JIRSEA Journal of Institutional Research South East Asia | Sept/Oct | Vol.23 | No.3 | ISSN 1675-6061

25th SEAAIR Conference "Best Paper"

Diffusion and Thematic Shifts in ChatGPT Research for Higher Education

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Received: 26 August 2025 | **First revision:** 9 June 2025 | **Second revision:** 28 May 2025 | **Accepted:** 11 November 2025

APA citation for this article:
Chiu, Y. M. (2025). Diffusion and Thematic Shifts in ChatGPT Research for Higher Education. *Journal of Institutional Research South East Asia, 23*(3), 465-481.

ABSTRACT

Since ChatGPT's debut in late 2022, its rapid integration into higher education has sparked vigorous debate on academic integrity, instructional innovation, and assessment reform. To delineate the evolving research landscape, this study employs bibliometric methods and visualization analysis using VOSviewer on 11,072 education-related papers indexed in the Scopus database (2022–2025). Through keyword co-occurrence mapping, thematic clustering, and overlay visualizations based on publication year, the findings reveal the dynamic and interdisciplinary nature of this emerging field. The results indicate an exponential growth of publications after 2023, with the research focus expanding from technical applications toward pedagogical practice and institutional governance. The United States and United Kingdom remain leading contributors, while China, Taiwan, India, and Singapore have become major contributors in Asia. Although international collaboration has increased, cross-national partnerships are still limited. The analysis identifies several thematic clusters—ranging from AI technology development and professional or medical education to issues of assessment innovation, ethics, data security, and regulatory policy. Interpreted through Rogers's Diffusion of Innovations (DOI) theory, the findings suggest that ChatGPT's swift adoption in academia is driven by its perceived advantages, ease of experimentation, and low complexity, even as its compatibility with educational values and the visibility of its learning outcomes continue to be debated. This study recommends that the academic community strengthen the linkage between theoretical and empirical research, that policymakers establish timely ethical and regulatory frameworks, and that frontline educators actively explore AI-assisted teaching while enhancing learners' digital and AI literacy. Overall, this bibliometric mapping fills a major synthesis gap and—through a diffusion-based lens—offers strategic insights for future research development, institutional practice, and higher education policy formation.

Keywords: Generative Artificial Intelligence, ChatGPT, Higher Education, Bibliometric Analysis

1. Introduction and Research Objective

Since its public release in late 2022, ChatGPT has rapidly become a focal point of discussion in higher education, sparking debates over academic integrity, pedagogical transformation, and assessment design. A growing body of research warns that students' reliance on ChatGPT to generate assignments may compromise academic honesty, raising concerns about plagiarism, biased evaluation, and distorted learning outcomes (Rahman & Watanobe, 2023; Lo, 2023). Other scholars contend that excessive dependence on such tools could diminish students' critical thinking and creativity, ultimately reducing their motivation for independent learning and problem-solving (Grassini, 2023). Meanwhile, doubts remain regarding the accuracy and reliability of AI-generated content—particularly in domains requiring formal logic or professional expertise—where model outputs may fluctuate or contain conceptual errors (Lo, 2023). As these issues accumulate, educators have called for a reconsideration of traditional assessment mechanisms, arguing that existing models must evolve to maintain fairness and validity in an AI-augmented learning environment (Rudolph, Tan, & Tan, 2023).

Despite the growing attention to ChatGPT, the current literature on its educational applications exhibits significant limitations in both geographical coverage and thematic diversity. Most studies originate from English-speaking countries such as the United States, the United Kingdom, and Australia, while research from Asia has been concentrated in a few regions—most notably Singapore, Taiwan, and South Korea (Lo, 2023). Previous works have primarily explored ethical risks, instructional use cases, learning outcomes, and AI-assisted programming education, with limited attention to institutional policy responses or cross-national comparisons (Rahman & Watanobe, 2023; Grassini, 2023). Moreover, publication venues remain concentrated in a small number of high-impact educational technology journals (Bhullar, Joshi, & Chugh, 2024), suggesting that this area is still in its early diffusion phase. Consequently, the field lacks a macro-level synthesis that clarifies the overall knowledge structure, research dynamics, and developmental trajectory of ChatGPT integration in higher education.

To provide a deeper theoretical interpretation, this study adopts Everett M. Rogers's Diffusion of Innovations (DOI) theory (2003) as its guiding framework. The DOI model explains how technological innovations are adopted and disseminated through a social system over time. According to Rogers, the rate and pattern of adoption depend on five perceived characteristics of an innovation—relative advantage (the degree of improvement over previous practices), compatibility (alignment with existing values and institutional needs), complexity (ease of use), trialability (ease of experimentation), and observability (visibility of results)—as well as the roles of different adopter categories (innovators, early adopters, early majority, late majority, and laggards). Within this framework, the rapid rise of ChatGPT in academia can be understood as a diffusion process shaped by both driving forces (e.g., perceived usefulness, accessibility) and restraining factors (e.g., ethical uncertainty, regulatory gaps, and institutional misalignment).

