary and focused perspective on emerging research trends.

Data Analysis

VOSviewer, established by Nees Jan van Eck and Ludo Waltman at Leiden University, Netherlands, is a widely recognized and user-friendly bibliometric software H Arruda, ER Silva, M Lessa (2022); Norh Hassin & M Kamaludin (2024). It is particularly valued for its capacity to visualize and analyze large volumes of scientific literature by generating intuitive

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network visualizations, clustering related items, as well as producing density maps. Its versatility extends to examining co-citation, co-authorship, and keyword co-occurrence networks, thereby offering scholars a thorough comprehension of evolving research landscapes. With its interactive interface, continuous software enhancements, and compatibility with multiple bibliometric data sources, VOSviewer has become an indispensable tool for both novice and experienced researchers seeking to extract meaningful insights from complex datasets.

One of VOSviewer's most distinctive contributions lies in its ability to transform intricate bibliometric datasets into visually interpretable maps. Its strength in network visualization allows the clustering of related items, the identification of keyword co-occurrence patterns, and the generation of density maps that highlight research trends. The software's ongoing development ensures methodological relevance and adaptability, cementing its position at the forefront of bibliometric analysis.

In this study, datasets in PlainText format containing information, for example, publication title, year, journal, author, citation count, and keywords, were extracted from the Scopus database, encompassing the period from 2020 to October 2025. The datasets were then assessed utilizing VOSviewer version 1.6.20, utilizing clustering and mapping techniques to generate insightful visual representations. Unlike traditional Multidimensional Scaling (MDS), which mainly employs similarity measures, for instance, cosine and Jaccard indices, VOSviewer situates items in low-dimensional spaces where proximity reflects relatedness and similarity S Slat, MHM Yatim, NM Abdullah (2024; Zulaffendi Jamalludin, Nur Rahmas Mohd Saman, Noreen Noor Abd Aziz, 2025). Crucially, it employs the **Association Strength (AS_{ij})** as a normalization method for co-occurrence frequencies, providing a more robust measure of item similarity (N Jamil Noor Ashikin Mat Shoib, Roslee Talip, Nursuhaidah Sukor, 2025).

$$AS_{ij} = \frac{C_{ij}}{w_i w_j},$$

which is "proportional to the ratio between on the one hand the observed number of co-occurrences of *i* and *j* and on the other hand the expected number of co-occurrences of *i* and *j* under the assumption that co-occurrences of *i* and *j* are statistically independent" (YM Chang, S Rakshit, CH Huang, WH Wu, 2023; Noor Ashikin Mat Shoib, Roslee Talip, Nursuhaidah Sukor, 2025).

Data Search Strategy

For the aims of this research, the data collection process was conducted using the **Scopus advanced search function**, which is widely regarded as one of the most comprehensive and authoritative databases for scholarly publications. The search strategy employed a carefully constructed string: *TITLE-ABS-KEY ("artificial intelligence" AND (higher order OR thinking) AND (science OR education OR technology)) AND PUBYEAR > 2019 AND PUBYEAR < 2026*

International Journal of Modern Education
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IJMOE
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DOI: 10.35631/IJMOE.728058
AND (LIMIT-TO (LANGUAGE, "English")) to ensure precision in retrieving relevant literature. This query was deliberately designed to capture publications addressing the intersection of AI, HOT, science, education, and technology within the specified time frame. To guarantee the reliability and reproducibility of results, the search was conducted in **October 2025 (refer to Table 1)**, providing a fixed access date for transparency and academic rigor. After retrieval, the datasets underwent a screening process based on predefined inclusion and exclusion criteria. Moreover, publications were included if they were written in English, peer-reviewed, and published between 2020 and 2025 (refer to Table 2), ensuring both accessibility and contemporary relevance. Conversely, non-English language publications and those outside the time window were excluded to maintain focus and consistency. After applying these filters, the final dataset comprised **2,009 documents**, representing a significant corpus of literature for bibliometric analysis. This comprehensive dataset provides a robust foundation for mapping research trends, identifying influential contributions, and exploring the intellectual landscape of AI in HOT within science education and related domains.

