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

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Abstract: This research aims to evaluate the existing body of literature on the application of artificial intelligence (AI) in the field of education. Using a bibliometric analysis of 1,192 scholarly articles indexed in the Scopus database, the study maps the scholarly network in this field, identifies publication trends, influential contributors, core research themes, and areas that require further investigation. The findings reveal a significant exponential growth in publications since 2010, establishing AI in education as a vibrant field. Prolific contributors include individual authors, institutions like the Education University of Hong Kong, and countries such as China and the US. Network analyses highlight extensive collaborations through co-authorship within and between regions, while core themes focus on AI's transformative role in pedagogy and learning experiences. Although the study is limited to Scopus-indexed publications, the insights from the bibliometric maps provide valuable implications for strengthening collaborative ties and addressing under-represented areas. This in-depth and systematic analysis offers a unique contribution to the field, informing future research directions in AI-enhanced education.

Keywords: Artificial Intelligence, education, Bibliometrics, VOSviewer, Biblioshiny.

1. Introduction

Artificial Intelligence (AI) has emerged as a transformative technology with the potential to revolutionize various sectors, including higher education [1]. This technological evolution involves the development and implementation of computer systems capable of performing human-like intelligence tasks, such as learning, reasoning, problem-solving, and decision-making [2]. In education, AI technologies such as machine learning, natural language processing, and intelligent tutoring systems offer promising avenues for improving teaching, learning outcomes, and educational experiences [3]. Researchers have been exploring various applications of AI in education, including personalized learning, adaptive assessments, intelligent teaching assistants, and automated essay scoring [2]. Moreover, in the field of education AI has sparked attention for its ability to enhance academic advising procedures and enhance student performance, by offering guidance on course choices career directions and academic accomplishments in general [4],[5]. There has been a rapid increase in publications focused on applying AI in higher education between 2016 and 2022. Systematic reviews have highlighted the emergence of new trends in geographical distribution, researcher affiliations, and subjects covered [2]. Similarly, AI's role in K-12 education and STEM fields is expanding, with benefits including personalized and adaptive learning through intelligent tutoring systems, collaborative learning environments, and enhanced assessment methods [6]. AI is increasingly seen as a mean to enhance student engagement and optimize learning outcomes in STEM disciplines. Furthermore, AI holds potential to transform other aspects of education. [7] evidenced 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 [7]. 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 analysed 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, the aim of this research is to perform an evaluation of the current body of literature regarding the application of artificial intelligence (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.

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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 area of utilizing AI in education evolved over time?
2) Which authors are the most productive in this area, and what are their key research subject areas?
3) Which institutions contributed the most, and how have they influenced to the development of the field?
4) Which countries contributed most, and how does this differ between different regions and time frames?
5) Which documents are the most highly cited, and what are the key subject areas in their researches?
6) What are the most common keywords in the literature, and how have their usage pattern changed over time?
7) What are the patterns of co-authorship, and how different are they across different regions, institutions, and research topics?

2. Literature Review

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 [2], laying the groundwork for subsequent developments. Recent research has expanded on these foundations by integrating theoretical frameworks like constructivism and connectivism to enhance learning through personalized, adaptive, and collaborative features enabled by AI [8]. For example, AI has allowed the development of interactive learning environments that adapt based on individual student needs and provide customized scaffolding [6]. 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 [9]. 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 [10]. Recent developments in AI applications in education reveal emerging trends and challenges. New technologies like natural language processing and automated essay scoring are being applied to support personalized feedback and assessment [3]. However, concerns regarding data privacy, algorithmic bias, and the need for human oversight continue to be addressed [6]. Theories are being expanded to examine AI adoption from an organizational perspective using frameworks such as the technology-organization-environment model [10]. Models are also being developed to understand challenges like the "black-box" nature of AI and its impact on authority structures in pedagogy [11]. This study builds upon the existing literature by conducting a comprehensive bibliometric analysis, which systematically maps and analyses the scholarly network of AI in education. Unlike previous studies that often focus on specific applications or case studies, this approach provides a panoramic view of the field, identifying publication trends, influential contributors, productive institutions, and collaboration patterns. By utilizing tools like Bibliomagika and VOSviewer, this research goes beyond traditional bibliometric methods, integrating machine learning techniques to uncover hidden patterns and relationships within publications [12], [13]. This approach addresses the limitations of prior work by incorporating a broader dataset from the Scopus database, including publications in multiple languages and various types of documents. Furthermore, this study harmonizes author names, affiliations, and country names to ensure data consistency and accuracy, something that has often been overlooked in previous research. The manual verification and addition of missing author, affiliation, and country details enhance the reliability of the dataset, providing a more comprehensive understanding of the collaborative networks and research contributions. Moreover, VOSviewer, which is a visualization tool, was used to facilitate the exploration and interpretation of bibliometric data, using tables and graphs to present the collaborative networks and thematic clusters within the field of AI in education [13].

