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Research trajectories and collaborative networks of generative artificial intelligence in education: a bibliometric analysis based on ChatGPT (2023–2025)

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ABSTRACT

While ChatGPT and other generative artificial intelligence (AI) technologies are significantly influencing education, a systematic quantitative analysis remains lacking. Following preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines, this paper screens 626 Web of Science (WoS) core collection articles and employs CiteSpace and Bibliometrix for visualization. The findings reveal publications rose from 78 in 2023 to 299 in 2025, with the US contributing 187 papers and China 161, while international co-authorship reached 28.43%; thematic shifts from technological ethics to interdisciplinary integration and critical thinking are observed. This study offers the first systematic quantification of the global landscape and thematic evolution, though limited to the WoS core collection over a relatively short period.

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1. INTRODUCTION

Although hundreds of studies have examined ChatGPT in education, existing reviews are primarily narrative or systematic. Few studies quantitatively reveal the global intellectual structure, collaboration networks, and thematic evolution of this rapidly expanding field. Therefore, this study employs bibliometric analysis to map research trajectories between 2023 and 2025. Generative artificial intelligence (AI) tools like ChatGPT have reshaped conventional educational practices [1]. Since its publication at the end of 2022, this technology has moved quickly from early-stage theoretical debates [2] and questions about academic honesty [3] toward a widening array of educational uses. These now span higher education [4], science, technology, engineering, and mathematics (STEM) disciplines [5], medical training [6], and teacher professional development [7]. Most current reviews, however, as noted earlier, are still qualitative [8]–[10] and lack a systematic quantitative depiction of the evolution of the field, its core knowledge, international collaboration networks, and dynamic thematic changes.

Earlier bibliometric work has made useful contributions, but it also comes with notable limitations. The majority have looked at just 2023, the first one after ChatGPT was introduced, and have not included the later stages of consolidation and diversification of research. Very few have tried to combine CiteSpace, Bibliometrix, and VOSviewer to do methodological triangulation. Rarely have international collaboration networks been studied, paying more attention to the number of publications. Thematic evolution has not been studied on the evolution of the initial hype phase and how it moves towards subject-specific pedagogy. These limitations make it difficult to see the entire path of development of this field and the diversification of the field itself.

This study has used the Web of Science (WoS) core collection (2023–2025), and a bibliometric analysis of peer-reviewed journal articles was performed using the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines and CiteSpace, Bibliometrix, and VOSviewer for visualization. In particular, publication trends, most prominent authors, institutions, and countries, high-impact publications, and co-occurrence of keywords are investigated. In three respects, this study has a contribution to make to the literature. First, it reveals the global distribution of research power and international collaboration networks. Second, it illustrates the thematic development from technology ethics in general to subject-specific pedagogies and fostering higher-order thinking. Third, it provides empirical insights that can be used to guide educational policy, curriculum design, and teacher preparation. To systematically map the field, we focused on four research questions:

- How has the knowledge structure of ChatGPT education research evolved over time? (RQ1)
- Which countries and institutions dominate knowledge production in this field? (RQ2)
- What collaborative patterns characterize global research networks? (RQ3)
- What emerging research themes can guide future educational research and practice? (RQ4)

2. METHOD

2.1. Research design

This study makes use of bibliometric analysis to investigate the distribution patterns and emerging trends of ChatGPT applications in the educational area. The process was completed by retrieving and analyzing the relevant English-language literature indexed in the core databases of WoS. As a well-established quantitative research approach, bibliometric analysis is an efficient tool for uncovering the trends of disciplinary formation, knowledge structures, and collaboration patterns by means of statistical analysis and graphical presentation of a considerable amount of academic literature [11]. Within the past few years, this approach has become popular and is being used by researchers around the globe to evaluate academic research and track research trends.

2.2. Data collection

2.2.1. Scope, objectives, and methods

This research uses bibliometric analysis with data from the WoS database, which was chosen for its quality publications, interdisciplinary coverage, and powerful analytical tools [12]. Retrieving the data is accomplished through the WoS advanced search engine, which is also recognized as an official platform for academic resources [13]. To ensure the rigor of the research methodology and the quality of the literature sources, this study strictly adhered to the PRISMA statement, conducting systematic retrieval, screening, eligibility assessment, and inclusion of relevant literature [14]. The source of data in the research is the WoS database. Figure 1 shows that, through synthesizing multi-dimensional analytic method approaches, the current study offers a methodological review of the academic literature in the ChatGPT project space and an in-depth examination of the research. This has helped to understand the direction the research has taken in this field and provided major factors for where it could develop in the future.

2.2.2. Retrieval strategy

We searched the WoS core collection (SCIE, SSCI, A&HCI, and ESCI) on January 7, 2026, using the core term “ChatGPT” along with keywords covering major educational concepts (educat, teach, learn, pedagog, higher education, and educational technology). The Boolean search string was: (TS=“ChatGPT” AND TS=(education* OR teach* OR learn* OR pedagog* OR curriculum OR “educational technology” OR “instructional design” OR “online learning” OR “distance education” OR “blended learning” OR “flipped classroom” OR “classroom” OR “higher education” OR “K-12” OR “e-learning” OR “digital learning” OR “learning environment” OR “student” OR “teacher” OR “learner” OR “instructor”)). To refine the focus, we limited the results to the following WoS categories: “Education & Educational Research”, “Education Scientific Disciplines”, and “Computer Science Artificial Intelligence”. The time span was initially set to the last five years and was further narrowed during screening. This process yielded 3,412 records.

