Examining the Expansion and Collaborative Patterns of Artificial Intelligence in Education: A Bibliometric Study

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Abstract

Purpose – The purpose of this study is to conduct a comprehensive bibliometric analysis of the existing literature on the use of artificial intelligence (AI) in education. The study aims to map the scholarly network in this emerging field and identify trends in publication output, influential contributors, core research themes and areas that require further investigation.

Design/methodology/approach – The study conducts a bibliometric analysis of scholarly articles on AI in education indexed in the Scopus database. A total of 1,192 publications meeting the selection criteria were analysed using bibliometric mapping and visualization tools including VOSviewer, Microsoft Excel and biblioshiny. Frequency analyses, network mapping and citation metrics were used to analyse publication trends, collaborations, and impact.

Findings – The findings indicate a significant exponential growth in publications since 2010, establishing AI in education as a vibrant field. Prolific contributors include individual authors, institutions such as the Education University of Hong Kong, and countries like China and the US. Network analyses revealed extensive collaborations through co-authorship within and between regions. Core themes centred around AI's role in transforming pedagogy and learning experiences.

Research limitations/implications – The study is limited to publications indexed in Scopus. Future research could expand the analysis to other databases and languages. Insights from the bibliometric maps have implications for focusing efforts to strengthen collaborative ties and under-represented areas

Originality/value – This is the first comprehensive bibliometric study to map the scholarly network in this emerging field. The systematic analysis provides a holistic view of trends, influencers and conceptual themes, with value for informing future research directions in AI-enhanced education.

Keywords: Artificial Intelligence, education, Bibliometrics, VOSviewer, biblioshiny

1. INTRODUCTION

Artificial intelligence (AI) is a technological evolution that involves the development and implementation of computer systems capable of performing human-like intelligence tasks, such as learning, reasoning, problem-solving, and decision-making (Crompton, H., & Burke, D., 2023, p. 1). Education. AI has captured considerable attention in the field of education in recent years. Promising

opportunities for enhancing teaching, learning, and educational outcomes have emerged through AI technologies such as machine learning, natural language processing, and intelligent tutoring systems (Alqahtani et al., 2023). Researchers have been exploring various applications of AI in education, including personalized learning, adaptive assessments, intelligent teaching assistants, and automated essay scoring (Crompton & Burke, 2023).

While there has been a rapid increase in publications focused on applying AI in higher education between 2016-2022, systematic reviews have highlighted the emergence of new trends in research locations, researcher affiliations, and subjects covered (Crompton & Burke, 2023). The use of AI in K-12 education and STEM fields, in particular, is also on the rise. For example, a review of the role of AI in STEM higher education revealed benefits such as personalized and adaptive learning through intelligent tutoring systems, collaborative learning environments, and improved assessment methods (Nagaraj et al., 2023). AI is seen as a means to enhance student engagement and optimize learning outcomes in STEM disciplines.

Furthermore, AI holds potential to transform other aspects of education. Lakshmi et al. (2023) noted that AI-based online education systems in UAE military colleges can enhance the quality, efficacy, and accessibility of technical and vocational education by providing individualized, adaptive learning pathways and hands-on simulations. However, challenges exist in integrating AI-driven curricula and fostering collaboration between human educators (Lakshmi et al., 2023). While research on AI applications in education is growing rapidly, there is limited analysis of the overall structure and trends within this emerging field of scholarship.

Despite the rapid growth of AI in education research, there has been limited analysis of the overall structure and trends within this field. Understanding the distribution of existing literature across different variables such as publications over time, contributing authors, institutions, and countries can provide valuable insights. However, no prior study has systematically mapped and analyzed the scholarly network of AI in education using bibliometric techniques. Such analysis is crucial to comprehend the current status and future directions of this emerging field.

To address this gap, this study aims to conduct a comprehensive bibliometric analysis of the literature on AI in education. The specific objectives of this study are as follows:

1. Analyse publication trends over time to understand the expansion of the field.
2. Identify major contributors, including productive authors, institutions, and countries.
3. Examine patterns of collaborations through co-authorship and co-occurrence networks.
4. Determine influential works through citation metrics and highly cited references.
5. Map the conceptual structure by analysing keywords and their relationships.

To achieve these objectives, the study will address the following research questions:

1. How have the publication trends and patterns in the field of utilizing Artificial Intelligence (AI) in education changed over time?
2. Who are the most productive authors in the field, and what are the key subject areas in their research?
3. What institutions contributed most to the field of utilizing Artificial Intelligence (AI) in education, and how have they influenced to the development of the field?
4. What countries contributed most to the field of utilizing Artificial Intelligence (AI) in education, and how does this vary across different regions and time frames?
5. What are the most highly cited documents in the field of utilizing Artificial Intelligence (AI) in education, and what are the key subject areas in their researches?

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6. What are the most common keywords in the literature on utilizing Artificial Intelligence (AI) in education, and how have their usage pattern changed over time?
7. What are the patterns of co-authorship in the field of utilizing Artificial Intelligence (AI) in education, and how do they vary across different regions, institutions, and research topics?

2. LITERATURE REVIEW

2.1. Historical Development

Research on AI in education has grown rapidly in recent years. Early studies explored basic applications of AI such as computer-assisted instruction and intelligent tutoring systems (Crompton & Burke, 2023). Recent research has built on theoretical frameworks such as constructivism and connectivism to enhance learning through personalized, adaptive, and collaborative features enabled by AI (Lin, Huang, & Lu, 2023). For example, AI has allowed for the development of interactive learning environments that adapt based on individual student needs and provide customized scaffolding (Nagaraj et al., 2023).
Methodologically, research has shifted from small-scale implementations to large-scale evaluations using techniques such as learning analytics and educational data mining to analyze student interactions with AI systems (Shrivastava, 2023). Scholars have also utilized design-based and mixed methods approaches to understand the complex interplay between technological, pedagogical, and human factors involved in AI integration into education (Alhumaida et al., 2023).

2.2. Recent Development

Several trends are emerging in the concepts studied regarding AI in education. New technologies like natural language processing and automated essay scoring are being applied to support personalized feedback and assessment (Alqahtani et al., 2023). However, concerns regarding data privacy, algorithmic bias, and the need for human oversight continue to be addressed (Nagaraj et al., 2023).

Theories are being expanded to examine AI adoption from an organizational perspective using frameworks such as the technology-organization-environment model (Alhumaida et al., 2023). Models are also being developed to understand challenges like the “black-box” nature of AI and its impact on authority structures in pedagogy (Bearman et al., 2023).

Methodologically, studies are beginning to integrate AI techniques like machine learning within mixed methods approaches to derive insights from educational big data (García-Montalvo, 2023). Computational techniques allow for increasingly nuanced analyses of collaborative patterns and expertise networks within AI-augmented learning environments (Ruiz-Rojas et al., 2023).

As AI becomes more ingrained in education, its role in facilitating interdisciplinary and work-relevant learning is also being investigated (Lakshmi et al., 2023).

3. METHODS

In this study, we utilized data from the Scopus database as of September 6, 2023. We conducted a keyword search using "Artificial Intelligence" and "Education" specifically in the titles of relevant articles. We focused on the article titles as they reflect the important topics related to our research area and objectives, we obtained a total of 1234 documents for bibliometric analysis. However, we excluded 39 documents due to missing author names and IDs.

To analyse the data, we employed various tools. Firstly, Microsoft Excel was used to calculate and visualize the frequencies of the published materials. Additionally, we utilized VOSviewer (www.vosviewer.com) to construct bibliometric networks and create visualizations and graphs.

Openrefine for data cleaning and harmonizing. Finally, EndNote was employed for reference management purposes.