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. Focusing on article titles was crucial as they reflect important topics related to our research area and objectives. We obtained a total of 1234 documents for bibliometric analysis. However, we excluded 42 documents due to missing author names and IDs. To effectively analyse the data, we employed a range of tools and techniques. Firstly, we utilized Bibliomagika [14], a tool designed for comprehensive bibliometric analysis. It analyses bibliometric data and transforms them into meaningful metrics such as citation counts, h-index, g-index, and more. Bibliomagika also simplifies the process of cleaning and harmonizing author, affiliation, and country data, ensuring accuracy and reliability. We manually harmonized affiliations to remove duplicates and standardize their names, ensuring consistency across the dataset. Similarly, country names were harmonized to unify abbreviations and full names where discrepancies existed. For papers missing country names, we added them during the harmonization process. Furthermore, keywords were standardized to ensure accurate and consistent analysis. Moreover, author names were harmonized to ensure consistent usage even if their affiliations differed across studies. We manually checked and added last names for authors initially identified without them. This meticulous process ensured accurate and

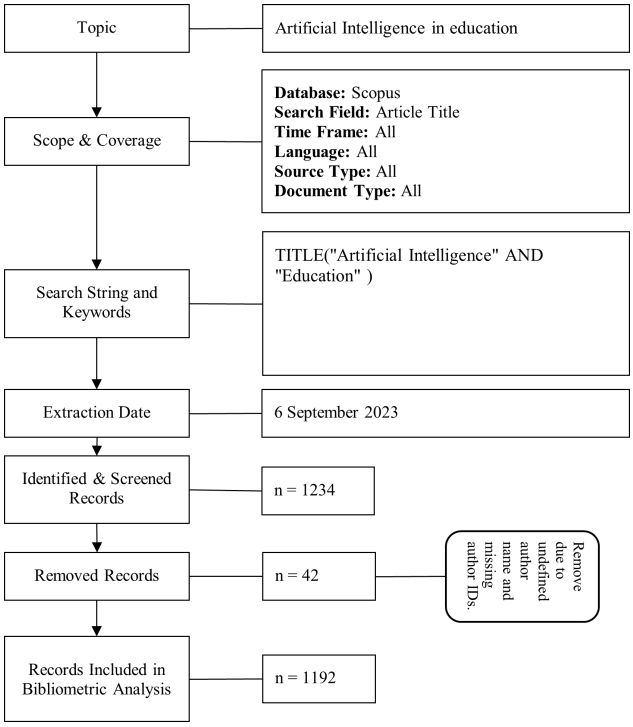

Figure 1. Search Strategy Flow diagram, Source: [15].

reliable analysis of authorship patterns. Additionally, we leveraged VOSviewer [3], a free software tool available at www.vosviewer.com, to construct bibliometric networks and create visually engaging graphs and visualizations. Using 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. Finally, for efficient reference management, we utilized EndNote, a widely recognized software tool that facilitated the organization and citation of relevant literature. Figure 1 serves as a visual representation of our search strategy, adapted from [15]. The flow diagram illustrates the various stages involved in the search process.

4. Results

A. 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 I, journal articles formed the major mass of the publications constituting 43.88% of the total quantity with 523 documents. This highlights the mature 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. Review papers

TABLE I. Document's Type

Document's Type	TP [a]	%
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%

[a]TP = total number of publications.

made up 6.29%, with 75 publications, reflecting efforts to consolidate knowledge through literature surveys. Editorials and letter articles formed a minor portion, with 43 documents (3.61%) and 15 documents (1.26%), respectively. When examining by source types in Table II, 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 the language of publication presented in Table III, 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 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 IV, 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.

B. Publication Trends

TableV and Figure 2 present 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 been observed 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 number of citations per publication and the

TABLE II. Source Type

Source Type	TP [a]	%
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%

[a]TP = total number of publications.

TABLE III. Languages

Source Type	TP [a]	%
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[b]	100%

[a]TP = total number of publications.
[b]7 research studies were done in dual languages.

number of 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 signifying the impact 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.

