International Journal of Management, Accounting, Governance and Education
2025, Volume 5, Issue 2

Mapping the Knowledge Structure and Thematic Evolution of Artificial Intelligence Applications in Higher Education with CiteSpace (2015–2025)

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ABSTRACT

Artificial intelligence is reshaping teaching, learning, assessment, and institutional practices in higher education. This study maps the knowledge structure and thematic evolution of the field through a scientometric analysis of 376 English-language articles and reviews indexed in the Web of Science Core Collection from 2015 to 2025. CiteSpace 7.0.1 was used to examine publication growth, reference co-citation clusters, timeline patterns, and citation bursts. The results show limited activity before 2021, followed by rapid expansion in 2024 and 2025. The co-citation network demonstrated clear clustering (Q = 0.7111; S = 0.7551) and identified nine major themes, including artificial intelligence technologies, systematic reviews, self-regulated learning, software programming, and artificial intelligence capability. Thematic development shifted from general AI systems and adoption toward generative AI, ChatGPT-supported learning, student perceptions, and learning outcomes. These findings clarify the field's intellectual foundations and highlight the growing importance of learner-centred and institutionally embedded AI applications.

Keywords: artificial intelligence, CiteSpace, generative AI, higher education, thematic evolution

1. INTRODUCTION

1.1 Research Background

Artificial intelligence (AI) has become an important technological force in the transformation of higher education. Its applications have expanded from intelligent tutoring systems, automated assessment, learning analytics, and student prediction to academic writing support, content generation, programming assistance, and institutional decision-making. As AI tools become increasingly accessible, universities are exploring how these technologies can support teaching, learning, assessment, and student services.

Earlier research mainly focused on intelligent systems, adaptive learning, and the prediction of student behaviour. Zawacki-Richter et al. (2019) identified profiling and prediction, assessment and evaluation, adaptive systems, and intelligent tutoring as major areas of AI application in higher education. Later studies extended this discussion to online learning, institutional transformation, student adoption, and the ethical implications of AI-supported education. The strong citation burst of Zawacki-Richter et al. (2019) in the present analysis also indicates its importance in shaping the intellectual foundation of the field.

The emergence of generative AI and ChatGPT has accelerated the growth of this research area. Recent studies have examined their use in feedback, academic writing, programming, language learning, assessment, and personalised academic support. At the same time, concerns have emerged regarding academic integrity, inaccurate information, privacy, bias, and student overdependence. As a result, research attention has gradually shifted from the technical functions of AI to its educational effects, adoption conditions, institutional capability, and responsible implementation.

Although several systematic reviews have examined AI in higher education, the literature has grown rapidly and become increasingly fragmented. Existing reviews often focus on particular technologies, educational contexts, or recent developments. They provide useful summaries, but they do not always show how influential studies are connected or how major research themes have evolved over time. A scientometric approach can therefore complement traditional reviews by identifying the intellectual structure, major knowledge clusters, and temporal development of the field.

1.2 Research Objective and Questions

This study aims to map the knowledge structure and thematic evolution of artificial intelligence applications in higher education from 2015 to 2025. Using publications indexed in the Web of Science Core Collection, the study applies CiteSpace to examine publication growth, reference co-citation clusters, timeline patterns, citation bursts, and influential references.
The study addresses the following research questions:
RQ1: How did research output on artificial intelligence applications in higher education develop between 2015 and 2025?
RQ2: What major knowledge clusters constitute the intellectual structure of this field?
RQ3: How have the principal research themes evolved over time, and which references have played influential roles in this development?

2. LITERATURE REVIEW

2.1 Development of Artificial Intelligence Applications in Higher Education

The application of artificial intelligence in higher education initially developed around intelligent tutoring systems, adaptive learning, automated assessment, learning analytics, and student performance prediction. These technologies were designed mainly to improve instructional efficiency, identify students requiring additional support, and provide more responsive learning environments. Early research therefore tended to emphasise the technical functions of AI systems and their capacity to process educational data.
Zawacki-Richter et al. (2019) provided one of the most influential reviews of this field. They classified AI applications in higher education into four broad areas: profiling and prediction, assessment and evaluation, adaptive systems and personalisation, and intelligent tutoring systems. The study also found that much of the research was technology-driven and involved limited participation from educators. Its strong citation burst in the present dataset indicates that it became an important intellectual foundation for later studies on AI-supported higher education.
As research expanded, greater attention was given to the institutional and educational conditions surrounding AI adoption. Chatterjee and Bhattacharjee (2020) examined the factors affecting institutional adoption of AI, while Ouyang et al. (2022) reviewed empirical research on AI in online higher education. Chu et al. (2022) further identified major roles and research trends through an analysis of highly cited publications. These studies showed that AI research was gradually moving beyond isolated technical applications toward broader questions involving institutional readiness, educator participation, student acceptance, and the integration of intelligent technologies into teaching and learning practices.
This development also widened the range of educational settings in which AI was studied. Researchers examined AI-supported library services, online learning environments, institutional management, student advising, assessment, and personalised learning. Consequently, the field became increasingly interdisciplinary, combining educational technology, computer science, information systems, psychology, and higher education research.