Guided by this theoretical lens, the present study applies bibliometric analysis and knowledge mapping techniques to systematically examine publications related to ChatGPT and education indexed in the Scopus database between 2022 and 2025. Through quantitative and visual analyses—including thematic clustering, geographic distribution mapping, and journal network analysis—this research seeks to delineate the structure and evolution of ChatGPT-related studies in higher education. The goal is to uncover major research hotspots, disciplinary concentrations, and developmental trends, thereby filling the current gap in macro-level

synthesis and offering a foundation for theoretical advancement and policy-oriented decision-making in the AI era of higher education.

Building on the premise that bibliometric methods enable systematic evaluation of research productivity and thematic patterns (Hwang & Tu, 2021; Bahroun et al., 2023), this study collects and analyzes relevant publications from the Scopus abstract and citation database. The analysis focuses on three dimensions—country or region, academic discipline, and keyword co-occurrence—to provide a comprehensive overview of the global diffusion of ChatGPT-related educational research. Accordingly, this study addresses the following research questions:

1. What is the geographical distribution of research on the educational applications of ChatGPT?
2. Which academic disciplines are most actively engaged in this area of study?
3. What are the most frequently used core keywords, and how do these terms reflect thematic evolution within the field?

2. Methodology

Data Sources and Analysis

a. Data Collection

Bibliometric data were retrieved from the Scopus abstract and citation database on May 26, 2025, ensuring the inclusion of the most recent publications. Scopus was chosen for its comprehensive interdisciplinary coverage, encompassing more than 36,000 peer-reviewed journals from over 11,000 publishers across the social sciences, humanities, life sciences, and education.

Using “ChatGPT” as the primary search term, the search was restricted to the article title, abstract, and author keywords fields. The initial search yielded 19,886 publications. To refine the dataset, additional education-related keywords—“education,” “learning,” “teaching,” and “training”—were applied, narrowing the corpus to 11,072 relevant documents.

The time frame was limited to 2022–2025, covering the period from ChatGPT’s public emergence to the most recent available data. No restrictions were applied regarding subject areas, document types, or languages, allowing for comprehensive inclusion of all relevant materials. The final dataset was exported in CSV format, and duplicates or clearly irrelevant entries were manually removed to ensure data quality and accuracy.

b. Data Analysis and Visualization

This study employed bibliometric and co-occurrence analyses to map the conceptual structure and thematic evolution of research on generative artificial intelligence (GenAI) in education. Two complementary analytical approaches were adopted:

(1) Direct citation analysis, which traces intellectual linkages among documents, and

(2) Co-word analysis, which identifies patterns of keyword co-occurrence to reveal thematic clusters and the progression of research interests over time (Boyack & Klavans, 2010; Bodily et al., 2019; González-Zamar et al., 2020).

Data visualization and network mapping were performed using VOSviewer (version 1.6.20) (van Eck & Waltman, 2010). The analysis focused on author keywords, with parameters set as follows:

(1) Minimum occurrence: 5
(2) Normalization method: Association strength
(3) Clustering algorithm: LinLog/modularity-based

The Overlay Visualization function was used to represent the average publication year, illustrating the temporal evolution of research topics. Labels were displayed according to relevance scores to enhance readability and interpretability of the resulting network maps.

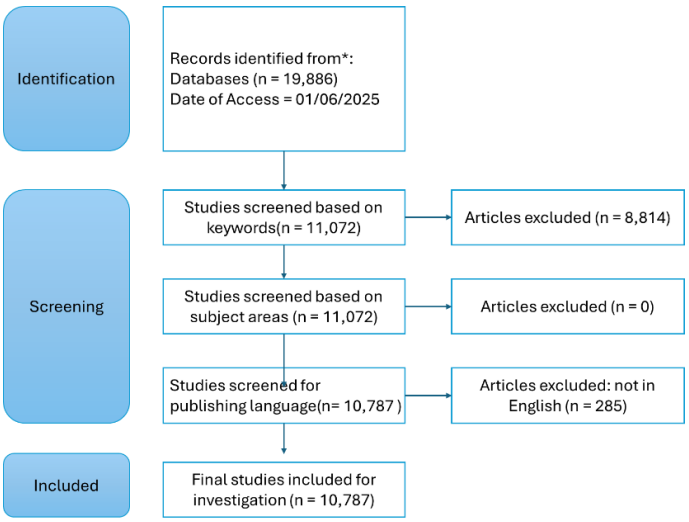

Figure 1: Research Flowchart

Distribution of ChatGPT Applications in Educational Research

Figure 2 depicts the publication trajectory of studies concerning ChatGPT's integration into educational research between 2022 and 2025. The data reveal a marked and sustained surge in scholarly output beginning in late 2022, followed by a sharp escalation through 2023. Although 2022 represents the emergent phase of this topic, publication activity expanded exponentially in 2023 and reached its highest point in 2024, signaling a substantial escalation in academic engagement. This upward momentum reflects how educational researchers have increasingly prioritized the pedagogical implications of generative artificial intelligence (GAI) across teaching, learning, and assessment domains.