Table 1
The Search String.

Scopus	**TITLE-ABS-KEY ("artificial intelligence" AND (higher order OR thinking) AND (science OR education OR technology)) AND PUBYEAR > 2020 AND PUBYEAR < 2025 AND (LIMIT-TO (LANGUAGE , "English"))** **Access date: October 2025**

Table 2
The Selection Criterion Is Searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Time line	2020 – 2025	< 2021

International Journal of Modern Education
EISSN: 2637-0905
IJMOE
Volume 7 Issue 28 (December 2025) PP. 844-858
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Finding and Discussion

RQ 1- What Are The Trends / What Are The Research Trends In Online Learning Studies According To The Year Of Publication?

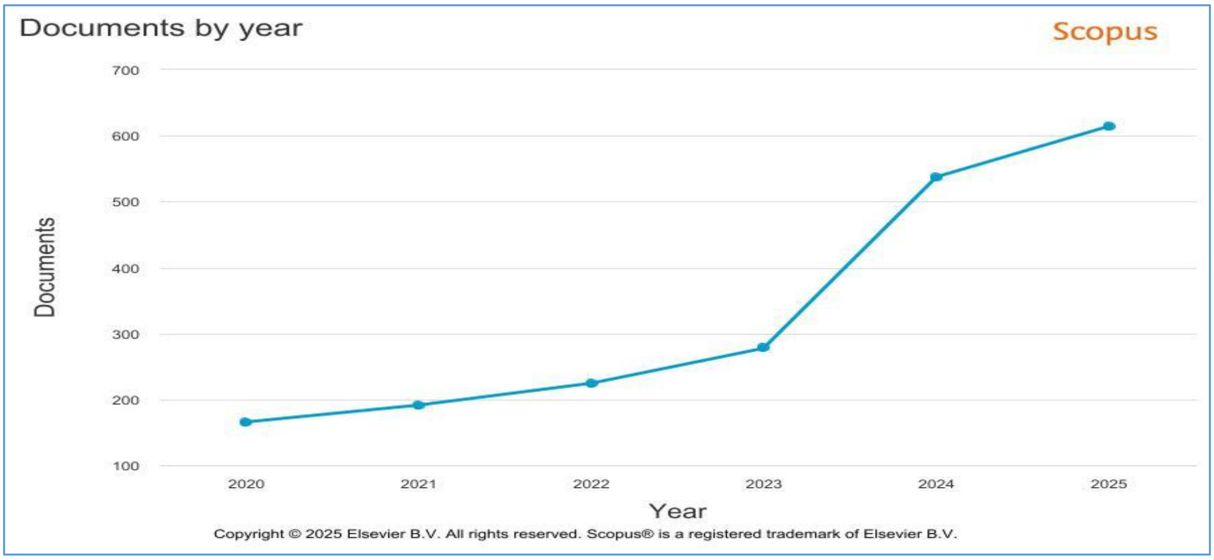

Figure 2: Number Of Documents Based On Year Of Publication.

The bibliometric data retrieved from Scopus reveal a clear upward trajectory in research publications addressing *artificial intelligence in higher-order thinking within science, education, and technology* from 2020 to 2025. Beginning with 165 documents in 2020, the number of publications grew steadily, reaching 191 in 2021 and 224 in 2022, before showing a sharper rise to 278 in 2023. The most striking growth appears in 2024 and 2025, with 537 and 614 publications, respectively, indicating more than a threefold increase within a five-year span. This pattern suggests that AI integration in education and cognitive development has rapidly evolved from an emerging area of interest to a mainstream research priority. Such growth reflects both the accelerating adoption of AI in educational technologies and the increased scholarly attention toward its potential to enhance critical and HOT skills in science and related disciplines.