To effectively analyse the data, we employed a range of tools and techniques. Firstly, we utilized Microsoft Excel to calculate frequencies and generate visual representations of the published materials. This allowed us to gain insights into the prevalence and distribution of the identified articles. Additionally, we leveraged the power of VOSviewer, a software tool available at www.vosviewer.com, to construct bibliometric networks and create visually engaging graphs and visualizations. The use of VOSviewer enabled us to identify patterns, connections, and clusters within the scholarly literature.
To ensure data quality and consistency, we employed OpenRefine, a tool specifically designed for data cleaning and harmonization. This allowed us to address any inconsistencies or inaccuracies in the dataset, ensuring the reliability of our analysis. Lastly, for efficient reference management, we utilized EndNote, a widely recognized software tool that facilitated the organization and citation of relevant literature. According to Figure 1, it serves as a visual representation of this search strategy, which has been adapted from Zakaria et al. (2021) and Moher et al. (2009). The flow diagram illustrates the various stages involved in the search process.

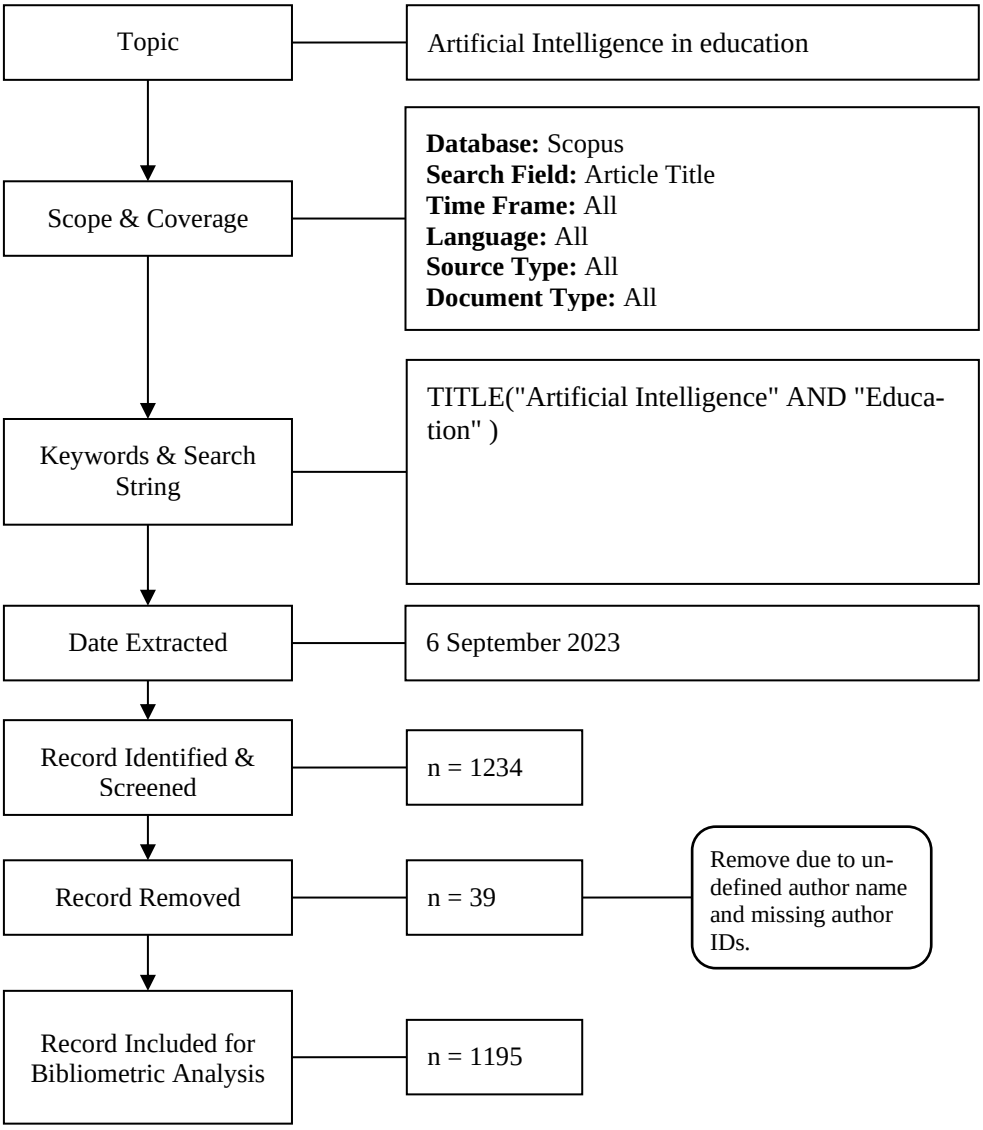

Figure 1: Flow diagram of the Search Strategy

Source: Zakaria et al. (2021), Moher et al. (2009)

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4. RESULTS

4.1. Documents Profiles

A bibliometric analysis of the research landscape on AI in education was conducted based on 1,192 scholarly works that met the selection criteria. As presented in Table 1, journal articles formed the major mass of the publications constituting 43.88% of the total quantity with 523 documents. This highlights the matured status of research in this field as important findings and insights tend to be published in peer-reviewed journals. Conference papers accounted for the second largest share of 33.98% with 405 publications, indicating ongoing advances are also actively discussed through specialized events and proceedings.

In terms of document type and purpose, review papers made up 6.29% with 75 publications, reflecting efforts to consolidate knowledge through literature surveys. Editorials and letter articles formed a minor portion respectively with 43 documents (3.61%) and 15 documents (1.26%). When examining by source types in Table 2, journals remained the dominant channel accounting for 57.21% of publications with 682 documents, followed by conference sources at 24.66% with 294 documents. Book series comprised 12.33% with 147 publications, signifying knowledge is also being compiled and disseminated through book imprints.

Regarding language of publication presented in Table 3, the field demonstrated notable international reach with works in 11 different languages. English dominated the landscape by a wide margin, representing 97.65% of total publications with 1164 documents. This is expected given the global nature of research. Other languages in the descending order included Spanish, Russian, Chinese and others, with their respective shares ranging from 1.01% to 0.08%. Seven documents were even published using a dual language format.

In terms of subject classification areas in Table 4, Computer Science understandably topped the list with a dominant 58.22% share of 694 publications owing to the technical foundations of AI. Social Sciences (39.26%), while other substantially represented domains in descending order included Engineering (27.77%), Health Professions (10.49%), and others related to interdisciplinary research involving education such as Medical (10.49%) and Psychology (3.69%). This cross-domain spread affirms the diverse and multifaceted nature of studying AI's role and impact in education.

Table 1: Document Type

Document Type	TP	%
Article	523	43.88%
Conference Paper	405	33.98%
Book Chapter	78	6.54%
Review	75	6.29%
Editorial	43	3.61%
Note	20	1.68%
Letter	15	1.26%
Book	14	1.17%
Erratum	13	1.09%
Retracted	5	0.42%
Short Survey	1	0.08%

Table 2: Source Type

Source Type	TP	%
Journal	682	57.21%
Conference Proceeding	294	24.66%
Book Series	147	12.33%
Book	65	5.45%
Trade Journal	4	0.34%
Total	1192	100

Table 3: Languages

Language	TP	%
English	1164	97.65%
Spanish	12	1.01%
Russian	7	0.59%
Chinese	5	0.42%
Portuguese	4	0.34%
French	2	0.17%
Italian	2	0.17%
Arabic	1	0.08%
German	1	0.08%
Korean	1	0.08%
Total	1199	100

*Seven documents have been prepared in dual languages

Table 4: Subject Area

Subject Area	TP	%
Agricultural and Biological Sciences	4	0.34%
Arts and Humanities	38	3.19%
Biochemistry, Genetics and Molecular Biology	9	0.76%
Business, Management and Accounting	46	3.86%
Chemical Engineering	8	0.67%
Chemistry	1	0.08%
Computer Science	694	58.22%
Decision Sciences	109	9.14%
Dentistry	9	0.76%
Earth and Planetary Sciences	4	0.34%
Economics, Econometrics and Finance	14	1.17%
Energy	46	3.86%
Engineering	331	27.77%
Environmental Science	47	3.94%
Health Professions	30	2.52%
Immunology and Microbiology	3	0.25%

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Materials Science	24	2.01%
Mathematics	150	12.58%
Medicine	125	10.49%
Multidisciplinary	7	0.59%
Neuroscience	17	1.43%
Nursing	19	1.59%
Pharmacology, Toxicology and Pharmaceutics	3	0.25%
Physics and Astronomy	56	4.70%
Psychology	44	3.69%
Social Sciences	468	39.26%
Veterinary	1	0.08%
Undefined	1	0.08%

4.2. Publication Trends

In Table 5 and Figure 2 we can find an analysis of the publication patterns, in the AI field concerning education. Over time there has been a rise in the number of published works indicating an increasing interest and research activity in this area. Collaboration among authors and publications has also witnessed a trend. The total number of citations has experienced growth suggesting that research in this domain is gaining recognition and relevance. It is worth noting that both the average citations per publication and the citations per publication have shown an increase over time reflecting the growing impact of these studies. Moreover, indicators such as the h index, g index and m index have all displayed trends indicating the influence and quality of these publications. Notably starting from 2018 there has been a surge in both publications and citations which underscores the rising prominence and significance of AI in education research as well as increased collaboration, among researchers.