From the perspective of Rogers's Diffusion of Innovations (DOI) theory (2003), this pattern mirrors a classic S-shaped diffusion curve. The year 2022 corresponds to the innovator stage, when only a few pioneering scholars explored ChatGPT's educational potential. By 2023, the field had transitioned into the early adopter phase, characterized by rapid expansion and growing institutional experimentation. The proliferation observed in 2024 suggests entry into

the early majority stage, where adoption becomes mainstream across disciplines. Preliminary evidence from early 2025 indicates that growth is beginning to stabilize, suggesting a maturation phase in which novelty diminishes and academic discourse becomes more structured and evaluative.

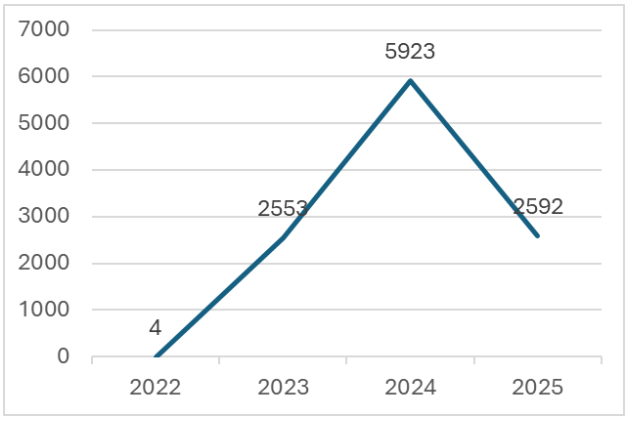

Figure 2: Distribution of Publications on ChatGPT Applications in Educational Research (as of June 1, 2025)

3. Limitations

Despite its comprehensive coverage, as with most bibliometric investigations, this study is subject to several methodological limitations. First, the dataset was restricted to publications indexed in Scopus, using "ChatGPT" as the primary search keyword. Consequently, studies indexed in other databases or those referring more broadly to "generative artificial intelligence" without explicitly mentioning ChatGPT may have been excluded. This constraint may have particularly limited coverage of early-stage research (2020–2021), prior to the widespread use of the term ChatGPT.

Second, the dataset reflects a temporal snapshot as of mid-2025. Given the rapid pace of research in this area, subsequent publications emerging after the cutoff date are not represented. Likewise, citation metrics and co-authorship network data were captured at the time of retrieval and may have evolved since, potentially leading to minor variations in citation rankings or network centrality measures.

Third, the thematic interpretation of clusters and research trends depends on the accuracy of author-supplied keywords and the performance of the clustering algorithm employed by VOSviewer. Automated classification can occasionally oversimplify complex topics or cause thematic overlaps, meaning that a certain degree of interpretive subjectivity remains in the naming and conceptualization of clusters.

While these limitations warrant cautious interpretation of the results, the large dataset and systematic analytical procedures adopted in this study nonetheless provide a reliable macro-level overview of the research landscape. Despite the inherent constraints, the insights derived from this analysis offer a robust and meaningful foundation for understanding the diffusion and development of ChatGPT-related scholarship in higher education.

4. Findings and discussion

Publication trend

To capture the global dynamics of Generative Artificial Intelligence (GenAI) research within the educational domain, this study examines two complementary dimensions: national publication output and international co-authorship networks. Figure 3 displays the top 20 countries ranked by the number of publications indexed in the Scopus database, while Figure 4 illustrates the structure of cross-national collaborations, highlighting each country's position and connection strength within the broader academic ecosystem.

As shown in Figure 3, the United States leads the field with 3,003 publications, far exceeding other nations and reaffirming its central influence in GenAI-related educational research. China (1,389 publications) and India (763) follow as major contributors, signaling the rapid advancement of AI education research in Asia. Established research hubs such as the United Kingdom, Germany, Australia, Canada, and Italy continue to demonstrate strong productivity, forming a multi-centered and globally dispersed research network.

In addition, several emerging Asian economies—notably Malaysia (497 publications), Hong Kong (261), and Taiwan (198)—have entered the global top 20. Their increasing output underscores the broadening diffusion of AI-assisted education research beyond traditional Western contexts, with growing participation from developing academic markets. This geographical diversification reflects an accelerating diffusion pattern, where innovation in AI-driven education is progressively reaching new regional and institutional frontiers.