2.2.3. Exclusion and inclusion criteria

The screening phase then commenced, during which the literature was refined according to specific criteria. The number of records excluded at each stage of the screening process, in accordance with the PRISMA framework, is shown in Figure 1.

- Step 1: narrowing down the time frame

No literature was published before 2023, and the publication period was limited to 2023-2025. This was mainly due to the development path of ChatGPT itself and the evolution trend of research. ChatGPT is

a natural language processing (NLP) model created by OpenAI. After this initial screening 3,387 articles were retained.

– Step 2: document types definition

This study was limited to the types of documents: research article and review, and excluded non-research document types: conference abstract, editorial, letter, and brief. These research articles and reviews help us to determine the cutting-edge directions and hot topics of this field. After this second screening, 2,990 documents were left.

– Step 3: fine-tuning article types

In order to narrow the scope of the research topic, this study only included literature that was classified in the following four WoS subject categories: 'education and educational research', 'educational sciences', 'computer science and AI', and 'computer science and interdisciplinary applications'. After this process, 626 articles were finally selected to be the core analysis sample. The articles subjected to this screening process are only from peer-reviewed literature that have high academic standards, assuring readers a reliable and comprehensive view of the current state of ChatGPT-related research in the area of education. The complete records and references were downloaded and saved in plain text format (txt) for systematic visualization analysis later with software like CiteSpace and Bibliometrix.

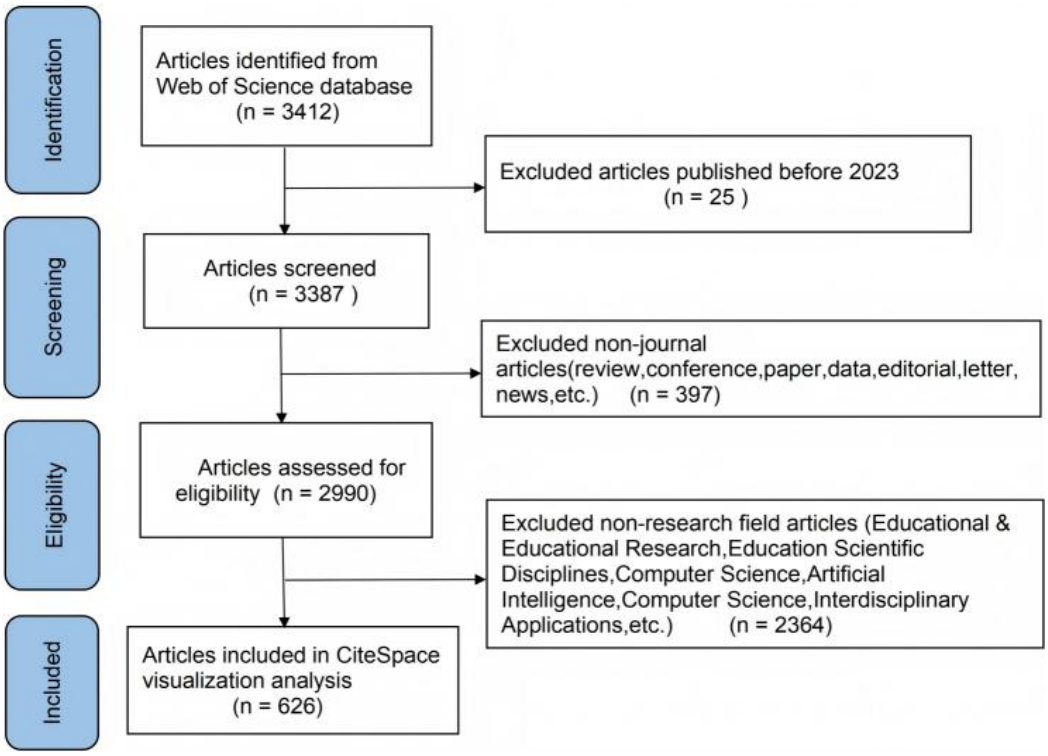


Figure 1. PRISMA flow diagram

2.3. Data analysis

To facilitate data visualization and enhance interpretative depth, this study employs tools commonly used in bibliometrics-CiteSpace (6.3.R1) [15], Bibliometrix (4.2) [16], and VOSviewer (1.6.20) [17]. Moreover, Microsoft Excel was used for creating and analyzing tabular statistics. This paper employed both a quantitative and qualitative approach to carry out a methodological review of research activities [18]. CiteSpace is an information visualization software developed at Drexel University in the United States (US), primarily analyzing data exported from academic databases such as WoS, Scopus, CSSCI, and CNKI. In studies, it uses a systematic analysis and appraisal of the sources and degrees of authors, institutions, and nations, as well as keywords. It uses scientific mapping methods to turn this information into visualized networks (co-author networks and co-occurrence maps), which visually display the outlay, hotspots, collaborative structure, and any trend of evolution in research disciplines [15].