Several factors may account for this surge. The global push toward digital transformation, particularly following the COVID-19 pandemic, has heightened reliance on AI-driven educational tools, thereby intensifying scholarly interest. Furthermore, the growing recognition of AI's role in fostering personalized learning and critical thinking has aligned with policy initiatives and funding priorities worldwide, encouraging further research output. The significant rise in 2024 and 2025 may also be attributed to the cumulative effects of earlier foundational studies, the expansion of open-access publishing, and interdisciplinary collaboration bridging computer science, cognitive psychology, and pedagogy. This indicates a maturing research landscape, where AI is no longer explored merely as a technological novelty but as a strategic instrument shaping the future of science education and HOT development.

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RQ 2-What Are The Most Cited Articles?

Table 3: Most Cited Author

Authors	Title	Year	Source title	Cited by
Bi et al., (2023)	Accurate medium-range global weather forecasting with 3D neural networks	2023	Nature	897
Farrokhnia et al. (2024)	A SWOT analysis of ChatGPT: Implications for educational practice and research	2024	Innovations in Education and Teaching International	674
Dergaa et al. (2023)	From human writing to artificial intelligence-generated text: Examining the prospects and potential threats of ChatGPT in academic writing	2023	Biology of Sport	468
Michel-Villarreal et al. (2023).	Challenges and Opportunities of Generative AI for Higher Education as Explained by ChatGPT	2023	Education Sciences	464
Santodomingo-Rubido et al., (2022)	Keratoconus: An updated review	2022	Contact Lens and Anterior Eye	461
Yilmaz & Karaoglan Yilmaz, (2023)	The effect of generative artificial intelligence (AI)-based tool use on students' computational thinking skills, programming self-efficacy and motivation	2023	Computers and Education: Artificial Intelligence	415
Bhayana et al., (2023)	Performance of ChatGPT on a Radiology Board-style Examination: Insights into Current Strengths and Limitations	2023	Radiology	291
Herath & Mittal, (2022)	Adoption of artificial intelligence in smart cities: A comprehensive review	2022	International Journal of Information Management Data Insights	254
Javaid & Haleem, (2020)	Critical components of Industry 5.0 towards a successful adoption in the field of manufacturing	2020	Journal of Industrial Integration and Management	244
Cui et al., (2021)	A New Subspace Clustering Strategy for AI-Based Data Analysis in IoT Systems	2021	IEEE Internet of Things Journal	227

Table 3 presents an analysis of the dominance of recent publications (2020–2024) among the top 10 most cited articles, which can be attributed to the exponential growth of AI research,

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particularly following the global acceleration of digital transformation triggered by the COVID-19 pandemic. Here, this period marked a surge in both practical applications and theoretical exploration of AI, especially with the emergence of generative AI tools, for instance, ChatGPT, which reshaped discourse in education, healthcare, and industry. The exceptionally high citation counts of works like Farrokhnia et al. (2024) and Dergaa et al. (2023) reflected the immediacy and relevance of AI's impact on academic writing, teaching, and research ethics, leading to rapid scholarly uptake. Meanwhile, the prominence of interdisciplinary applications, such as weather forecasting (Bi et al., 2023), radiology (Bhayana et al., 2023), and ophthalmology (Santodomingo-Rubido et al., 2022), demonstrates how AI solutions address pressing global challenges, ensuring high visibility and citation across multiple fields. Furthermore, journals with strong reputations and broad readership, such as Nature and Computers and Education: Artificial Intelligence, amplified the visibility of these studies, accelerating their citation rates. Overall, the results suggest that AI-driven research, especially when tied to urgent societal needs and disruptive technologies like ChatGPT, achieves rapid scholarly recognition due to its novelty, cross-disciplinary relevance, and alignment with current global priorities (Alabidi et al., 2023).

RQ 3- Where Is The Top 10 Countries Based On The Number Of Publications?