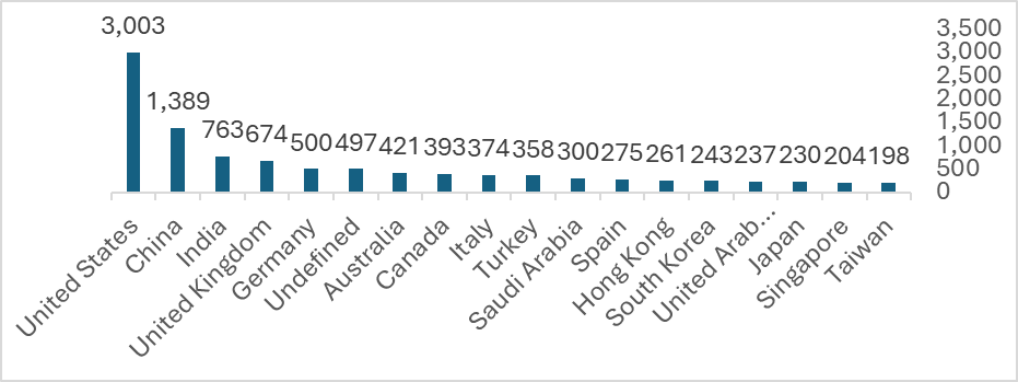

Figure 3: Number of Publications by Country (2022–2025)

Figure 4 illustrates the international co-authorship network of Generative AI research in education, revealing both the structure and intensity of global scholarly collaboration. The United States stands out not only as the most productive country but also as the central hub in the worldwide collaboration landscape, maintaining strong academic linkages with a broad range of partner nations. Surrounding this nucleus, China, India, and Germany occupy prominent positions, forming a densely interconnected cluster that links North America, Europe, and Asia.

In contrast, several emerging economies—including Malaysia, the Philippines, and Algeria—though contributing comparatively fewer publications, have begun to develop cross-regional partnerships. These new collaborative ties suggest that the diffusion of research activity is

gradually extending beyond traditional centers of academic influence, signaling the globalization of AI-in-education research networks.

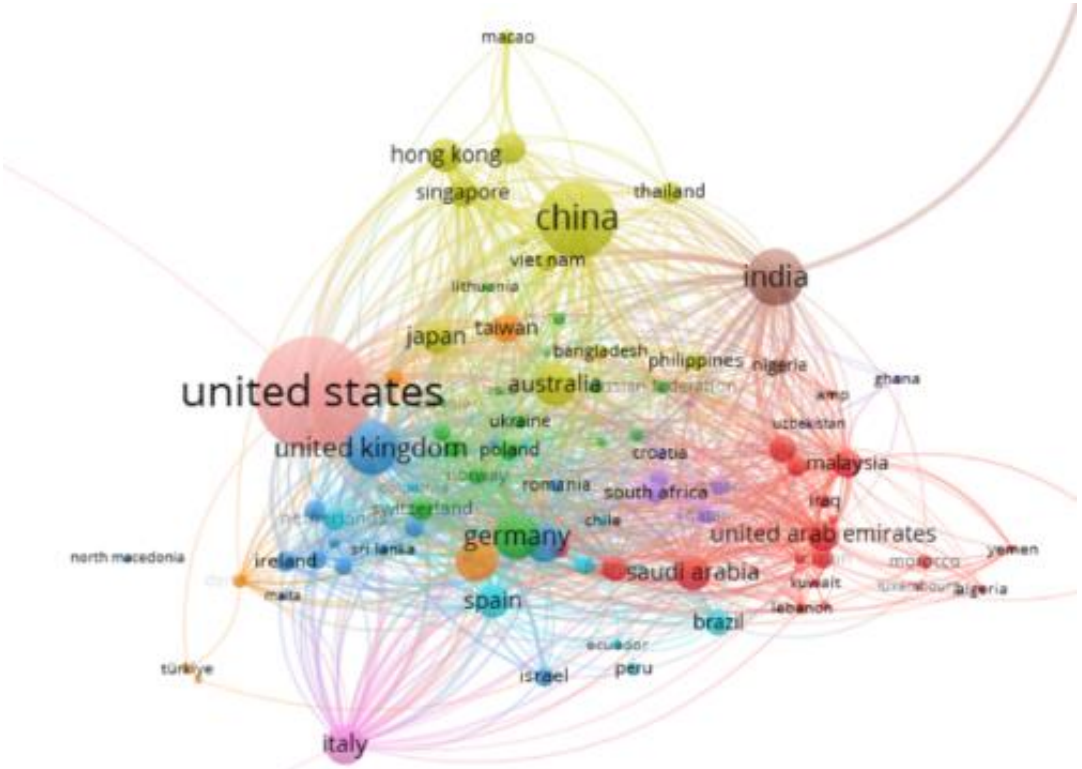

Figure 4: Country-Level Co-authorship Network (2022–2025)

Overall, the results demonstrate a positive association between publication volume and the degree of international collaboration. Countries with greater research output tend to act as network anchors, shaping collaboration flows and knowledge circulation. This configuration embodies a core–periphery structure, where highly connected nations—particularly the United States—drive the global dissemination and institutional adoption of GenAI-related educational knowledge.