Table 5: Year of Publication

Year	TP	NCA	NCP	TC	C/P	C/CP	h-index	g-index	m-index
1976	1	1	1	5	5.00	5.00	1	1	0.02
1984	1	1	1	2	2.00	2.00	1	1	0.03
1985	5	8	2	25	5.00	12.50	2	5	0.05
1986	5	9	3	18	3.60	6.00	3	4	0.08
1987	4	4	3	13	3.25	4.33	2	3	0.05
1990	4	5	2	2	0.50	1.00	1	1	0.03
1991	2	5	1	8	4.00	8.00	1	2	0.03
1992	2	5	1	1	0.50	1.00	1	1	0.03
1993	2	4	2	11	5.50	5.50	1	2	0.03
1994	1	2	1	3	3.00	3.00	1	1	0.03
1998	1	1	1	14	14.00	14.00	1	1	0.04
1999	1	1	1	1	1.00	1.00	1	1	0.04
2004	1	1	1	57	57.00	57.00	1	1	0.05
2006	1	2	1	3	3.00	3.00	1	1	0.06
2008	1	1	1	5	5.00	5.00	1	1	0.06
2009	6	18	4	33	5.50	8.25	2	5	0.13
2010	2	2	1	18	9.00	18.00	1	2	0.07
2011	2	3	2	3	1.50	1.50	1	1	0.08

2012	2	6	2	38	19.00	19.00	2	2	0.17
2013	7	12	7	75	10.71	10.71	4	7	0.36
2014	5	13	5	27	5.40	5.40	3	5	0.30
2015	5	13	3	40	8.00	13.33	2	5	0.22
2016	9	22	9	518	57.56	57.56	6	9	0.75
2017	11	21	11	614	55.82	55.82	5	11	0.71
2018	25	67	21	586	23.44	27.90	9	24	1.50
2019	58	186	49	1575	27.16	32.14	15	39	3.00
2020	136	373	113	2019	14.85	17.87	19	42	4.75
2021	253	663	167	1775	7.02	10.63	20	34	6.67
2022	361	1053	226	1236	3.42	5.47	15	25	7.50
2023	278	957	85	582	2.09	6.85	11	21	11.00
Grand Total	1192	3459	727	9307	7.81	12.80	134	258	

Notes: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.

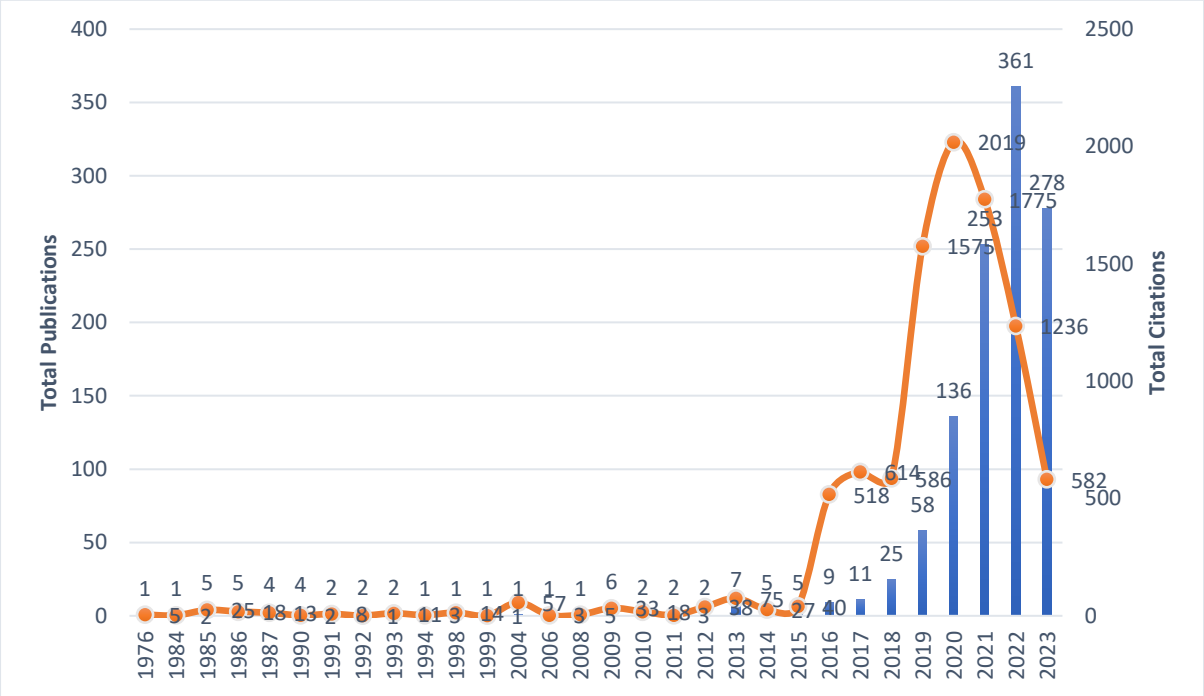

Figure 2: Total Publications and Citations by Year

4.3. Publications by Authors

Table 6 reveals that amongst the 3,459 authors contributing to this research area, Hwang, Gwo-Jen emerges as the most prolific author based on an outstanding total of 720 publications. This exceptional volume of scholarly output over the years establishes Hwang as a towering figure pushing the boundaries of knowledge in this domain.

Beyond quantitative measurements, Hwang also exhibits immense citation impact evident from higher metrics such as the h-index value of 7. The citation per publication ratio of 54.17 further underscores the seminal influence and widespread recognition of Hwang's body of work shaping conversations worldwide. It is also noteworthy that 81.25 citations per cited paper is received on average, highlighting the sustained relevance of Hwang's contributions.

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Other esteemed authors like Kose, Utku and Jiao, Pengcheng have also significantly advanced the field through their substantial scholarly contributions reflected in Table 5. While Kose accounts for 23 publications with an h-index of 2, Jiao has an comparable h-index of 4 based on 109 publications. Their consistent research focusing on pertinent issues has enriched both theory and practice.

In Table 7 we can see the breakdown of author numbers, in AI and education research papers. Most of the documents have either one (352) or two (279) authors, which indicates that single or dual authored papers are quite common in this field. However, there is also a number of documents with three (214) or four (160) authors suggesting a level of collaboration in AI and education research. This distribution provides insight into the nature of research, within this domain, where many papers involve multiple authors working together to contribute to advancements in the field.

Table 6: Top 15 Productive Authors

Author's Name	TP	NCP	TC	C/P	C/CP	h-index	g-index
Hwang, Gwo-Jen (7202677655)	12	8	650	54.17	81.25	7	2
Kose, Utku (36544118500)	10	4	23	2.30	5.75	2	2
Jiao, Pengcheng (55604705500)	8	4	109	13.63	27.25	4	2
Ouyang, Fan (57193380924)	8	4	109	13.63	27.25	4	2
Holmes, Wayne (56720856800)	7	3	9	1.29	3.00	1	2
Mitrovic, Antonija (7003631144)	7	3	11	1.57	3.67	3	2
Alavi, Amir H. (33867483600)	6	2	8	1.33	4.00	2	2
Cankaya, Ibrahim Arda (56998609700)	6	2	4	0.67	2.00	2	2
du Boulay, Benedict (6602083684)	6	2	6	1.00	3.00	2	2
Yuksel, Asim Sinan (36999050000)	6	2	4	0.67	2.00	2	2
Koyun, Arif (54883083200)	6	2	4	0.67	2.00	2	2
McLaren, Bruce M. (25652179400)	6	2	2	0.33	1.00	1	2
Yigit, Tuncay (57223411924)	6	2	4	0.67	2.00	2	2
Tu, Yun-Fang (57200279952)	6	4	72	12.00	18.00	3	1
Chetyrbok, Petr V. (57195324976)	6	4	8	1.33	2.00	2	2

Notes: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.