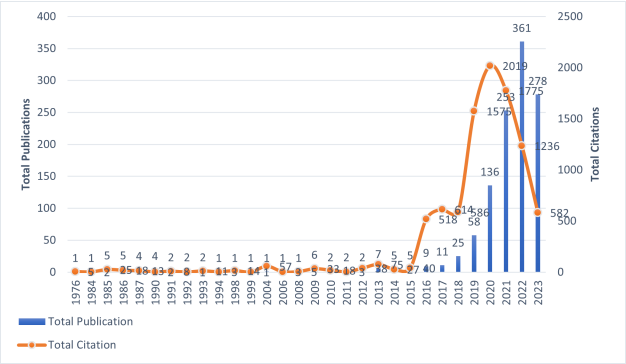

Figure 2. Total Publications and Citations by Year

TABLE IV. Subject Area

Subject Area	TP [a]	%
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	1	0.25%
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%

[a]TP = total number of publications.

C. Publications by Authors

Table VI 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 are received on average, highlighting the sustained relevance of Hwang's contri-butions. Other esteemed authors like Kose, Utku, and Jiao, Pengcheng have also significantly ad-vanced the field through their substantial scholarly contributions reflected in Table VI.

TABLE V. Publication Year

Year	TP[a]	NCP[b]	TC[c]	C/P[d]	C/CP[e]	h-index	g-index	m-index
1976	1	1	5	5.00	5.00	1	1	0.02
1984	1	1	2	2.00	2.00	1	1	0.03
1985	5	2	25	5.00	12.50	2	5	0.05
1986	5	3	18	3.60	6.00	3	4	0.08
1987	4	3	13	3.25	4.33	2	3	0.05
1990	4	2	2	0.50	1.00	1	1	0.03
1991	2	1	8	4.00	8.00	1	2	0.03
1992	2	1	1	0.50	1.00	1	1	0.03
1993	2	2	11	5.50	5.50	1	2	0.03
1994	1	1	3	3.00	3.00	1	1	0.03
1998	1	1	14	14.00	14.00	1	1	0.04
1999	1	1	1	1.00	1.00	1	1	0.04
2004	1	1	57	57.00	57.00	1	1	0.05
2006	1	1	3	3.00	3.00	1	1	0.06
2008	1	1	5	5.00	5.00	1	1	0.06
2009	6	4	33	5.50	8.25	2	5	0.13
2010	2	1	18	9.00	18.00	1	2	0.07
2011	2	2	3	1.50	1.50	1	1	0.08
2012	2	2	38	19.00	19.00	2	2	0.17
2013	7	7	75	10.71	10.71	4	7	0.36
2014	5	5	27	5.40	5.40	3	5	0.30
2015	5	3	40	8.00	13.33	2	5	0.22
2016	9	9	518	57.56	57.56	6	9	0.75
2017	11	11	614	55.82	55.82	5	11	0.71
2018	25	21	586	23.44	27.90	9	24	1.50
2019	58	49	1575	27.16	32.14	15	39	3.00
2020	136	113	2019	14.85	17.87	19	42	4.75
2021	253	167	1775	7.02	10.63	20	34	6.67
2022	361	226	1236	3.42	5.47	15	25	7.50
2023	278	85	582	2.09	6.85	11	21	11.00
Grand Total	1192	727	9307	7.81	12.80	134	258	

[a]TP = total number of publications.
[b]NCP= no. of cited publications
[c]TC=total no of citations
[d]C/P=average no. of citations per publication
[e]C/CP=average no. of citations per cited publication.

While Kose accounts for 23 publications with an h-index of 2, Jiao has a comparable h-index of 4 based on 109 publications. Their consistent research focusing on pertinent issues has enriched both theory and practice. In Table VII, 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 are 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.

D. Publications by Institutions

Table VIII 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 the 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 uni-

TABLE VI. Top 15 Productive Authors

Name of Author	TP[a]	NCP[b]	TC[c]	C/P[d]	C/CP[e]	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

[a]TP = total number of publications.
[b]NCP= no. of cited publications
[c]TC=total no of citations
[d]C/P=average no. of citations per publication
[e]C/CP=average no. of citations per cited publication.

TABLE VII. Number of Author(s) per document

Author Count	Frequency
1	325
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

versities 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.