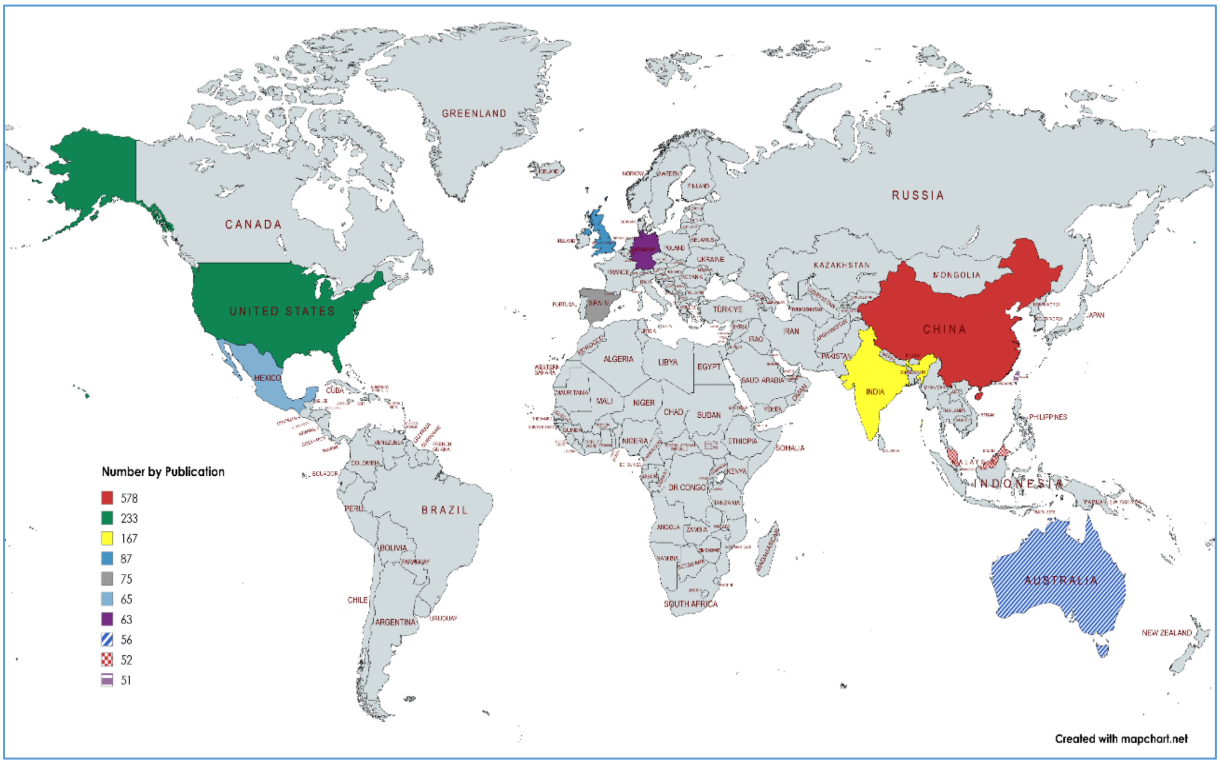

Figure 3: Country Mapping Based On The Number Of Publications

The country-wise distribution of publications reveals that studies on *artificial intelligence in higher-order thinking within science, education, and technology* are led by China, which dominates with 578 publications. The United States follows with 233 outputs, while India secures the third position with 167 contributions. European countries like the United Kingdom

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IJMOE
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(87), Spain (75), and Germany (63) occupy mid-level positions, indicating a stable yet comparatively modest engagement in the field. Meanwhile, countries like Mexico (65), Australia (56), Malaysia (52), and Taiwan (51) demonstrate growing participation, highlighting the increasingly global nature of research in this domain. The data suggests a clear concentration of scholarly output in Asia as well as North America, with China as the most influential hub of research activity.

Several contextual factors account for this trend. China's strong performance can be linked to its national policy prioritizing AI as a strategic sector, coupled with heavy investment in education technology and its rapid expansion of higher education institutions. The United States' leadership in AI innovation and well-established academic infrastructure similarly contribute to its significant research presence. India's rise reflects its increasing focus on digital transformation, government-funded initiatives in education, and an expanding academic publishing base. The comparatively lower output from Europe and other regions may stem from differences in research funding priorities, although their contributions remain impactful through high-quality publications and collaborative networks. The inclusion of emerging economies such as Malaysia and Mexico demonstrates how global interest in AI for education is expanding, supported by international collaborations and open-access platforms that make participation more accessible.

RQ 4: What Are The Popular Keywords Related To The Study?