Table 7: Number of Author(s) per document

Author Count	Frequency
1	352
2	279
3	214
4	160
5	76
6	45
7	20
8	13
9	7
10	10
11	5

12	4
13	1
14	3
15	1
16	1
21	1
Grand Total	1192

*Conference review document. No author is listed.

4.4. Publications by Institutions

Table 8 presents a ranking of the top 15 most productive institutions contributing a minimum of six publications to this field. It reveals the breadth of institutional participation from around the world. While some universities based in China and the United States feature prominently due to large volumes, it is noteworthy that Education University of Hong Kong achieves top ranking despite moderate publication outputs of 13 articles.

What is particularly commendable about Education University of Hong Kong's performance is the exceptionally high citation metrics recorded. With an outstanding average of 35.31 citations per publication and 38.25 citations per cited publication, it demonstrates immense quality impact beyond quantitative measures. This highlights the institution's ability to conduct seminal, highly influential research advancing both theory and practice.

Beyond the single top performer, other universities spanning diverse geographical regions also make notable contributions. Powerhouses from Asia like Chinese University of Hong Kong, National Taiwan University of Science and Technology and Zhejiang University are joined by reputed European institutions such as University College London and King's College London as well as esteemed American universities including University of California and Carnegie Mellon University.

This diverse, globally distributed representation of high-achieving institutions underlines the collaborative and interdisciplinary nature of the field. As depicted graphically in Figure 6, intensive linkages are established not just across international boundaries but also within national academic clusters. The network map vividly captures the spirit of scholarly exchange essential for progressing this nascent, fast-evolving domain.

Table 8: Top 15 productive institutions with minimum of six publications

Institution	TP	TC	NCP	C/P	C/CP	h-index	g-index
Affiliation NA	16	257	10	16.06	25.70	5	3
Education University of Hong Kong	13	459	12	35.31	38.25	9	1
University College London	11	49	8	4.45	6.13	5	2
National Taiwan University of Science and Technology	10	650	8	65.00	81.25	7	1
Chinese University of Hong Kong	10	431	9	43.10	47.89	7	1
University of California	10	44	6	4.40	7.33	4	2
University of Hong Kong	9	135	6	15.00	22.50	6	1
Zhejiang University	9	189	7	21.00	27.00	4	1
University of Sydney	9	86	6	9.56	14.33	3	2
University of Pittsburgh	7	22	4	3.14	5.50	4	1
Beijing Normal University	7	7	3	1.00	2.33	2	2
Carnegie Mellon University	7	11	4	1.57	2.75	2	2
King's College London	6	21	3	3.50	7.00	2	2
Stanford University	6	22	5	3.67	4.40	3	1

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Usak University	6	21	3	3.50	7.00	2	2

Notes: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.

4.5. Publications by Countries

The analysis of contributions by country presented in Table 7 reveals some interesting trends. China is identified as the largest contributor with 421 publications, reflecting massive investment and progress in artificial intelligence research. However, when impact is considered, other countries start to stand out.

While China's output is significant in quantity, the United States demonstrates higher average citations per paper at 9.05. This indicates that American works in this field tend to be more influential based on citation metrics. Another top performer is Australia, which achieves the highest average citations of 23.55 per document. This highlights the quality research coming from Australian institutions.

Beyond individual leading nations, it is interesting to note collaborative ties that have been formed between different regions as visualized in Figure 7. Distinct communities organized by geographical proximity are evident, with dense connections within regional blocs. For example, East Asian countries like China, Taiwan, South Korea and Japan exhibit strong collaborative networks. European states also collaborate closely.

At the same time, collaborative links bridge these communities internationally. Countries from every region are interconnected, showing global scholarly exchange is helping drive progress. This is essential in a field as rapidly evolving as artificial intelligence, where boundaries are continually pushed through sharing of multinational knowledge and resources.

Furthermore, Figure 3 depicts the contributions of each continent to the field of AI in education. It highlights a collaborative international landscape, with Asia, North America, Europe, Oceania, South America, and Africa all contributing to the evolving research in this domain.

In conclusion, while China leads in volume of research output so far, citation metrics point to higher impact work currently being done in other countries. The overlay map also demonstrates how collaborative ties have reinforced distinctive regional clusters of innovation while connecting the worldwide academic community.

Table 9: Top 15 Countries contributed to the publications.

Country	TP	TC	NCP	C/P	C/CP	h-index	g-index
China	421	1551	234	3.68	6.63	16	20
United States	197	1783	124	9.05	14.38	19	13
India	87	473	46	5.44	10.28	10	8
United Kingdom	71	568	44	8.00	12.91	13	7
Australia	38	895	28	23.55	31.96	10	5
Canada	37	759	26	20.51	29.19	13	4
Hong Kong	34	1082	30	31.82	36.07	15	2
Spain	33	154	13	4.67	11.85	6	5
South Korea	32	335	20	10.47	16.75	8	4
Germany	31	736	20	23.74	36.80	8	4
Taiwan	27	915	20	33.89	45.75	12	3
Russian Federation	24	233	17	9.71	13.71	5	4
Turkey	21	79	13	3.76	6.08	7	3
Malaysia	20	127	12	6.35	10.58	7	3
Saudi Arabia	20	52	11	2.60	4.73	4	4

Notes: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.

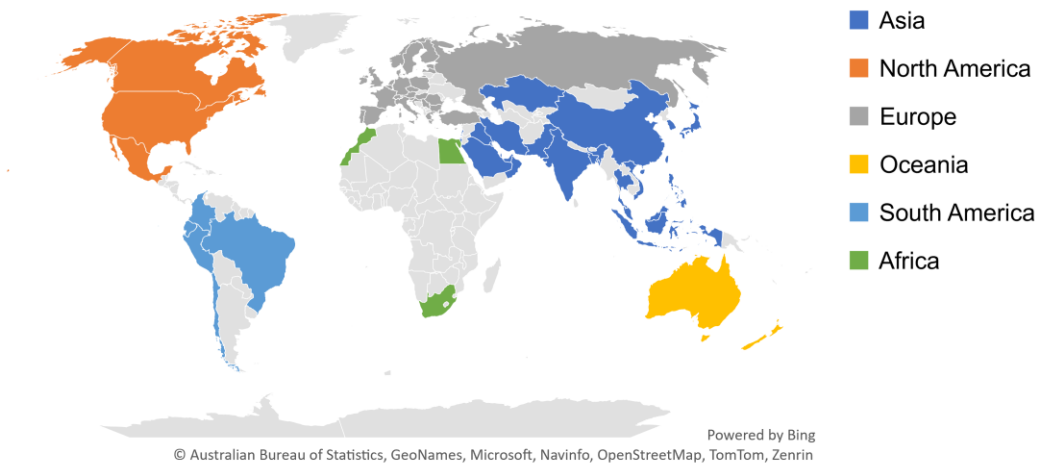

Figure 3: Worldwide scientific production indexed by Scopus on labour relations. https://iipmaps.com/

4.6. Publications by Source Titles

Based on the results presented in Table 10, journals emerge as a major channel for disseminating research within this field. The large number of publications indexed in the Journal of Physics: Conference Series underscores the level of discussion and exchange occurring through this venue.

Beyond journals, it is notable that various indexed book series and imprints from academic publishers also feature prominently among the sources. For instance, the high counts recorded for sources like Advances in Intelligent Systems and Computing and Lecture Notes in Computer Science point to the value researchers place on curated editorial book content for conveying new perspectives. Their inclusion reiterates the usefulness of multiple publication formats for facilitating scholarly conversations.