E. Publications by Countries

The analysis of contributions by country presented in Table IX 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 considering impact, other countries begin to stand out. While China's output is significant in quantity, the United States demonstrates a 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 such as China, Taiwan, South Korea and Japan exhibit strong collaborative networks. European countries also collaborate closely. Simultaneously, collaborative links bridge these communities internationally. Countries from every region are interconnected, showing that global scholarly exchange is helping drive progress. This is essential in a rapidly evolving field like artificial intelligence, where boundaries are continually pushed through sharing of multinational knowledge and resources. Furthermore, Figure 3 depicts the contributions

TABLE VIII. Top 15 productive institutions with minimum of six publications

Institution	TP[a]	TC[b]	NCP[c]	C/P[d]	C/CP[e]	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	2	4	3.50	7.00	2	2
Stanford University	6	22	5	3.67	4.40	3	1
Usak University	6	21	3	3.50	7.00	2	2

[a]TP = total number of publications.
[b]TC=total no of citations
[c]NCP= no. of cited publications
[d]C/P=average no. of citations per publication
[e]C/CP=average no. of citations per cited publication.

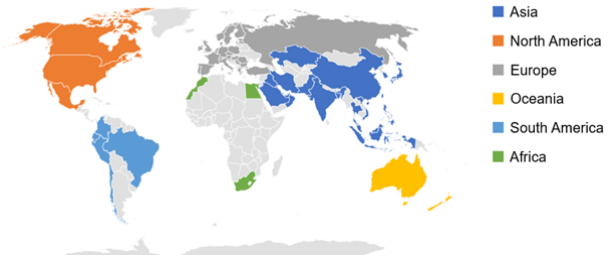

Figure 3. Worldwide scientific production indexed by Scopus on AI contribution in Education.

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.

F. Publications by Source Titles

Based on the results presented in Table X, 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. In addition to 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 such as 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. Additionally, 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 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 researchers' 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.

G. Citation Metrics

The bibliometric indicators presented in Table XI 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, considering 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 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

TABLE IX. Top 15 Countries contributed to the publications.

Country	TP[a]	TC[b]	NCP[c]	C/P[d]	C/CP[e]	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

[a]TP = total number of publications.
[b]TC=total no of citations
[c]NCP= no. of cited publications
[d]C/P=average no. of citations per publication
[e]C/CP=average no. of citations per cited publication.

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 substantial 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 XI 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.

H. Highly Cited Documents

The data presented in Table XII provides useful insights into the key influential contributions within this field. Notably, comprehensive review articles and broad overview papers comprise the bulk of the most widely cited works. The study that topped the citation count, authored by Zawacki-Richter [16], 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 15 most-cited list also focused on insights gleaned from mapping the broad educational technology landscape and forecasting the impending shifts brought by intelligent systems. For instance, [17] and [18] respectively placed emphasis on discussing the paradigm changes as well as issues related to liberating AI's full capacities in dynamically optimized learning environments. 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.

I. Top Keywords

The keywords and their frequency of occurrence presented in Table XIII provide useful insights into the main topics investigated within the literature under review. As illustrated graphically in Figure 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 educational approaches. Their positioning at the centre of the keyword network map also highlights how discussions have prominently cantered around AI's potential impact on instructional techniques and overall learning experiences. Furthermore, keywords like 'human', 'students', and 'learning systems' underscore efforts to understand AI's implications for learners. This ensures human support remains key in the teaching-learning process, even as machines become increasingly involved. The rise of certain keywords over the years shown in Figure 4 provides further insight into evolving research narratives. For example, the emergence of terms like "education com-

TABLE X. Top 15 active source titles

Source's Title	TP[a]	TC[b]	NCP[c]	C/P[d]	C/CP[e]	h-index	g-index
Journal of Physics: Conference Series	29	21	73	2.52	3.48	6	6
ACM International Conference Proceeding Series	27	8	21	0.78	2.63	2	4
Sustainability (Switzerland)	24	13	245	10.21	18.85	8	15
Computers and Education: Artificial Intelligence	23	20	973	42.30	48.65	13	23
International Journal of Artificial Intelligence in Education	22	9	459	20.86	51.00	5	21
Advances in Intelligent Systems and Computing	22	17	61	2.77	3.59	4	7
Lecture Notes in Computer Science	21	12	34	1.62	2.83	4	4
Lecture Notes in Electrical Engineering	20	7	39	1.95	5.57	2	6
Wireless Communications and Mobile Computing	20	15	56	2.80	3.73	4	6
Communications in Computer and Information Science	17	11	41	2.41	3.73	3	5
Mobile Information Systems	16	8	20	1.25	2.50	2	4
Lecture Notes in Networks and Systems	14	7	14	1.00	2.00	2	3
Journal of Intelligent and Fuzzy Systems	14	14	123	8.79	8.79	8	10
Computational Intelligence and Neuroscience	13	8	15	1.15	1.88	2	3
Frontiers in Psychology	13	10	102	7.85	10.20	3	10

[a]TP = total number of publications.
[b]TC=total no of citations
[c]NCP= no. of cited publications
[d]C/P=average no. of citations per publication
[e]C/CP=average no. of citations per cited publication.