From the perspective of Rogers's Diffusion of Innovations theory (2003), these findings parallel an early-adopter pattern at the national level: a small group of innovation leaders initially propelled the field's development, followed by a progressive inclusion of new participant countries. As diffusion continues, the global network is expected to evolve toward a more balanced structure characterized by diversified contributors and collaborative maturity.

Citation analysis

Table 1: Top 10 influential articles

Rank	Article Title and Author, Year	Citations
1	ChatGPT for good? On opportunities and challenges of large language models for education (Kasneci et al., 2023)	2,367
2	"So what if ChatGPT wrote it?" Multidisciplinary perspectives on opportunities, challenges and implications of generative conversational AI for research, practice and policy (Dwivedi et al., 2023)	2,127
3	Performance of ChatGPT on USMLE: Potential for AI-assisted medical education using large language models (Kung et al., 2023)	1,994
4	ChatGPT Utility in Healthcare Education, Research, and Practice: Systematic Review on the Promising Perspectives and Valid Concerns (Sallam, 2023)	1,452

5	ChatGPT: A comprehensive review on background, applications, key challenges, bias, ethics, limitations and future scope (Ray, 2023)	1,335
6	How Does ChatGPT Perform on the United States Medical Licensing Examination? The Implications of Large Language Models for Medical Education and Knowledge Assessment (Gilson et al., 2023)	1,147
7	ChatGPT: five priorities for research (van Dis et al., 2023)	1,114
8	ChatGPT: Bullshit spewer or the end of traditional assessments in higher education? (Rudolph, Tan & Tan, 2023)	936
9	Chatting and cheating: Ensuring academic integrity in the era of ChatGPT (Cotton, Cotton & Shipway, 2024)	930
10	What Is the Impact of ChatGPT on Education? A Rapid Review of the Literature (Lo, 2023)	911

Source: Scopus Database

Thematic clusters

To further examine the thematic landscape and knowledge distribution of research on ChatGPT and generative artificial intelligence (GenAI) in education, this study utilized VOSviewer to perform a keyword co-occurrence analysis, generating a visualized network map (Figure 5). The analysis drew on author-supplied keywords from publications indexed in the Scopus database. By applying a minimum co-occurrence threshold and clustering algorithms, high-frequency terms were identified and grouped into thematic clusters based on network association strength.

The visualization reveals that "artificial intelligence" appears as the most frequently used keyword and occupies a central position in the network, closely linked to terms such as "large language models," "medical education," "deep learning," and "natural language processing." This centrality suggests that contemporary research on ChatGPT is primarily anchored in technological perspectives, particularly the integration of AI systems within professional and medical education contexts.

Distinct colors in the network map represent automatically generated thematic clusters, which can be characterized as follows:

(1) Technology-Oriented Cluster (Green) — This group encompasses technical terms such as "deep learning," "BERT," "copilot," and "multimodal AI models." It captures research examining the algorithmic foundations and computational innovations underlying GenAI models. Studies in this cluster emphasize the relative advantage of emerging LLMs over earlier technologies, underscoring ChatGPT's technological sophistication and efficiency as a catalyst for educational transformation.
(2) Educational and Medical Applications Cluster (Orange) — Centered around keywords such as "medical education," "nursing education," "resident education," and "urology," this cluster reflects the practical incorporation of ChatGPT in clinical and professional training environments. These applications demonstrate the compatibility of generative AI with domain-specific pedagogical needs, especially in settings that benefit from adaptive, feedback-oriented learning tools.
(3) Learning Assessment and Educational Ethics Cluster (Red) — This cluster includes keywords like "formative assessment," "academic writing," and "automated grading." Research in this domain focuses on the influence of AI tools on assessment design, academic integrity, and teaching practices. The prominence of this theme suggests

that educators are critically assessing both the observability of learning outcomes and the ethical implications of integrating AI into evaluation systems.

(4) Educational Attitudes and Societal Response Cluster (Blue) — Featuring terms such as "attitude," "general public," and "quality assurance," this cluster captures the social dimension of diffusion, emphasizing user perception, institutional trust, and organizational readiness for AI adoption. As ChatGPT's visibility grows, scholars are increasingly investigating acceptance, confidence, and cultural readiness, aligning with the trialability and observability stages of innovation diffusion.

(5) Information Security and Legal Issues Cluster (Purple/Pink) — Comprising keywords like "cybersecurity," "copyright," "phishing," and "information security," this cluster represents the ethical, regulatory, and governance challenges emerging from AI adoption. Studies in this domain examine the compatibility of ChatGPT with existing legal and ethical frameworks, as well as strategies for mitigating data privacy and misuse risks to ensure safe implementation in educational settings.

Beyond these dominant clusters, peripheral nodes—including "custom GPT," "predictive model," and "academic publishing"—represent emerging areas of inquiry still in the early stages of diffusion. These peripheral terms indicate the presence of ongoing innovation at the margins, where researchers are experimenting with new directions that have yet to be fully embraced by the early majority.