Co-occurrence analysis concerning author keywords in VOSviewer is a bibliometric technique used to identify the relationships and connections among frequently used keywords in a body of literature. Note that analyzing how often specific keywords appear together in publications helps reveal major themes, research trends, and intellectual structures of a field. In this study, the co-occurrence map was generated via the full counting method, where each occurrence of a keyword is counted equally. A minimum threshold of 5 was set, meaning only keywords appearing at least 5 times were included, which reduced the total 6,676 keywords to 863 that met this condition. Additionally, the minimum cluster size was set to 5, and based on these parameters, 8 clusters were generated. These clusters represent thematic groups of research topics, where the strength of links shows the closeness of relationships between concepts.

The findings highlight that the most dominant and highly connected keywords are AI, students, higher education, teaching, and machine learning. This indicates that current research is strongly centered on AI integration into education, particularly in higher education contexts. The high total link strength of keywords such as "artificial intelligence" (11,569) and "students" (4,585) reflects their central role in connecting different research themes. Emerging terms like "ChatGPT," "generative AI," and "large language model" also demonstrate the increasing attention to generative technologies in teaching and learning. These clusters contribute to the body of knowledge by mapping how traditional themes in education, such as critical thinking, curricula, and e-learning, intersect with advanced AI technologies, signalling a paradigm shift toward AI-driven educational innovation. This advances theoretical understanding and provides a foundation for practical applications in teaching, learning systems, and educational policy.

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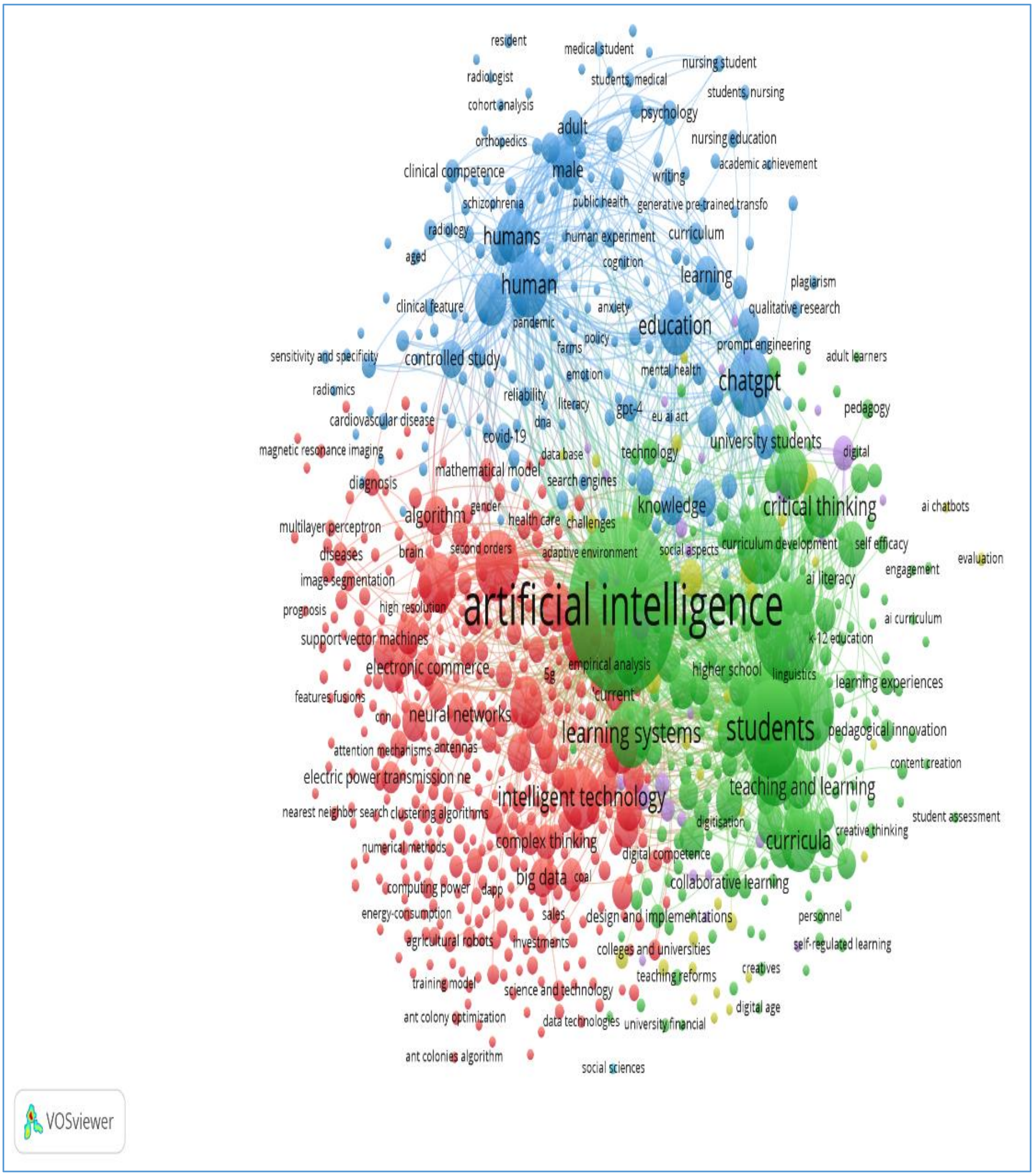