Keyword co-occurrence maps visualize hot topics within research domains, the strength of thematic connections, and field structures by mining the co-occurrence relationships of keywords within a collection

of literature. Keywords serve as nodes, while co-occurrence relationships form the connecting lines. Co-authorship networks also show the level of affiliation among the countries or the authors using the visualized graphs, using the graphical language to reveal the structural features, the degree of collaboration, and the density of the networks of the cooperation networks.

3. RESULTS

3.1. Current state of research on the topic

3.1.1. General information

As per the results shown in Table 1, there are 626 publications in this field, and the average age of publications is 1.51 years. The average citations per paper is 16.83, and a total of 25,934 references are cited. The average number of authors per article was 4.49, and 28.43% of the articles were written with international collaborators. There were 49 articles that had only one author, and authors gave 1,741 self-defined keywords, of which 343 were standardized.

Table 1. General information form

Category	Value
Timespan	2023–2025
Sources (journals and books)	126
Documents	626
Document average age	1.51
Average citations per doc	16.83
References	25,934
Keywords plus (ID)	458
Author's keywords (DE)	1,741
Authors	2,555
Authors of single-authored docs	49
Single-authored docs	49
Co-authors per doc	4.49
International co-authorships (%)	28.43

3.1.2. Trends in thematic research literature

The field saw a rapid growth from 2023 to 2025. The number of publications rose from 78 to 299, and total citations from 401 to 6,716, as seen in Figure 2. In 2024, there was a significant increase in both publications (249) and citations (3,233). By 2025, publications increased to 299, and citations went up to 6,716. In terms of the most influential publications, the top 5 most cited publications in this topic area are shown in Table 2. Cooper [5], Pan *et al.* [19], and Kocoń *et al*. [20] are the authors with the top 3 numbers of citations with 602, 446, and 392, respectively.

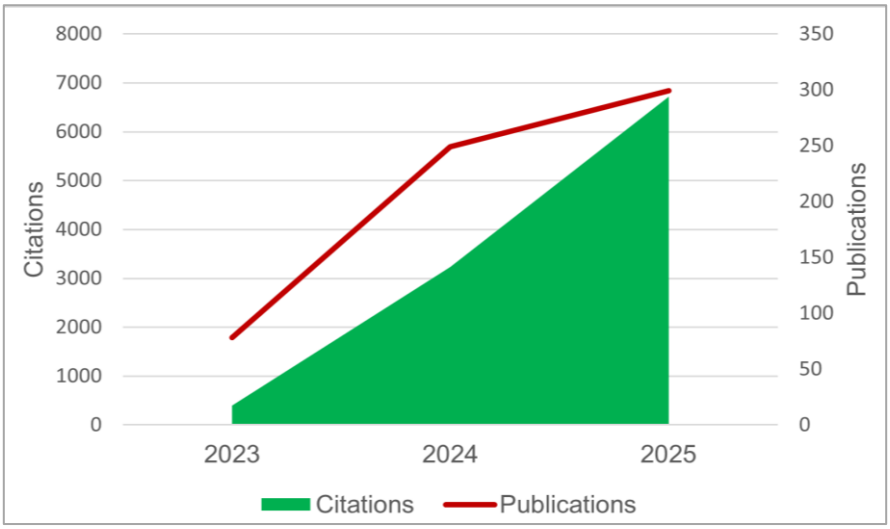


Figure 2. Annual publication and citation trends of ChatGPT research in the education sector

Table 2. Highly cited references

Paper	DOI	TC[a]
Cooper [5]	https://doi.org/10.1007/s10956-023-10039-y	602
Pan *et al*. [19]	https://doi.org/10.1109/TKDE.2024.3352100	446
Kocoń *et al*. [20]	https://doi.org/10.1016/j.inffus.2023.101861	392
Liu *et al*. [21]	https://doi.org/10.1093/jamia/ocad072	241
Boscardin *et al*. [22]	https://doi.org/10.1097/ACM.0000000000005439	219

[a]TC denotes total citations.

3.1.3. The author's analysis

Table 3 provides an overview of the publications and citations of the top five authors in this area. Klyak YS and Masters K each published six papers, respectively, with a total of 198 citations received by Masters K. Although publishing only three papers, Cooper G. had the top total citations and averaged 222.7 citations per paper of any author.

Using VOSviewer [17], the author's co-authorship network was visualized. As seen in Figure 3, it has 16 authors who have researched this subject. The red cluster, centered around West, Joseph K., and Franz, Jeanne L., exhibits tightly interconnected nodes. Blue Cluster revolves around Masters, centered around Ken as the central node, as an independent and principal author. In addition, the diagram illustrates independent author nodes such as Gregorcic, Bor, Li, and Chen, alongside small-scale dispersed clusters including Xiao, Bo, and Clark, Ted M.

Table 3. Number of publications by author

Author	NP[a]	TC[b]	Institution	Country
Klyak YS	6	69	Jagiellonian University	Poland
Masters K	6	198	Sultan Qaboos University	The Sultanate of Oman
Clark TM	5	141	The Ohio State University	US
Zhang YT	4	10	Sun Yat-sen University	China
Cooper G	3	668	Curtin University	Australia

[a]NP total number of publications; [b]TC total number of citations.