In addition, the data confirms the ongoing role of subject-specific conferences as platforms enabling active debate. This is evidenced by the significant volume of works channelled through outlets such as the ACM International Conference Proceeding Series. By convening specialists, conferences furnish opportunities to present works-in-progress, solicit peer feedback, and refine ideas - activities important for advancing familiarity with evolving topics.

Overall, the distribution indicates that journals, book series, and conferences collectively make up important venues anchoring discussion in this field. The presence of diverse source types underscores how their complementary attributes help address different researcher needs, from disseminating mature findings to informally exchanging early insights. Their collective support of intellectual dissemination further highlights the value of multifaceted pathways for knowledge diffusion within a research domain.

Table 10: Top 15 active source titles

Source Title	TP	NCA	NCP	TC	C/P	C/CP	h-index	g-index
Journal of Physics: Conference Series	29	46	21	73	2.52	3.48	6	6
ACM International Conference Proceeding Series	27	56	8	21	0.78	2.63	2	4
Sustainability (Switzerland)	24	94	13	245	10.21	18.85	8	15
Computers and Education: Artificial Intelligence	23	78	20	973	42.30	48.65	13	23
International Journal of Artificial Intelligence in Education	22	61	9	459	20.86	51.00	5	21

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Advances in Intelligent Systems and Computing	22	39	17	61	2.77	3.59	4	7
Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	21	63	12	34	1.62	2.83	4	4
Lecture Notes in Electrical Engineering	20	41	7	39	1.95	5.57	2	6
Wireless Communications and Mobile Computing	20	45	15	56	2.80	3.73	4	6
Communications in Computer and Information Science	17	45	11	41	2.41	3.73	3	5
Mobile Information Systems	16	30	8	20	1.25	2.50	2	4
Lecture Notes in Networks and Systems	14	52	7	14	1.00	2.00	2	3
Journal of Intelligent and Fuzzy Systems	14	26	14	123	8.79	8.79	8	10
Computational Intelligence and Neuroscience	13	24	8	15	1.15	1.88	2	3
Frontiers in Psychology	13	45	10	102	7.85	10.20	3	10

Notes: TP=total number of publications; TC=total citations; CiteScore = average citations received per document published in the source title; SJR = SCImago Journal Rank measures weighted citations received by the source title; SNIP = source normalised impact per paper measures actual citations received relative to citations expected for the source title's subject field.

4.7. Citation Metrics

The bibliometric indicators presented in Table 11 provide useful insights into the development and reach of this research field over time.

The h-index and g-index values of 47 and 78 respectively are remarkable given that this domain spans multiple disciplines involving artificial intelligence and education - disciplines that are still evolving. The high h-index suggests that a considerable number of publications in this collection have received above-average citations. Likewise, the high g-index points to the presence of many highly-cited papers. These scientometric indicators hence affirm the significant impact and prominence achieved within this niche area of study.

The total citations accumulated within the h-core publications of 6,742 underlines the considerable influence wielded by the most widely-cited works in the dataset. Moreover, the significant average number of citations, which stands at 198 showcases the growing importance of this field. It is evident that citations have consistently risen throughout the four decades examined in this study. This trend aligns with the rising focus on artificial intelligence applications in education in recent years.

Contextualized alongside other metrics such as the sizable number of contributing authors (3,459) and sizable citation sum within the 47-year citable window, these bibliographic data reinforce how this field has succeeded in bringing diverse stakeholders together around important discussions.

Overall, the quantitative evaluation offered in Table 11 validates the substantive body of high-impact work that has helped establish this multidisciplinary area as an important arena for innovation and scholarship at the intersection of technology and pedagogy.

Table 11: Citations metrics

Metrics	
Start Year	1976
End Year	2023
Total Publications	1192
Number of Contributing Authors	3459
Number of Cited Papers	727
Total Citations	9,307

Citation per Paper	7.79
Citation per Cited Paper	12.80
Citation per Author	2.69
Citation sum within h-Core	6,742
Citable Year	48
h-index	47
g-index	78
Publication Years	1976 - 2023
Citation Years	47
Citation per Year	198.02
Author per Paper	2.90
m-index	0.98

4.8. Highly Cited Documents

The data presented in Table 12 provides useful insights into the key influential contributions within this field. It is notable that comprehensive review articles and broad overview papers comprise the bulk of the most widely-cited works.

The study that topped the citations count, authored by Zawacki-Richter et al. in 2019, is a prime example of this trend. This extensive systematic review delved into exploring futuristic applications of artificial intelligence within educational contexts. Through synthesizing vast amounts of prior literature, it was able to paint a compelling big-picture vision of the transformational potentials as well as challenges involving AI integration into pedagogical practices. Not surprisingly, the depth and breadth of analysis captured by this great work has resonated strongly with other scholars, garnering almost 500 citations to date.

Several other works within the top 20 most-cited list also centered on insights gleaned from mapping the broad educational technology landscape and forecasting the impending shifts brought by intelligent systems. For instance, papers by Aoun (2017) and Timms (2016) respectively placed emphasis on discussing the paradigm changes as well as issues related to liberating AI's full capacities in dynamically optimized learning environments. Through refining lessons from diverse intersecting domains and crafting thought-provoking narratives, these far-reaching outlook articles have clearly struck a chord within the research community.

In conclusion, the highly cited works in this field are those that effectively synthesize existing knowledge and provide forward-looking perspectives. These studies, including comprehensive reviews and visionary articles, play a pivotal role in shaping the direction of research and strategic understanding in this rapidly evolving domain. They have gained widespread recognition because they shed light on major trends, opportunities, and debates, offering valuable insights to both scholars and practitioners. As we move forward, continued emphasis on such holistic and forward-thinking research is essential to further propel advancements in this nascent field of study.

Table 12: Top 20 highly cited articles

No.	Author(s)	Title	TC	C/Y

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1	Zawacki-Richter O.; Marín V.I.; Bond M.; Gouverneur F. (2019)	Systematic review of research on artificial intelligence applications in higher education – where are the educators?	499	99.80
2	Popenici S.A.D.; Kerr S. (2017)	Exploring the impact of artificial intelligence on teaching and learning in higher education	305	43.57
3	Chen L.; Chen P.; Lin Z. (2020)	Artificial Intelligence in Education: A Review	247	61.75
4	Roll I.; Wylie R. (2016)	Evolution and Revolution in Artificial Intelligence in Education	243	30.38
5	Aoun J.E. (2017)	Robot-proof: Higher education in the age of artificial intelligence	208	29.71
6	Hwang G.-J.; Xie H.; Wah B.W.; Gašević D. (2020)	Vision, challenges, roles and research issues of Artificial Intelligence in Education	196	49.00
7	Chen X.; Xie H.; Zou D.; Hwang G.-J. (2020)	Application and theory gaps during the rise of Artificial Intelligence in Education	184	46.00
8	Timms M.J. (2016)	Letting Artificial Intelligence in Education out of the Box: Educational Cobots and Smart Classrooms	168	21.00
9	Chassignol M.; Khoroshavin A.; Klimova A.; Bilyatdinova A. (2018)	Artificial Intelligence trends in education: A narrative overview	165	27.50
10	Paranjape K.; Schinkel M.; Panday R.N.; Car J.; Nanayakkara P. (2019)	Introducing artificial intelligence training in medical education	130	26.00
11	Wartman S.A.; Donald Combs C. (2018)	Medical education must move from the information age to the age of artificial intelligence	124	20.67
12	Hwang G.-J.; Chien S.-Y. (2022)	Definition, roles, and potential research issues of the metaverse in education: An artificial intelligence perspective	116	58.00
13	Gao P.; Li J.; Liu S. (2021)	An Introduction to Key Technology in Artificial Intelligence and big Data Driven e-Learning and e-Education	104	34.67
14	Chatterjee S.; Bhattacharjee K.K. (2020)	Adoption of artificial intelligence in higher education: a quantitative analysis using structural equation modelling	100	25.00
15	Bajaj R.; Sharma V. (2018)	Smart Education with artificial intelligence based determination of learning styles	100	16.67

4.9. Top Keywords

The keywords and their frequency of occurrence presented in Table 13 provide useful insights into the main topics investigated within the literature under review. As depicted graphically in Figures 4, terms such as "artificial intelligence", "education" and "teaching" emerge as the most prominent, speaking to the core focus on examining AI's growing role in reshaping pedagogical approaches.