In Rogers's Diffusion of Innovations (DOI) theory (2003) terms, these frontier topics embody the work of continuing innovators, extending the boundaries of generative AI's application in education and setting the stage for the next wave of scholarly adoption and specialization.

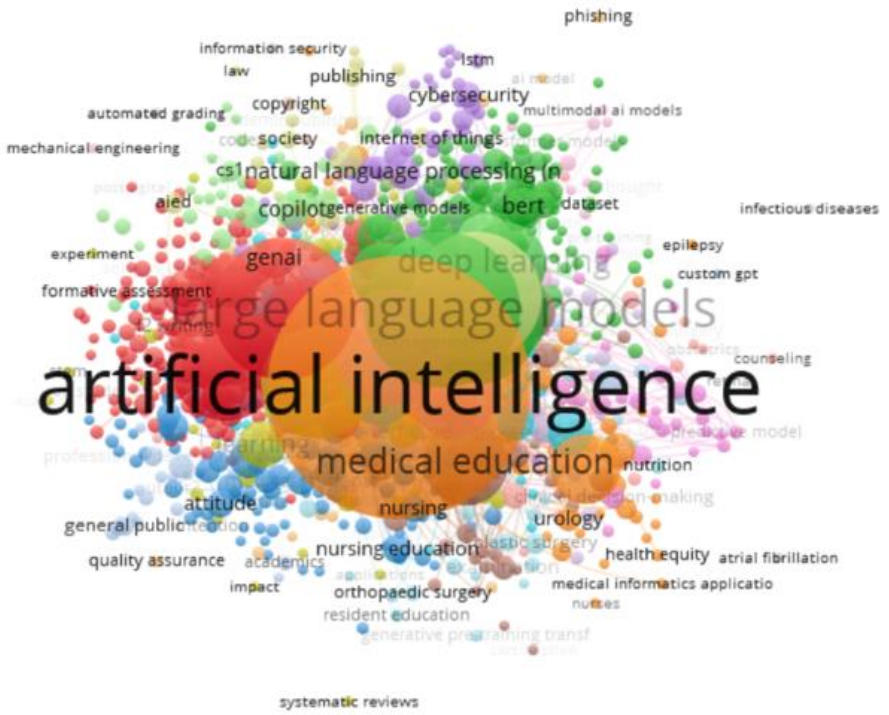

Figure 5: Keyword Clustering of ChatGPT Applications in Educational Research (2022 to June 2025)

Temporal Visualization of Keywords by Average Year of Publication

To further analyze the temporal evolution of research themes surrounding Generative Artificial Intelligence (GenAI) in education, this study employed a keyword co-occurrence analysis using VOSviewer. The Overlay Visualization function was applied to indicate the Average Publication Year (APY) of each keyword, as illustrated in Figure 6.

In this visualization, each node represents a keyword, with its size proportional to the frequency of occurrence. The color gradient—ranging from blue (representing publications before mid-2023) to yellow (representing studies from early 2024 onward)—indicates the relative recency of research topics. Lines between nodes depict co-occurrence relationships, where denser linkages signify stronger semantic associations within the literature.

The analysis reveals that keywords such as "artificial intelligence," "large language models," and "medical education" form the core cluster of the network. Their green-blue coloration shows these subjects have been actively investigated since 2023, indicating their establishment as mature and foundational research domains. In contrast, keywords such as "custom GPT," "copilot," "multimodal AI models," and "academic publishing" appear in shades of yellow, signaling newly emerging research foci with publication peaks concentrated in early 2024—reflecting rapidly increasing scholarly engagement in cutting-edge subfields.

Intermediate keywords such as "formative assessment," "nursing education," and "resident education" exhibit green-to-light-blue hues, representing steady and sustained interest from mid-2023 through early 2024. Meanwhile, terms like "cybersecurity," "copyright," and "phishing" have appeared more recently, highlighting the growing attention to ethical, legal, and data-security concerns as AI becomes embedded in educational ecosystems.

Overall, the overlay visualization depicts a distinct chronological progression in ChatGPT-related educational research. The thematic focus has evolved from technology-centered discussions (e.g., AI systems and large language models) to pedagogical applications (e.g., curriculum, feedback, and assessment), then to user and institutional experiences (e.g., attitudes, academic integrity), and finally to systemic and regulatory issues (e.g., data protection, copyright compliance). This trajectory exemplifies a developmental pathway that can be summarized as:
"technological introduction → pedagogical implementation → societal and institutional response."

Interpreted through the lens of Rogers's Diffusion of Innovations (DOI) theory (2003), this temporal pattern mirrors the sequential stages of innovation diffusion. Initially, scholarly attention emphasized relative advantage and trialability—demonstrating ChatGPT's functional value and feasibility (Phase 1: technological introduction). The subsequent phase focused on compatibility and reduction of complexity, as educators sought to align AI tools with existing pedagogical norms (Phase 2: implementation and adaptation). In the most recent phase, attention has shifted toward observability and consequence management, as institutions and policymakers evaluate outcomes and address systemic impacts (Phase 3: institutionalization and regulation).