TABLE XI. Citations metrics

Metrics	
Start Year	1976
End Year	2023
Total Publications	1192
Number of Contributing Au-thors	3459
Number of Cited Papers	727
Total Citations	9307
Citation per Paper	7.79
Citation per Cited Paper	12.80
Citation per Author	2.69
Citation sum within h-Core	6742
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

puting", "e-learning" and "educational technology" points to a growing interest in assessing AI's collaborations with digital platforms and tools. 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.

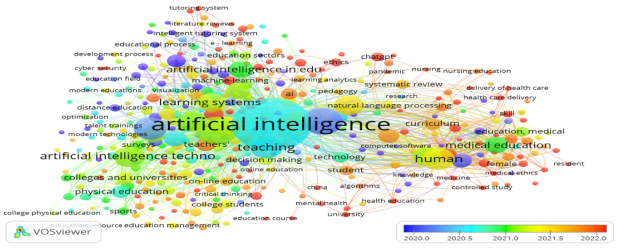

Figure 4. Overlay Visualization of Author's keywords.

J. Co-authorship Analysis

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

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 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,

TABLE XII. Top 15 highly cited articles

No.	Author(s)	Title	TC[a]	C/Y[b]
1	Zawacki-Richter O.; Marín V.I.; Bond M.; Gouverneur F. (2019) [16]	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) [19]	Exploring the impact of artificial intelligence on teaching and learning in higher education	305	43.57
3	Chen L.; Chen P.; Lin Z. (2020) [20]	Artificial Intelligence in Education: A Review	247	61.75
4	Roll I.; Wylie R. (2016) [21]	Evolution and Revolution in Artificial Intelligence in Education	243	30.38
5	Aoun J.E. (2017) [17]	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) [22]	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) [23]	Application and theory gaps during the rise of Artificial Intelligence in Education	184	46.00
8	Timms M.J. (2016) [18]	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) [24]	Artificial Intelligence trends in education: A narrative overview	165	27.50
10	Paranjape K.; Schinkel M.; Panday R.N.; Car J.; Nanayakkara P. (2019) [25]	Introducing artificial intelligence training in medical education	130	26.00
11	Wartman S.A.; Donald Combs C. (2018) [26]	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) [27]	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) [28]	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) [29]	Adoption of artificial intelligence in higher education: a quantitative analysis using structural equation modelling	100	25.00
15	0000000000 R.; Sharma V. (2018) [30]	Smart Education with artificial intelligence based determination of learning styles	100	16.67

[a]TC=total no of citations
[b]C/Y=Citations per year

TABLE XIII. Top author's keywords

Keyword	Occurrences
artificial intelligence	159
human	71
students	83
humans	59
teaching	46
education	29
engineering education	40
article	24
artificial intelligence technologies	37
education computing	30
medical education	31
e-learning	27
human experiment	15
learning	15
curricula	24
education, medical	20
learning systems	17
teachers'	17
colleges and universities	16
teaching methods	14
wireless networks	15
physical education	16
college students	14

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

Yang Stephen J. H., and Baltes Jacky. While from different institutional affiliations, Collaborations spanning international borders suggest an ability to work together despite geographical separation and cultural differences.

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 be-tween 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

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

productive collaborative ties between scholars in these two Chinese institutions. Their co-publications point to cooperative 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. These lesser groupings still contribute valuable knowledge through the cooperative work of their constituent scholars.

3) Co-authorship by Countries

Figure 7 examines the 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, the 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. 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. An interesting discovery is the sparse collaboration between Arabic countries in the gulf region such as Iraq, Qatar and Kuwait although sharing the same language and common culture, which suggest the need to build future collaboration and share knowledge in the field of study.