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Their positioning at the centre of the keyword network map also highlights how discussions have prominently centered around AI's potential impact on instructional techniques and overall learning experiences. This is reflective of the field's aim to explore both the affordances and limitations involved as technological advances progressively integrate within the education system. In particular, keywords like "human", "students" and "learning systems" underscore efforts to understand AI's implications for learners as well as ensuring human support remains key in the teaching-learning process even as machines become increasingly involved.

The rise of certain keywords over the years depicted in Figure 3 provides further insight into evolving research narratives. For example, the emergence of terms like "education computing", "e-learning" and "educational technology" points to a growing interest in assessing AI's synergies with digital platforms and tools. This aligns with the theme of grappling with possibilities opened by digital disruption across pedagogy. Overall, the frequent emphasis on topics like "teaching", "education" and associated concepts brings to light how the literature has primarily focused on examining AI's place and impact within mainstream educational contexts from various perspectives. The keyword analysis therefore offers a helpful overview of key progress and preoccupations within this dynamically developing field of inquiry.

Table 13: Top author's keywords

Keyword	Total link strength	Occurrences
artificial intelligence	543	159
human	334	71
students	332	83
humans	287	59
teaching	231	46
education	150	29
engineering education	141	40
article	140	24
artificial intelligence technologies	135	37
education computing	129	30
medical education	129	31
e-learning	117	27
human experiment	105	15
learning	99	15
curricula	96	24
education, medical	90	20
learning systems	87	17
teachers'	85	17
colleges and universities	77	16
teaching methods	70	14
wireless networks	70	15
physical education	64	16
college students	55	14

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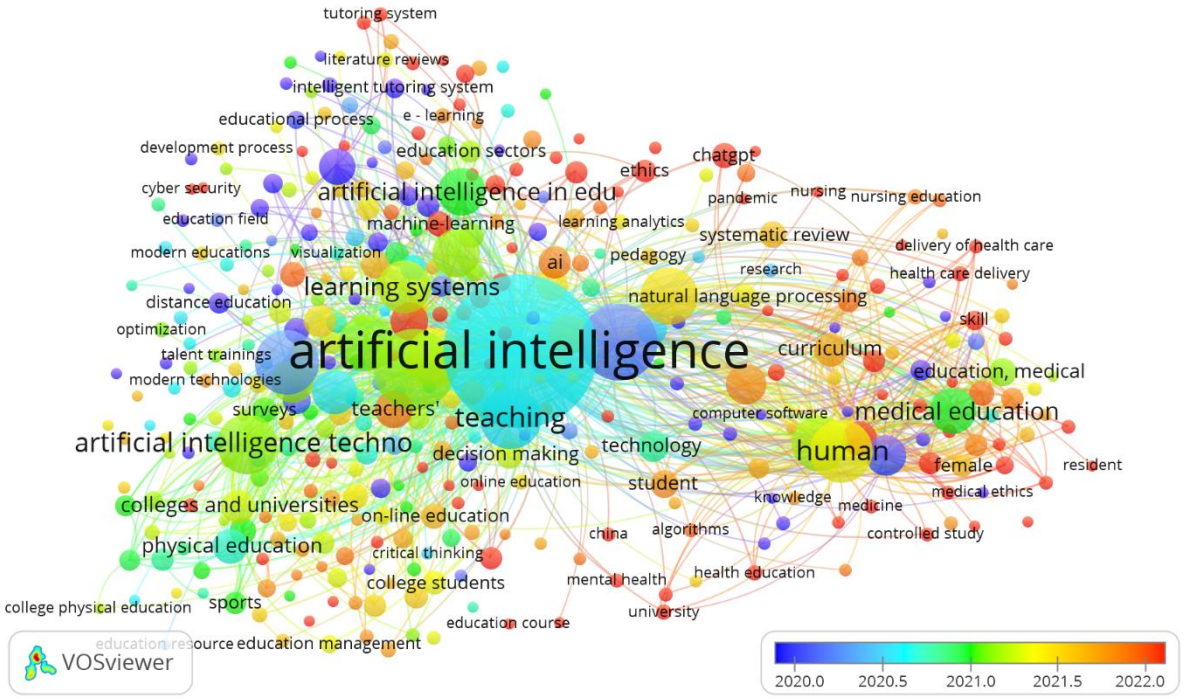

Figure 4: Overlay Visualization of keyword evolution

4.10. Co-authorship Analysis

The co-authorship analysis provides valuable insights into the collaborative relationships between researchers and institutions working in the field.

4.10.1. Co-authorship by author

Figure 5 examines the collaborative relationships between authors through co-authorship network analysis. The network visualization map of co-authorship by authors highlights several prominent clusters within the network. A closer examination of these clusters provides insights into collaborative relationships between researchers in this field.

One of the largest clusters is centred around Hwang Gwo-Jen and includes Chen Mei-Rong Alice and Chiu Min-Chi. With strong connections visualized between these three authors, it is clear they have a history of collaborative work together. Their co-authored papers likely focus on similar research topics or themes. A review of their publication histories may help elucidate the nature of their collaborations and the shared research focus bringing these scholars together repeatedly.

Another notable cluster includes Ogata Hiroaki, Yang Stephen J. H., and Baltes Jacky. While from different institutional affiliations, Collaborations spanning international borders suggest

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an ability to work together despite geographical separation and cultural differences

Figure 5:Network visualization map of the co-authorship by authors

4.10.2. Co-authorship by organisations

Figure 6. examines collaborative relationships between institutions through co-authorship network analysis at the organization level. The network map depicting co-authorship between organizational affiliations highlights several prominent clusters. The largest and most central cluster represents the Education University of Hong Kong, signifying its role as a major driver of collaborative research output in this field.

Also notable are the close collaborative ties between the University of Eastern Finland and University of Gothenburg visualized through their tightly linked positions. Researchers from these two northern European institutions appear to cooperate frequently on co-authored works. Similarly, the proximate positioning of Beijing Normal University and Ventry University reflects productive collaborative ties between scholars in these two Chinese institutions. Their co-publications point to synergistic partnerships leveraging complementary strengths.

Another significant collaboration network exists between Harvard University and Tsinghua University despite their more distal positions compared to other major affiliation clusters. These two elite global research universities maintain important cooperative relationships in the examined field, even if perhaps not as extensive as nearer groupings on the network map.

Several smaller collaborative clusters also appear, such as the collection of nodes representing Nordic and Australian universities proximal to the University of Gothenburg and University of Eastern Finland. These lesser groupings still contribute valuable knowledge through cooperative work of their constituent scholars.

In summary, the network visualization provides insights into the most central drivers of collaborative research as well as diverse partnership networks between institutions. Systematic analysis of these types of affiliation-based co-authorship maps can advance understanding of productive collaborative structures across diverse geographies and organizational cultures.

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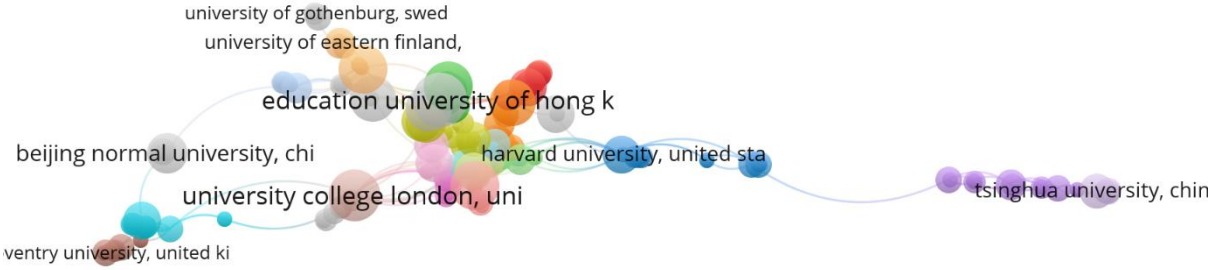

Figure 6: Network visualization map of the co-authorship by affiliation

4.10.3. Co-authorship by countries

Figure 7. examines collaborative relationships of co-authorship by countries. Examining the network map of international co-authorship patterns brings several prominent trends to light. Chiefly, the outsized circles representing China, United States, India, and United Kingdom showcase their dominant roles as centres driving global collaboration in the field.