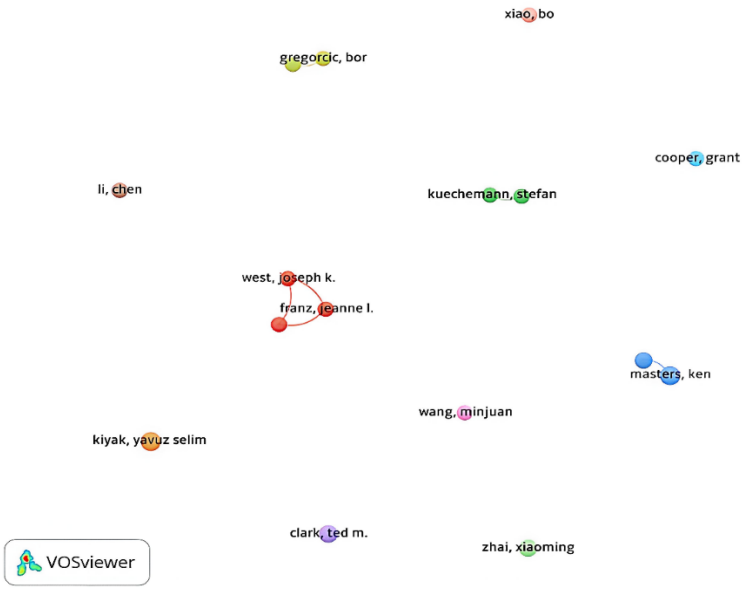


Figure 3. Co-authorship status of authors

3.1.4. Research institution analysis

Table 4 lists the top six institutions by publication count. The University of Texas System led with 14 papers and 565 citations, for an average of 40.36 citations per paper. The University System of Ohio and the University System of Georgia trailed at 12 papers (212 citations, with an average of 17.67 citations per paper) and 11 papers (346 citations, with an average of 31.45 citations per paper), respectively. Tsinghua University had 12 papers cited 148 times (on average, 12.33 citations per paper), and the University of Hong

Kong had nine papers cited 432 times (on average, 48 citations per paper) among the Chinese institutions. The highest number of papers (10) and the highest number of citations (687) of an institution were achieved by Nanyang Technological University in Singapore, with an average of 68.7 citations per paper.

Table 4. Number of publications by institution

Institution	Country	NP[a]	TC[b]	ACC[c]
University of Texas System	US	14	565	40.36
Tsinghua University	China	12	148	12.33
University System of Ohio	US	12	212	17.67
University System of Georgia	US	11	346	31.45
Nanyang Technological University	Singapore	10	687	68.7
University of Hong Kong	China	9	432	48

[a]NP denotes the total number of publicly available papers; [b]TC represents the total number of citations for publicly available papers; and [c]AAC indicates the average number of citations per paper.

3.2. Distribution of research topics

3.2.1. Thematic map analysis

Figure 4 presents a topic map generated using the Bibliometrix software package based on author keywords [16], dividing the subject area into four quadrants. The motor quadrant of the thematic map is taken up by "generative artificial intelligence", "chatbots", and "large language models". The basic quadrant is also "artificial intelligence" and the recurring theme of "large language models". The emerging or declining quadrant contains "framework", "science", and "knowledge", and the niche quadrant includes the words "students", "assessment", and "general public". Some key technologies, such as machine learning, deep learning, and NLP, are located near the center of the map, indicating they are neither very central nor very developed, but are rather a connecting ground between quadrants.