Figure 4: Network Visualization Map Of Keywords' Co-Occurrence

RQ5: What Are Relevant Cooperative Author Groups?

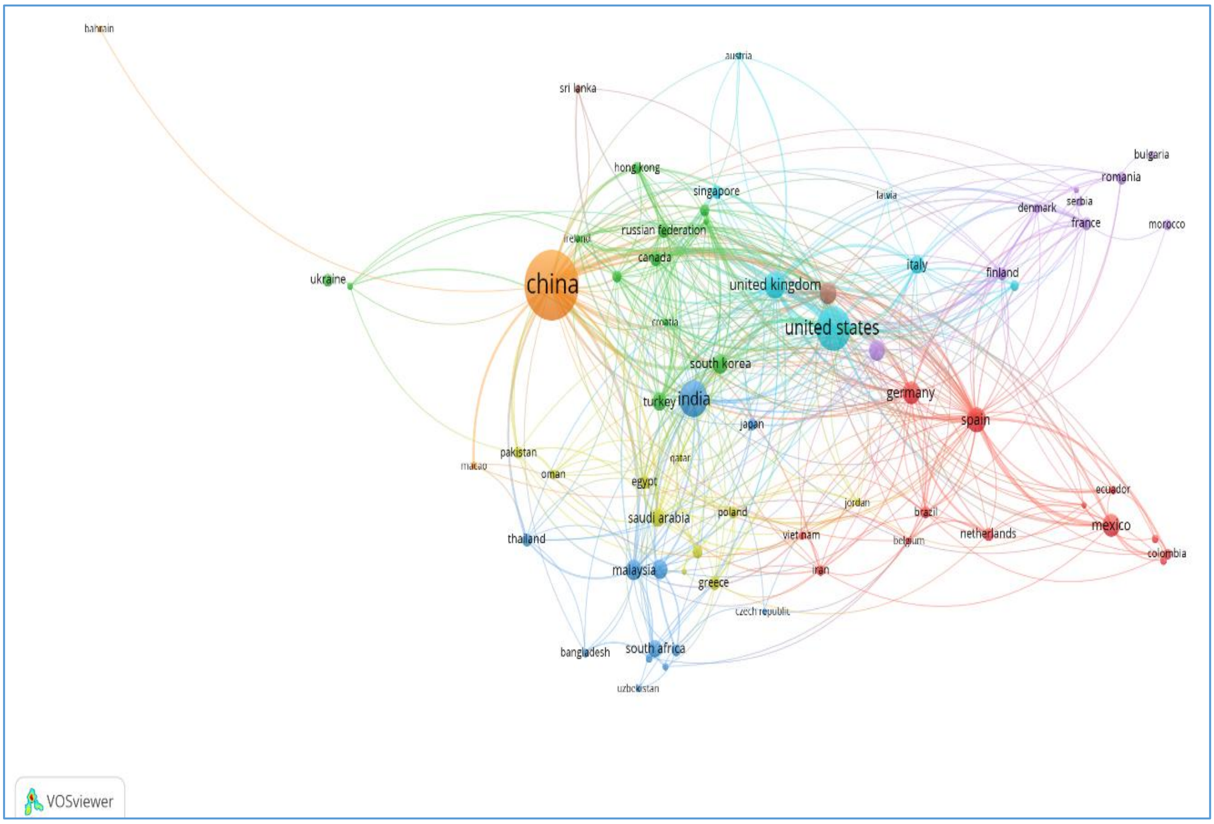

Figure 5: Relevant Cooperative Author Groups

As illustrated in Figure 5, the analysis revealed that the relevant cooperative author groups, which are the subject of urban poverty research, are displayed in various colors. The largest group is the red cluster, consisting of 14 authors. Among them, the most prolific contributors are Liu, Y. (16 publications), Zhang, H. (10 publications), and Chen, X., Zhang, X., and Li, Z. (9 publications each). The second group, represented in green, comprises 10 authors, with the most prominent being Wang, J. (18 publications), Wang, Y. (15 publications), and Zhao, J. and Khan, M.A. (9 publications each). The third-largest group, shown in blue, includes 9 authors, with Li, Y. standing out with 14 publications, followed by Liu, X. and Li, H. (12 publications each) and Li, B. (7 publications).

The concept of co-occurrence co-authorship by countries in VOSviewer refers to mapping and analyzing international research collaboration networks. Each country is represented as a node, and the links between them show how often researchers from different countries co-author scientific publications together. The strength of these links reflects the intensity of collaboration, while cluster group countries tend to collaborate more frequently with each other. In this case, the analysis was generated utilizing the full counting method, where each co-authorship relation is counted equally. A minimum threshold of 5 documents was implemented, which means only countries with at least 5 co-authored publications were incorporated. Out of 118 countries, 70 met this criterion, and by setting the minimum cluster size to 5, the visualization resulted in 8 distinct collaboration clusters.

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The findings show that leading contributors such as **China, the United Kingdom, the United States, and India** dominate in terms of both publication volume and citation impact, indicating their strong influence in the research landscape. Countries like Spain, Australia, and Germany also appear as important hubs, linking to both Western and Asian research communities. Regional