That this full diffusion cycle has occurred within roughly two years attests to the unprecedented pace at which ChatGPT has penetrated higher education research and practice. It highlights

how generative AI has transitioned from experimental novelty to an integral, debated, and increasingly regulated component of the academic ecosystem.

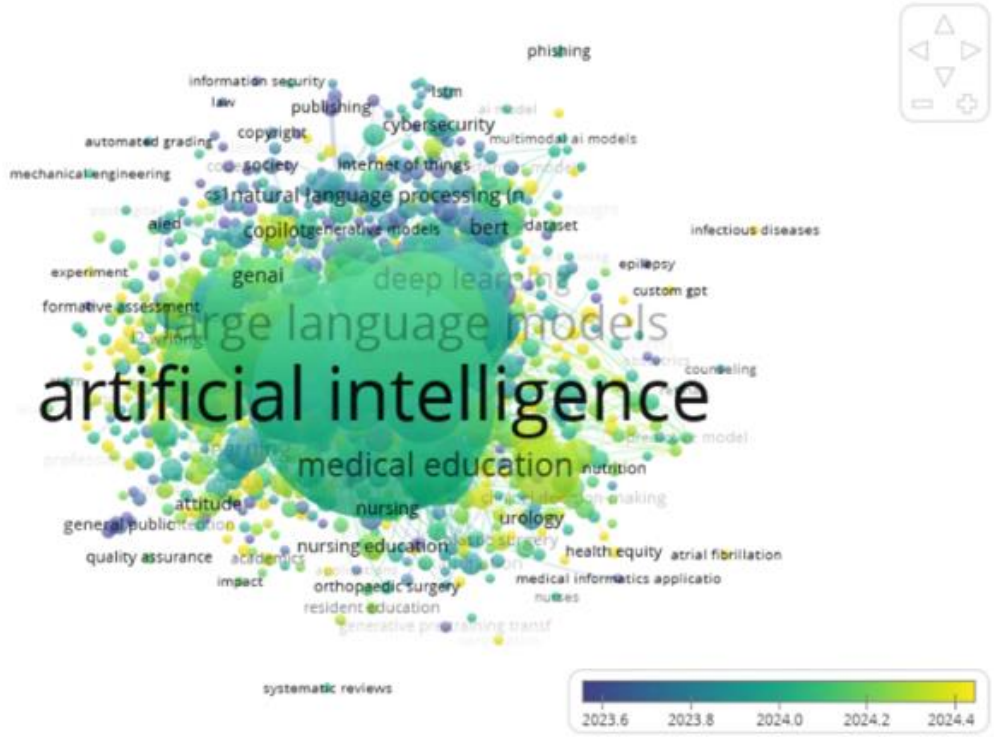

Figure 6: Average Publication Year of Keywords Related to ChatGPT (2022 to June 2025)

5. Conclusion and Recommendations

Conclusion

Based on the findings of this bibliometric investigation, research on the educational applications of ChatGPT has expanded at an unprecedented rate since 2022, demonstrating both strong momentum and increasing thematic diversity. The focus of inquiry has gradually shifted from exploring AI tools as instructional assistants to engaging in deeper reflection on their implications for **academic integrity, learning assessment, and educational ethics**. This transition signifies not only the **technological maturation** of generative AI but also a **pedagogical transformation**, as educational technology research evolves toward multi-domain, cross-disciplinary inquiry.

Geographically, English-speaking countries—particularly the **United States, the United Kingdom, and Australia**—remain dominant in research output, with the United States serving as the central hub of global collaboration networks. In Asia, **China, India, Taiwan, and Singapore** have become increasingly influential contributors, reflecting the growing engagement of emerging educational technology markets. Nonetheless, **cross-national collaboration** and interdisciplinary partnerships remain limited, indicating substantial potential for stronger international cooperation and policy alignment in the coming years.

Thematic clustering and keyword co-occurrence analyses identified four main research streams:

(1) foundational studies on generative AI technologies,
(2) applications in medical and professional education,
(3) investigations into academic integrity and assessment innovation, and
(4) emerging issues related to cybersecurity, privacy, and ethics.

Together, these clusters illustrate the interdisciplinary breadth of the field—spanning education, computer science, ethics, and applied professional contexts such as healthcare training. Temporal trend analysis further reveals a sequential trajectory from **technological introduction → pedagogical implementation → institutional and societal response**, consistent with innovation diffusion and adaptation models.

Interpreted through **Rogers's Diffusion of Innovations (DOI) theory (2003)**, ChatGPT's rapid diffusion in higher education has been driven by several favorable innovation attributes. Its **relative advantage** (improved efficiency in feedback and assessment), **high trialability**, and **low complexity** have lowered adoption barriers, encouraging educators to experiment with minimal cost or technical skill. These characteristics explain the explosive adoption in 2023, when many educators (the "early majority") followed the innovators and early adopters from 2022.