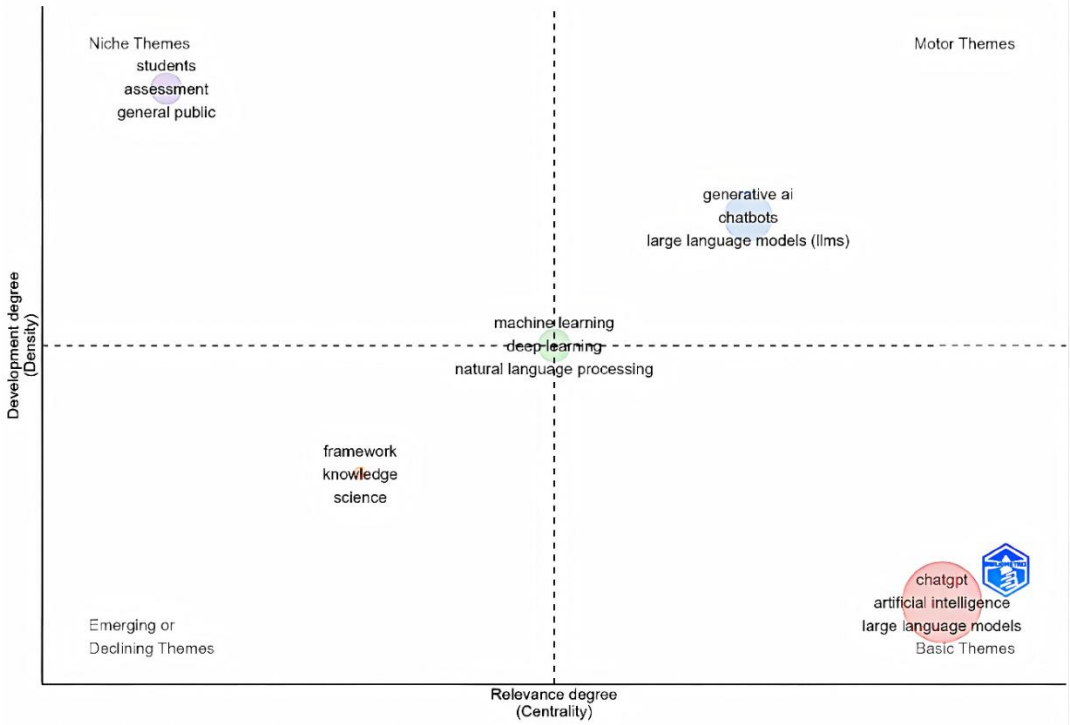


Figure 4. Thematic map

3.2.2. Research area distribution

Research was used to visualize scientometric data spatially, to illustrate the dispersion of scientific research all over the world [23]. Table 5 presents the top countries by publication and citation frequency. The US ranked first with 187 publications, 4,126 total citations, and an average of 22.06 citations per paper.

China was next with 161 papers, 2,611 citations, and an average of 16.22 citations per paper. The UK published 48 items, receiving 1,104 total citations (23.0 citations per publication), and Turkey published 44 items, receiving 219 total citations (4.94 citations per publication). Germany had 38 publications with 588 total citations (an average of 15.47 citations per publication), and Australia recorded 33 publications with 1,442 total citations (the highest average citations per publication among all countries listed).

Figure 5 shows the network of international cooperation. In June 2024, the number of co-authors was increased. China and the US are the nodes in the network with the largest sizes. Germany, France, and other countries in Europe are connected to both China and the US, as well as to each other in Europe. India, Canada, and Singapore are also above the baseline in June 2024.

Table 5. Top 10 countries by frequency of global scientific output

Region	Freq	TC[a]	AAC[b]
US	187	4,126	22.06
Peoples R China	161	2,611	16.22
England	48	1,104	23
Turkey	44	219	4.94
Germany	38	588	15.47
Australia	33	1,442	43.7

[a]TC represents the total number of citations for publicly available papers; [b]AAC indicates the average number of citations per paper.

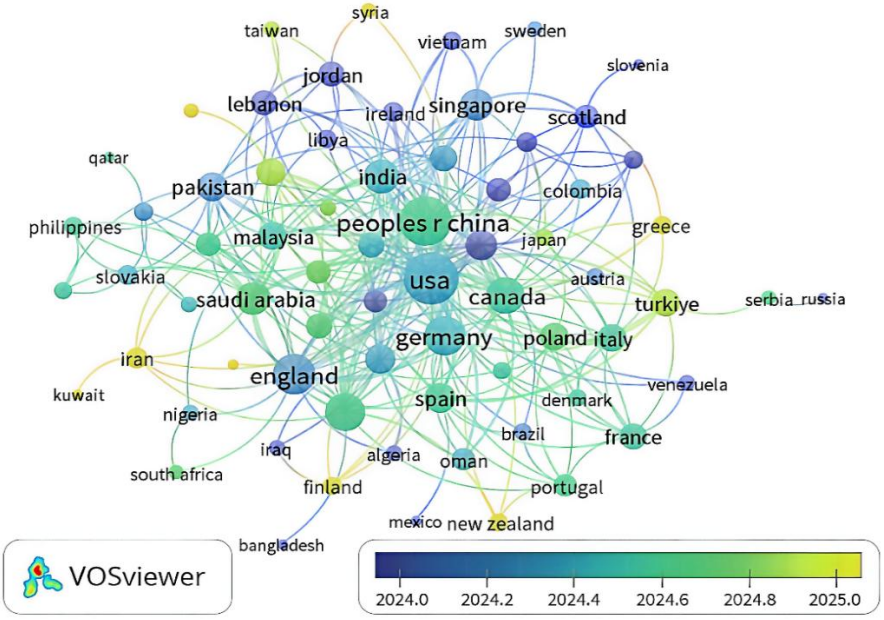


Figure 5. Visualization of co-authored publications by country

3.2.3. Researching highly cited journals

Table 6 lists the journals by publication volume. The BioMed Central (BMC) Medical Education ranked first with 79 publications and 567 total citations. The Journal of Chemical Education followed with 49 publications and 1,336 total citations. Medical Teacher published 48 papers with 797 citations, while IEEE Transactions on Learning Technologies contributed 29 publications with 461 citations. Expert Systems with Applications and the Journal of Science Education and Technology published 19 and 16 papers, with 275 and 733 citations, respectively.

As illustrated in Figure 6, BMC Medical Education has demonstrated the most pronounced growth trajectory. It steadily increased its output of publications, starting with about 10 articles in 2023 and almost 30 articles in 2024, with an annual output of above 60 articles in 2025. Some of the journals, like Medical Teacher and Journal of Chemical Education showed slight increases in publication volume between 2023 and 2024, while Azarian did so in 2025, with the volume generally remaining constant at around 20 articles. IEEE Transactions on Learning Technologies, in its turn, revealed the trend of the first increase and the second decrease.