K. Co-occurrence Analysis

1) Co-occurrence analysis of keywords

In Figure 8, a network visualization map was generated to analyse the co-occurrence of key-words 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

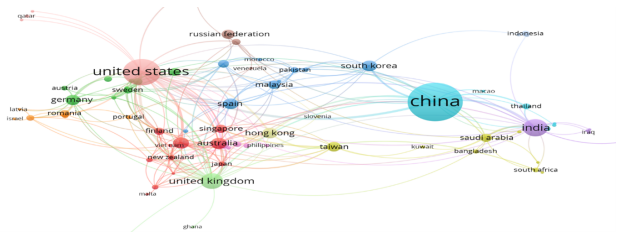

Figure 7. Network visualization map of the co-authorship by countries.

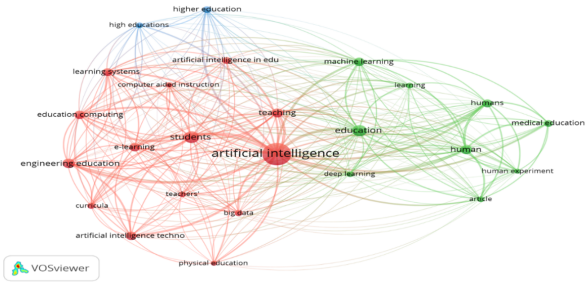

Figure 8. Network visualization map of Top 25 Authors' keywords.

frequently with machine learning, deep learning, and related technological subfields. Most notable 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 reinforce an emphasis on intelligent technologies within education specifically. Overall, this keyword network mapping confirms the spanning of topics collaborated with AI from theoretical computer science to applied educational systems through a technical yet human-centred.

5. Discussion

A. 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. Education University of Hong Kong has emerged as a central hub in the global research network. This institution's high citation impact underscores its influence and the quality of its research output. The collaborative ties between universities in different regions, such as the University of Eastern Finland and the University of Gothenburg, reflect a trend towards cross-border academic partnerships that enrich the research landscape. 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 co-authorship analysis revealed significant clusters of collaboration, notably cantered around prominent authors such as Gwo-Jen Hwang. These collaborations indicate a robust network of scholars working together to advance the field of AI in education. The strong connections among researchers from different institutions and countries suggest that the field is benefiting from diverse perspectives and expertise. This international and interdisciplinary collaboration is crucial for addressing the complex challenges and opportunities presented by AI in education. 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 keyword co-occurrence analysis provided insights into the thematic evolution of AI in education research. Central keywords such as "artificial intelligence," "education," and "teaching" emphasize the dual focus on technological advancements and their application in educational settings. The prominence of terms like "machine learning," "deep learning," and "intelligent tutoring systems" indicates that researchers are exploring advanced AI technologies to enhance educational outcomes. Interestingly, the emergence of keywords related to "medical education" suggests a growing interest in applying AI to train healthcare professionals. This trend highlights the interdisciplinary nature of AI research and the importance of intelligent technologies in various educational domains.

B. Interpretation of Findings

These quantitative insights into publication trends, influential contributors, major topics, and collaborative structures provide an in-depth 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 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.

C. 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.

D. Recommendations for Future Research

To further push boundaries and address gaps in knowledge, future research should explore the long-term impacts of AI on educational practices and student outcomes. Longitudinal studies can provide valuable insights into how AI technologies evolve and their sustained effects on learning and teaching. Researchers should also investigate the scalability and transferability of AI applications across different educational contexts and cultures. 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. Future research could also explore the ethical implications of AI in education, including issues of data privacy, algorithmic bias, and the need for human oversight. These areas are critical for ensuring that AI technologies are implemented responsibly and equitably.

E. 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. These findings demonstrate the increasing integration of AI in educational practices and research, emphasizing its transformative potential in teaching and learning methodologies. The analysis also reveals significant interdisciplinary collaboration in AI and education research, as demonstrated by the diversity of subject areas and keywords analysed. Through the examination of subject areas and keywords across publications, it becomes evident that AI in education spans a wide range of disciplines, including computer science, psychology, engineering, and social sciences. This interdisciplinary nature enriches the theoretical frameworks and fosters innovative approaches in educational technology. 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. This shows a global interest in AI in education, with contributions from various countries and languages. 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. Moreover, while this paper outlines the current state of AI in education, further research should explore future 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. The integration of AI in education also raises questions about policy development and adaptation of educational frameworks, which should be a scope for future research. Despite its contributions, this bibliometric analysis has 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. Further research can shed light on its promising

future impacts.

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