However, as diffusion progresses, **compatibility** with institutional values and **observability** of credible learning outcomes have become critical. The field appears to be transitioning into a **validation phase**, where empirical evidence of effectiveness, fairness, and ethical compliance will determine long-term integration. This theoretical lens underscores the importance of addressing **assessment integrity, data security, and regulatory governance** to ensure responsible and sustainable adoption of ChatGPT in higher education.

In summary, the diffusion of ChatGPT represents both a **transformative opportunity** and a systemic challenge for education. Advancing this innovation toward a mature, evidence-based stage requires coordinated action among researchers, policymakers, and practitioners.

Recommendations

(1) For the Academic Community
Researchers should strengthen the integration between theoretical and empirical inquiry when studying ChatGPT and similar AI tools. While current literature focuses heavily on short-term ethical and pedagogical concerns, future research should investigate **long-**term, systemic, and institutional impacts—including how AI influences assessment reform, faculty roles, and instructional quality over time.

Longitudinal and comparative studies across institutions are essential to capture evolving adoption trajectories. Theoretical frameworks such as **Rogers's DOI** should guide these investigations, linking micro-level case findings to broader adoption patterns and thereby enhancing conceptual coherence.

In addition, scholars should diversify publication outlets. Beyond educational technology journals, research dissemination should extend to fields such as **education policy, sociology, cognitive science, and information ethics.** This cross-field engagement will democratize knowledge production, enrich scholarly dialogue, and accelerate the diffusion of AI understanding to the "late majority" of educators and disciplines that have yet to adopt these tools meaningfully.

(2) For Educational Authorities

(A) Strategic Allocation of Research Resources
The bibliometric results reveal a geographic and institutional concentration of research, with key contributions from a limited number of universities—such as Monash University and leading teams like Kasneci et al. Governments and funding agencies should establish **interdisciplinary AI-in-education research centers**, particularly in underrepresented regions, to promote equitable global participation and build sustainable capacity.

(B) Strengthening Policy and Governance Frameworks
As highlighted in prior studies (Rudolph et al., 2023; Lo, 2023), ChatGPT challenges existing systems of academic integrity and assessment. Educational authorities should proactively **update regulatory frameworks** to reflect the realities of AI integration, developing coherent policies on assessment reform, academic honesty, and AI-enhanced pedagogy to balance innovation with accountability.

(C) Enhancing Ethical and Legal Safeguards
Emerging keywords such as "cybersecurity" and "copyright" reflect increasing attention to digital ethics and data protection. Authorities should implement **clear ethical and legal guidelines** governing AI use in education to prevent misuse, ensure transparency, and safeguard intellectual property. Such measures will strengthen **compatibility** and observability—two crucial conditions for stable diffusion under the DOI framework.

(3) For Frontline Educators

(A) Leveraging AI Tools Responsibly
Educators should adopt ChatGPT as a **pedagogical aid** rather than a replacement for human teaching. Empirical studies, such as **Kung et al. (2023)** on medical education and Kasneci et al. (2023) on classroom applications, demonstrate how AI can enhance content generation, feedback provision, and student engagement while maintaining critical thinking and originality. Early adopters play a pivotal role as **change agents**, helping peers overcome uncertainty by showcasing concrete examples of effective practice.

(B) Innovating Assessment Practices
The keyword analysis (red cluster) revealed strong emphasis on "formative assessment" and "automated grading," highlighting growing interest in AI-supported evaluation models. Teachers should explore **open-ended, AI-assisted assessment designs** that integrate generative feedback and adaptive learning analytics to personalize instruction. Sharing best practices across institutions can enhance trialability, reduce complexity, and support broader acceptance consistent with DOI principles.

Limitations and Future Research Directions

Despite its breadth, this study faces several limitations.

First, the analysis relies solely on the **Scopus** database, which, while comprehensive, may exclude relevant studies indexed in other databases such as **Web of Science, ERIC**, or **Google Scholar**, as well as regional journals not covered by major indexing services.

Second, a **language and publication bias** may exist, as most Scopus-indexed literature is in English and originates from high-income countries, potentially underrepresenting insights from developing or non-English-speaking regions.

Third, the **bibliometric method** is inherently descriptive. Although it effectively maps research structures and trends, it does not assess theoretical depth or causal relationships. Future studies could integrate **systematic reviews, meta-analyses, or qualitative methods** to provide richer interpretive insights.

Finally, the **rapid evolution of generative AI** means that new studies continuously emerge. The results here represent a **snapshot as of May 2025**; ongoing updates and multi-database comparisons are recommended to ensure the continued relevance and accuracy of findings.

Acknowledgment
The author acknowledges the use of **AI-assisted language editing** under full author supervision to enhance clarity and fluency of English expression.

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