Table 6. Number of publications by journal

Journal	NP	TC	Q[a](SJR[b])	Publisher
BMC Medical Education	79	567	Q1(0.947)	Springer Nature
Journal of Chemical Education	49	1336	Q2(0.596)	Amer Chemical Soc
Medical Teacher	48	797	Q1(1.254)	Taylor & Francis
IEEE Transactions on Learning Technologies	29	461	Q1(1.071)	IEEE
Expert Systems with Applications	19	275	Q1(1.854)	Elsevier
Journal of Science Education and Technology	16	733	Q1(1.579)	Springer Nature

[a]Q Quartile; [b]SJR SCImago Journal Rank

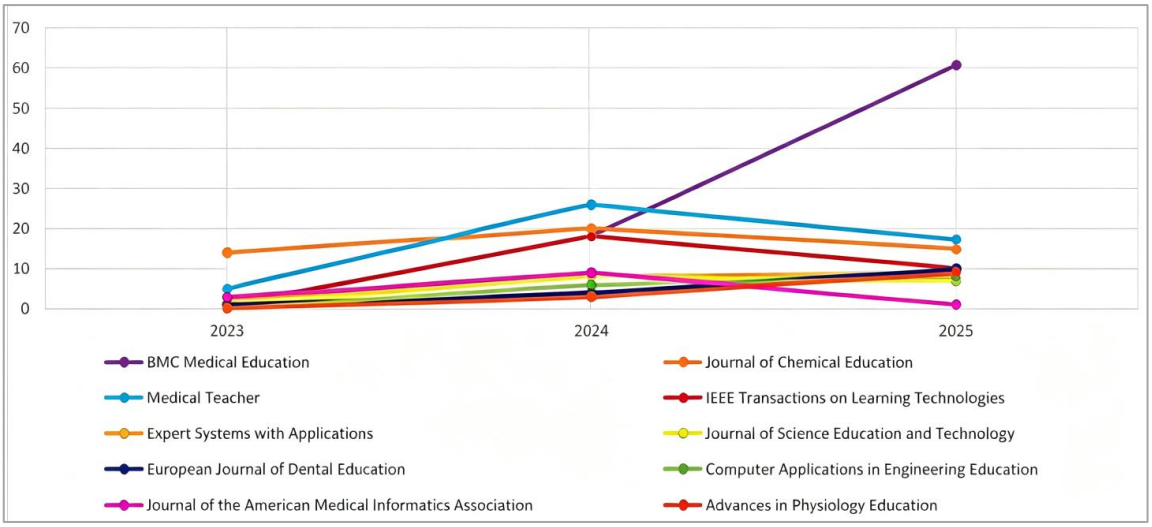


Figure 6. Annual publication trends by journal

3.3. Research keyword analysis

The co-occurrence of keywords in literature was analyzed by using CiteSpace [15]. The network's core, as indicated in Figure 7, is "artificial intelligence", which is linked to "generative AI", "ChatGPT", and "natural language processing". "ChatGPT" functions as a secondary hub that references several terms. Several discipline-related nodes stand out: "students" to "large language models" and "deep learning", "medical education" to "self-directed learning", "large language models", "artificial intelligence", and "higher education" to "generative AI", "natural language processing", "students", and "marketing".

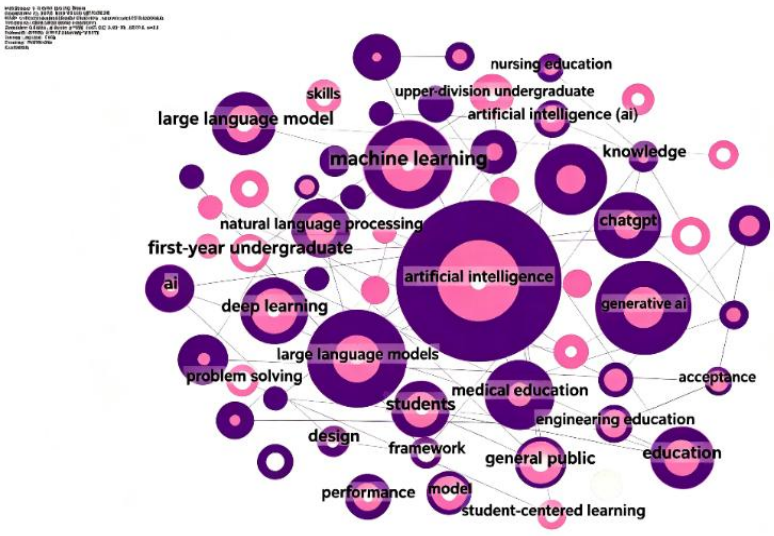


Figure 7. Keyword co-occurrence map

Figure 8 maps the keyword co-occurrence network into nine clusters. Connections are dense within clusters, though links across clusters are also visible. The clusters we identified are: an unlabeled group covering scope reviews and comprehensive overviews; "ChatGPT and the Development of Critical Thinking"; "Medical Students"; "Speech Recognition Chatbots" (#4); "Potential Applications of ChatGPT in Chemistry Experiments"; "Analysis of Chemistry Exam Questions and AI Answers"; and "Perspectives of Engineering Educators".