players such as Malaysia, Saudi Arabia, and South Korea highlight the growing contribution of emerging economies to global research networks. Consequently, the formation of 8 clusters demonstrates that scientific collaboration is shaped by geographic proximity and by thematic and institutional partnerships. These results contribute to the body of knowledge by revealing global patterns of cooperation, highlighting disparities between high-output and low-output countries, and emphasizing the role of international networks in advancing scientific innovation and knowledge exchange.

Conclusion

We analyzed a total of 12,272 publications regarding e-learning from 2020 to 2025, representing 0.06466% of all research on e-learning published in Scopus during the same period (12,272 out of 18,976,811 records). Initially, a performance/descriptive analysis of the metadata was conducted to examine publication output by year, institution, country, author, journal, and research area. Thematic analysis categorized the topics into four groups based on their centrality and density. Declining themes included computer-based, electronic, and motivational topics, while niche themes showed limited relevance to broader subjects and disciplines. “alcohol”, “college students”, and “depression” clustered. Here, the second cluster in this area encompassed themes such as “learning analytics”, “e-assessment system”, and “moocs”. These concerns were significantly more central. Note that the cluster contained “online formative assessment”, “collaborative learning”, and “distance education”. The section on “Motor themes” included topics such as “alternative assessment”, “self-assessment”, and “authentic assessment”. “Basic themes” were “distance learning”, “accessibility”, and “assessment design”. The second one was “Covid”, “medical education”, and “online education”. The third cluster comprised themes such as “online assessment,” “formative assessment,” and “online learning,” which, although less dense, represent more critical concepts. The terms “e-assessment,” “higher education,” and “assessment” exhibited the highest centrality, indicating stronger connections with other themes but lower intensity within their own cluster (co-occurrence).

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