The dense web of connections between these four nations signifies deep cooperative relationships underpinning widespread cross-border co-authored works. In particular, the strong China-United States linkage may reflect complementary advantages like large research communities combined with elite universities and private sector support from the United States helping to fuel productive Sino-American partnerships.

Meanwhile, cultural and linguistic affinities likely aid India's close co-authorship with both the United Kingdom and other former British colonies like Pakistan and Bangladesh as visualized on the map. Historical education system export and researcher mobility could also explain collaborative tendencies.

While other represented countries show more sparse connections, some secondary hubs emerge such as South Korea, Japan, and Australia in relation to China. Germany, France and Canada's positioning near the United Kingdom also implies meaningful if less prominent partnerships.

In summary the network map provides insights, into both global collaboration patterns and smaller specialized connections that could benefit from extra support. An interesting discovery is the growing collaborations between Latin America and other regions suggesting the potential to strengthen these relationships for a distribution of knowledge worldwide. In a context the international co authorship map acts as a tool for identifying areas where we should focus our efforts. Whether its building new connections or strengthening existing ones. All, with the aim of advancing global scientific endeavours.

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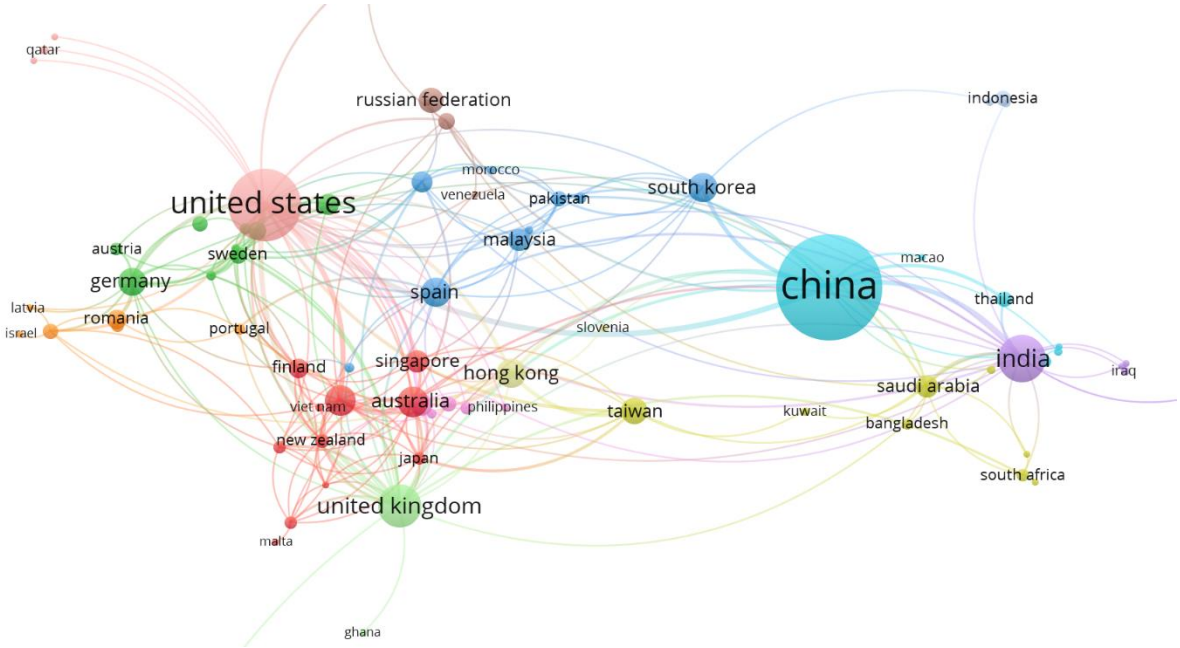

Figure 7: Network visualization map of the co-authorship by countries

4.11. Co-occurrence Analysis

4.11.1. Co-occurrence analysis of keywords

A network visualization map (see Figure 8) was generated to analyze the co-occurrence of keywords within the relevant literature. This provided insights into the predominant research topics and themes represented.

Artificial intelligence emerged as the most central keyword, co-occurring frequently with machine learning, deep learning, and related technological subfields. Most notable, however, was artificial intelligence's strong connections to education-focused keywords like learning, teaching, students, and curricula. This duality indicates the literature's core focus on examining AI both as an academic domain and emerging educational tool.

Machine learning, as a founding subdomain of AI, maintained close associations with computer-aided instruction, learning systems, and e-learning. These ties point to analyses of intelligent tutoring systems and technology-enhanced learning models. Related topics such as education computing and engineering education showcase AI's exploration across diverse learning contexts.

Notably, medical education also featured prominently, implying interests in AI for healthcare professional training. Its co-occurrence with educational rather than clinical keywords reinforces an emphasis on intelligent technologies within education specifically.

Overall, this keyword network mapping confirms the literature concentrated on intelligent education technologies, particularly AI and its potential to transform processes and environments. Topics spanned theoretical computer science to applied educational systems through a technical yet human-centred lens, illuminating avenues for future collaborative research at their interactive frontier.

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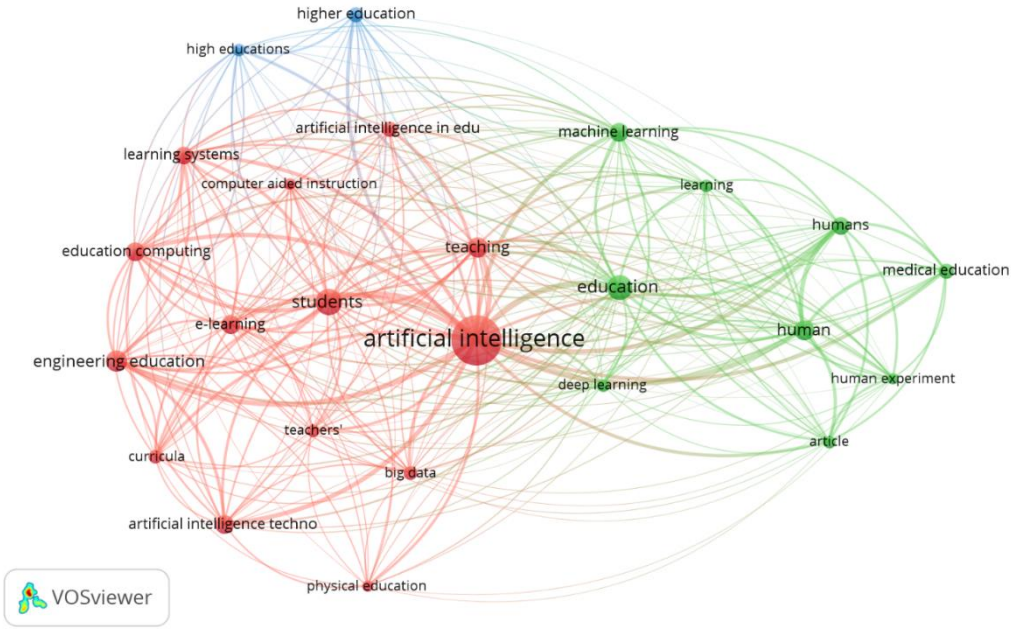

Figure 8: Top 25 keywords

5. DISCUSSION

Summary of Key Findings: The comprehensive bibliometric analysis conducted in this study has yielded strong findings regarding the evolving research landscape of AI applications in education over the past decade. Notably, there has been a significant exponential growth in publications since 2010, with the number of papers increasing from a few per year to over 1,000 in recent years. This indicates the clear establishment of AI in education as a mainstream and vibrant transdisciplinary field, attracting substantial scholarly attention globally.