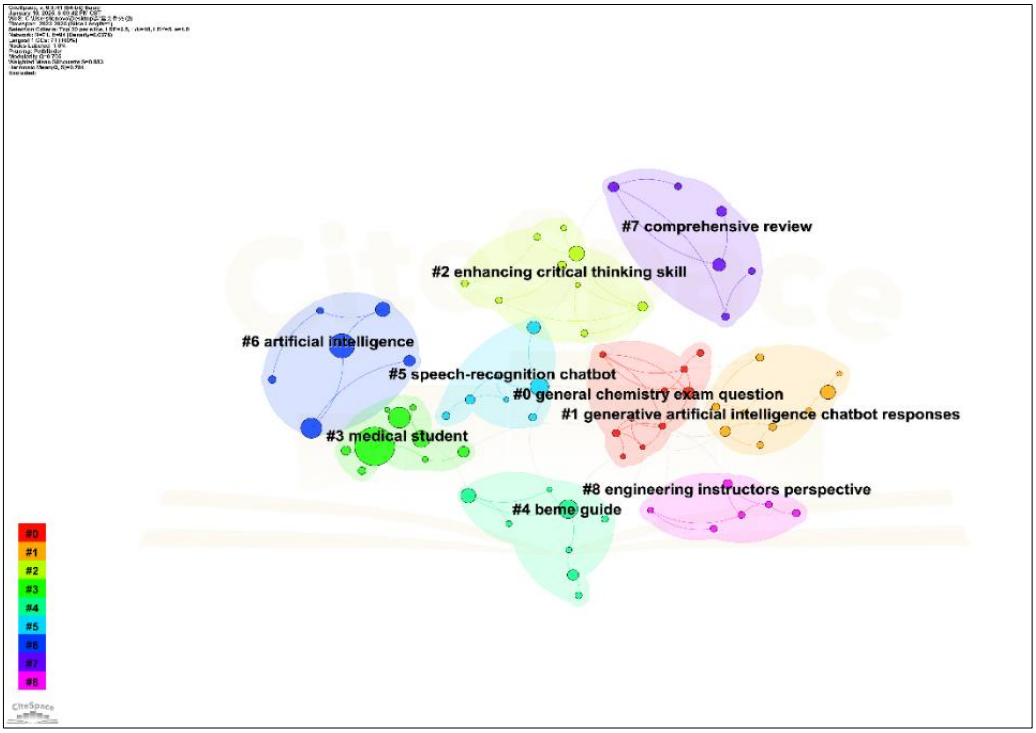


Figure 8. Keyword clustering map

4. DISCUSSION

4.1. How has the knowledge structure evolved over time?

The thematic course of this area has moved significantly from general aspects of technology ethics to pedagogies for subjects and, more recently, to a higher-order thinking aspect. During 2023, research centered on ethical issues, academic honesty, and ChatGPT's transformative capabilities [19], [20]. This is in accord with Rogers' diffusion of innovations theory [24], which decrees that early adopters focus upon relative advantage and compatibility, and the technology is the main topic of discussion. Akpan *et al.* [25] offered an account of this phase.

In 2024-2025, the research landscape was quite different. Focus became more on applications in medical and chemistry education, and the critical thinking aspect became a topic of interest [26], [27]. This movement basically implies that researchers have come to understand that there is no value in the generative AI tool itself, but in how it is pedagogically used. This growth beyond the initial techno-optimism was documented by Ilieva *et al.* [28] and McGrath *et al.* [29]. Singh and Strzelecki [30] added that perceived complexity emerged as the strongest predictor of behavioral intention, suggesting that practical implementation considerations become paramount as novelty fades.

What makes chemistry and medicine lead to this integration? Medical education is a high-stakes clinical reasoning process that naturally fits simulation-based learning. The realistic clinical scenarios and immediate feedback with ChatGPT can be parallel to repeated practice with a low-risk factor [6]. Likewise, chemistry education requires extensive experimental processes to be mastered, which can be simulated and explained by ChatGPT [31]. Chakraborty *et al*. [32] showed a wide medical use case, which led to their interest in the area. Viewed through the technological pedagogical content knowledge (TPACK) framework perspective [33], [34], medical and chemistry teachers have proven to be highly capable in integrating content knowledge with AI-supported pedagogical approaches to achieve what Dickerson and Cherner refer to as "high-level integration". The substitution, augmentation, modification, redefinition (SAMR) model [35]

offers a complementary perspective. In these specific fields, ChatGPT has transcended substitution and modification to redefinition, allowing students to accomplish things that were previously impossible.

"Critical thinking" also became a salient cluster, further evidence that the field is maturing. According to the AI literacy framework [36], critical assessment of AI outputs, ethical decision-making, and collaboration by using AI are fundamental skills. Clusters such as "speech-recognition chatbots" suggest a transition from text-based to multimodal interaction [37], enabling contextualized learning. Zhou *et al.* [38] and Mysore *et al.* [39], offer further evidence that AI research is extending beyond the conventional confines of educational settings.

4.2. Which countries and institutions dominate knowledge production?

The US leads with 187 publications and an average of 22.06 citations per paper, a position shaped by a mix of institutional, policy-related, and cultural factors. AI research and funding in education has become a major focus of major funding agencies in the US, and there are 'AI centers' at universities such as Harvard and Ohio State that focus on cross-disciplinary research. Fütterer *et al.* [40] observed US as a pioneer country because of the country's high level of innovation in educational technology. A recent report from Stanford showed that 56% of US university students have interacted with generative AI in the past year since its launch [41]. Singh and Strzelecki [30] empirical study revealed that relative advantage, compatibility, and perceived complexity have a significant effect on the adoption intention. The more well-resourced a faculty is, the fewer barriers seem to exist, and the less well-resourced a country is, the more complex it is, and the slower the adoption is [42].

China is second, but the impact on the citations is lower. This could be attributed to the increasing percentage of applied and descriptive research, and Chinese researchers should focus more on research innovation in theory. Zhang *et al.* [43] have shown how AI research is being applied across a range of disciplines, yet systematic theoretical frameworks remain thin in many of these contexts. The technology acceptance model (TAM) [44], [45] provides an insightful view: when institutions focus on the perceived ease of use, they tend to produce more descriptive studies than contributions with a theoretical base.

Singapore Nanyang Technological University and National University of Singapore have achieved high impact, in line with the Singaporean strategic emphasis on "future learning" [46]. Australia's "low output, high impact" pattern points to a strategic focus on quality and conceptual depth. Institutions there have been at the forefront of developing ethical frameworks, and this work has attracted global attention. Cataldo *et al.* [47] warned that Australia seems to have avoided this problem by maintaining both the theoretical and applied relevance.

4.3. What collaborative patterns characterize global research networks?

The co-authorship network is fragmented into several small clusters, with interaction between them. The red cluster concentrates on ChatGPT in the context of chemistry education [48] with West as the leader and Franz. In a few nodes, the connectivity is low, and this suggests the need to improve the networking mechanisms. Geographically, the US and China together form a dual-core structure. Germany and France are hubs, active on both sides, for the European region, as well as India, Canada, and Singapore, which have activity above baseline. The international co-authorship rate indicates that cross-regional cooperation has considerable room to grow. Hao *et al.* [49] pioneered methods to obtain relationships from language models for knowledge graph constructions, yet the network structures we observe suggest that such sharing remains constrained by institutional and geographical boundaries.

4.4. What emerging research themes can guide future educational research and practice?

The conclusions have implications for educators and policymakers. On curriculum design, the heavy uptake of ChatGPT in medical and chemistry points to principles with practical applications that may be candidates for incorporating AI. For teacher training, "prompt engineering" and "critical evaluation of AI outputs" should be the terms "prompt engineering" and "critical evaluation of AI outputs" should be embedded within digital competency frameworks [7].

The AI literacy framework [36] proposes a useful structure for developing these capabilities. Different generations have different perceptions and acceptance of generative AI. Adarkwah [50] documented significant differences across Gen Z, Millennials, Gen X, and Baby Boomers in how they use these tools. Cai *et al.* [51] examined the multi-faceted effects of information and communications technology (ICT) on academic performance and mental well-being, while Lian *et al.* [52] highlighted ongoing ethical concerns in China. Regionally, the diffusion gaps we observe call for targeted policy support to encourage AI adoption in underrepresented areas. The predominance of Q1 journals among publications also raises questions about equitable access to knowledge dissemination.

Looking ahead, we see three priority areas for future research. First, more empirical studies are required to analyze the impact of AI tools on key skills like critical thinking and creative problem-solving. Second, research efforts into ChatGPT should be extended to other generative AI environments. As shown by Zhou *et al.* [38], the technological frontier is rapidly widening, going beyond text-based applications. Third, international collaborative networks should be strengthened through funding schemes prioritizing cross-regional partnerships.

4.5. Theoretical contribution

This study makes two principal theoretical contributions. First, it extends Rogers' diffusion of innovations theory [24] by empirically mapping the global diffusion network of ChatGPT in education. Combining TAM [42], [45], TPACK [33], [34], SAMR [35], and the AI literacy framework [36], we show that there are multiple factors at the individual, institutional, and disciplinary levels that influence educational technology adoption. Then, this research makes a contribution to the knowledge network theory by quantifying the process of thematic change from a general ethics to a field-specific pedagogy, offering empirical evidence of how knowledge domains mature in emerging fields. This path we see, from initial excitement to discipline-specific uses and cultivating critical thinking, aligns with Wong *et al.* [53] and echoes Akpan *et al*. [25] observation of the AI landscape moving from novelty toward meaningful integration.

5. CONCLUSION

Overall, this research traces the trajectory of ChatGPT in education research from rapid early expansion toward disciplinary integration, highlighting the two cores of the US and China, and themes from ethics to subject-specific pedagogies. The results suggest that educators have to develop activities that go beyond the mere use of the instrument and should stimulate critical thinking, particularly in practical subjects. The study builds and expands upon Rogers' diffusion of innovations theory and contributes to knowledge network theory by empirically documenting thematic maturation. Limited to WoS and 2023–2025, future work should integrate Scopus, Dimensions, and Lens, and track the shift from ChatGPT toward broader generative AI ecosystems.

FUNDING INFORMATION

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
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D : **D**ata Curation
O : Writing - **O**riginal Draft
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Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
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CONFLICT OF INTEREST STATEMENT

The authors have no competing interests to declare that are relevant to the content of this article.

ETHICAL APPROVAL

Ethical approval for this study was not required as per the institutional guidelines and national regulations, because it involved anonymous questionnaires that did not collect personally identifiable information and posed minimal risk to participants. All procedures were conducted in accordance with the ethical standards of the institutional research committee.

DATA AVAILABILITY

The data that support the findings of this study are available upon request.

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