In terms of individual contributors, certain authors such as Gwo-Jen Hwang from Taiwan and institutions like the Education University of Hong Kong have emerged as highly prolific, publishing numerous papers and establishing themselves as thought leaders in the field. At the national level, mainland China has demonstrated the highest overall publication volume, reflecting significant investment in AI research and development for education. However, when considering the citation impact using the adjusted average citation per paper metric, countries like the United States and Australia have produced work with above-average scholarly influence.

The analysis of publication sources has provided valuable insights into the different outlets through which knowledge in this field is disseminated. Journals such as Computers & Education and Thinking Skills and Creativity have contributed the highest volume of publications, alongside reputable book series and major conferences in related domains. Notably, papers that have received the most citations on average are reviews synthesizing existing literature and future-oriented works speculating on new directions. This highlights the scholarly value of consolidating past work and stimulating discussions around emerging trends.

The examination of conceptual structures through keyword co-occurrence networks has revealed the core topics under scholarly investigation. Dominant themes revolve around AI's potential to transform teaching methods, personalize learning experiences through adaptive technologies, and drive innovation in educational software, platforms, and intelligent tutoring systems. The analysis of author and institutional collaboration patterns, both at the global and regional levels, has shown cross-country connections as well as clustered national communities, indicating opportunities to strengthen international and inter-organizational ties.

Interpretation of Findings: These quantitative insights into publication trends, influential contributors, major topics, and collaborative structures provide a comprehensive understanding of the evolution and current state of AI in education as an emerging interdisciplinary domain. The significant increase in publications since 2010 indicates that AI has reached a tipping point of widespread

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recognition and integration into mainstream educational practice and discourse. This growth is driven by remarkable technological advancements that enable more sophisticated intelligent systems.
The concentration of research outputs in certain Asian countries, institutions, and authors reveals areas of focused funding and specialization that have propelled research volumes. However, the high citation rates for work from the United States and other countries emphasize the importance of a diverse, global scholarly community contributing work that resonates widely. These patterns highlight the presence of established leaders while also indicating opportunities to strengthen currently underrepresented areas.

Implications for Practice: The findings from this analysis have several implications for effective practice in the field of AI in education. Educators and educational policymakers should actively explore evidence-based AI applications highlighted in high-impact literature to modernize education, personalize instruction, and enhance learning outcomes. It is crucial, however, to maintain thoughtful human guidance to ensure that AI enhances rather than replaces the educational experience. This includes identifying and addressing algorithmic biases or unintended consequences.
Institutions worldwide can benefit from benchmarking against high-productivity groups to strengthen their internal research and development capacities, thereby accelerating innovation. Nurturing international partnerships can foster the mutual spread of expertise among communities, promoting collaboration and knowledge exchange.

Recommendations for Future Research: To further push boundaries and address gaps in knowledge, future research should focus on under-researched regions and delve deeper into specific topics. Qualitative and mixed-methods social science research is needed to examine the complex human and social impacts of AI.
Qualitative bibliometrics, such as expert interviews, could provide deeper insights into influential works. Continued monitoring and expansion of the methodology will contribute to a more comprehensive understanding of this rapidly evolving domain.

Limitations and Future Directions: It is important to acknowledge the limitations of this bibliometric mapping. The restriction of the dataset to Scopus and English sources may result in an incomplete view of the research landscape. Metrics such as citations are still evolving and may require further refinement. Widening the analytical lenses to include additional databases, languages, and non-textual sources like patents would complement this study.

6. CONCLUSION

In summary, this large-scale bibliometric analysis has provided a comprehensive and panoramic view of the current state and tracks of AI-driven education research over the past decade. The exponential growth in publications, the emergence of influential contributors, the identification of core topics, and the analysis of collaboration patterns all point to the establishment of educational AI as a vibrant and globally recognized field and demonstrates the increasing integration of AI in educational practices and research, emphasizing its transformative potential in teaching and learning methodologies. This also reveals significant interdisciplinary collaboration in AI and education research. A deeper discussion could examine how these collaborations influence the development of innovative educational technologies and methodologies, contributing to the evolution of the field.

While certain regions and institutions have shown concentrated research efforts, the high citation rates for work from diverse countries emphasize the importance of a global scholarly community. It shows a global interest in AI in education, with contributions from various countries and languages. Further

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future research could focus on the impact of this global collaboration on educational practices worldwide and how different regions are adapting AI technologies in education.

While the paper outlines the current state of AI in education, there is scope for further research to discuss future research directions, potential challenges, and ethical considerations in the broader implementation of AI in educational settings.

From a practical standpoint, educators and policymakers can leverage evidence-based AI applications to modernize teaching practices and enhance learning outcomes. However, the responsible integration of AI must be ensured, with careful consideration of ethical concerns and human guidance. However, the integration of AI in education raises questions about policy development and the adaptation of educational frameworks, which is a scope for future research.

While this bibliometric analysis has its limitations, such as dataset restrictions and evolving metrics, future research can expand on these findings by incorporating additional databases, languages, and non-textual sources. Qualitative bibliometrics can provide deeper insights, and ongoing monitoring and methodological improvements will contribute to a more comprehensive understanding of the rapidly evolving field of AI in education. In conclusion, with a commitment to open, evidence-based innovation and evaluation, AI has the potential to positively transform teaching and learning experiences, and further research can shed light on its promising future impacts.

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REFERENCES

Ahmi, A. (2023) biblioMagika, available from https://aidi-ahmi.com/index.php/bibliomagika

Crompton, H., & Burke, D. (2023). Artificial intelligence in higher education: the state of the field. International Journal of Educational Technology in Higher Education, 20, 22.

Lin, C.-C., Huang, A. Y. Q., & Lu, O. H. T. (2023). Artificial intelligence in intelligent tutoring systems toward sustainable education: a systematic review. Smart Learning Environments, 10, 41.

Lakshmi, A. J., Kumar, A., Kumar, M. S., Patel, S. I., Naik, S. K. L., & Ramesh, J. V. N. (2023). Artificial intelligence in steering the digital transformation of collaborative technical education. Journal of High Technology Management Research, 34, 100467.

Alhumaida, K., Al Naqbi, S., Elsori, D., & Al Mansoori, M. (2023). The adoption of artificial intelligence applications in education. International Journal of Data and Network Science, 7, 457-466.

Nagaraj, B. K., Kalaivani, A., Begum, R. S., Akila, S., Sachdev, H. K., & Kumar, N. S. (2023). The Emerging Role of Artificial Intelligence in STEM Higher Education: A Critical Review. International Research Journal of Multidisciplinary Technovation, 5(5), 1-19.

Shrivastava, R. (2023). Role of artificial intelligence in future of education. International Journal of Professional Business Review, 8(1), 1-15. https://doi.org/10.26668/businessreview/2023.v8i1.840

García-Montalvo, I. A. (2023). Artificial intelligence as a didactic resource in medical education. Educación Médica, 24, 100849. DOI: 10.1016/j.edumed.2023.100849
Ruiz-Rojas, L. I., Acosta-Vargas, P., De-Moreta-Llovet, J., & Gonzalez-Rodriguez, M. (2023). Empowering Education with Generative Artificial Intelligence Tools: Approach with an Instructional Design Matrix. Sustainability, 15, 11524

Bearman, M., Ryan, J., & Ajjawi, R. (2023). Discourses of artificial intelligence in higher education: A critical literature review. Higher Education, 86(2), 369-385. https://doi.org/10.1007/s10734-022-00937-2

Alqahtani, T., Badreldin, H. A., Alrashed, M., et al. (2023). The Emergent Role of Artificial Intelligence, Natural Language Processing, and Large Language Models in Higher Education and Research. Research in Social and Administrative Pharmacy, 19, 1236–1242.

N. J. van Eck and L. Waltman, ―VOSviewer manual‖, Leiden: Univeristeit Leiden, (2017).