2.2 Generative AI and the Expansion of Educational Research

The emergence of generative AI and large language models has substantially accelerated research in this field. ChatGPT and related tools can generate explanations, provide feedback, assist academic writing, support software programming, and facilitate language learning. Their accessibility has enabled students and educators to use AI directly, rather than relying only on specialised systems developed by institutions.

Recent studies have examined both the opportunities and risks associated with these technologies. Kasneci et al. (2023) discussed the potential of large language models to support personalised learning, tutoring, and feedback, while also noting limitations related to reliability, transparency, and bias. Dwivedi et al. (2023) examined the broader implications of generative conversational AI for research, education, policy, and professional practice. Chan and Hu (2023) investigated university students' perceptions of generative AI, showing that students recognised its value for learning support but remained concerned about accuracy and ethical use. Cotton et al. (2024) focused particularly on academic integrity and the implications of ChatGPT for assessment.

The literature has therefore shifted from asking whether AI can be introduced into higher education to examining how it influences learning behaviour, student engagement, academic performance, self-regulated learning, and institutional practice. Studies have also begun to explore AI capability at the institutional level, including university support, student self-efficacy, creativity, and participation in intelligent teaching environments. At the same time, concerns regarding misinformation, privacy, algorithmic bias, unequal access, overdependence, and changes in the role of educators remain unresolved.

Although existing reviews provide valuable accounts of specific technologies and educational issues, the rapid expansion of the literature has produced a fragmented research landscape. General AI systems, generative AI, student perceptions, institutional adoption, learning outcomes, and responsible implementation are often examined separately. A longitudinal scientometric analysis is therefore needed to clarify how these themes are connected and how the intellectual focus of the field has evolved over time.

3. MATERIAL AND METHODS

3.1 Data Source and Screening

Bibliographic records were retrieved from the Web of Science Core Collection on 25 July 2026. The search focused on publications addressing artificial intelligence, generative AI, and ChatGPT in the context of teaching, learning, education, and assessment in universities and other higher education institutions. The publication period was limited to 2015–2025. The search was conducted in the title field to improve the thematic precision of the retrieved records.

Only English-language articles and review articles were retained. Conference proceedings, book chapters, editorials, meeting abstracts, and other document types were excluded. Retracted publications were also removed to ensure the reliability of the dataset. After the Web of Science screening process, 396 records remained.

The records were exported in plain-text format using the "Full Record and Cited References" option. CiteSpace detected no duplicated or invalid records. However, 20 records were classified under the formal publication year 2026, although they had appeared within the Web of Science date filter because of Early Access indexing. These records were excluded to maintain consistency with the stated research period. The final dataset contained 376 publications.

3.2 CiteSpace Configuration

CiteSpace 7.0.1 Advanced was used to analyse the intellectual structure and thematic evolution of the literature. The time span was set from January 2015 to December 2025, with one year per time slice. Titles, abstracts, author keywords, and Keywords Plus were selected as term sources.
Reference was selected as the node type because the analysis focused on the knowledge foundations of AI applications in higher education. The cosine coefficient was used to measure relationships within individual time slices. The g-index was applied as the selection criterion with a scaling factor of k = 25, while Pathfinder pruning was used to simplify the network and retain the most meaningful connections.
Reference co-citation analysis was conducted to identify publications that were frequently cited together. Cluster labels were generated using the log-likelihood ratio method, and the nine largest clusters were retained for interpretation. A timeline view was produced to examine the temporal development and continuity of the principal research themes. Citation counts and citation bursts were used to identify influential and rapidly emerging references, while degree, betweenness centrality, and Sigma were examined to identify structurally important publications and potential intellectual turning points.
The reliability of the clustering solution was evaluated using modularity Q and the weighted mean silhouette score. A modularity value above 0.30 indicates a clearly differentiated network structure, while a silhouette value above 0.70 indicates strong internal consistency among cluster members. These indicators were used to assess whether the identified clusters provided a reliable representation of the field's knowledge structure (Chen, 2006; Chen et al., 2010). The final analysis generated nine major clusters for subsequent interpretation.

4. RESULTS AND DISCUSSION

4.1 Annual Publication Trends

Table 1 presents the annual distribution of the 376 publications included in the final dataset. No eligible publications were identified in 2015 or 2016, while only one publication was recorded in each year from 2017 to 2019. Research output remained limited in 2020, with two publications, before increasing to 19 in 2021 and 30 in 2022. Although the number declined slightly to 28 in 2023, it rose sharply to 97 in 2024 and reached 197 in 2025.

Table 1. Annual distribution of publications from 2015 to 2025

Year	Number of publications	Percentage (%)
2015	0	0.00
2016	0	0.00
2017	1	0.27
2018	1	0.27
2019	1	0.27
2020	2	0.53
2021	19	5.05
2022	30	7.98
2023	28	7.45
2024	97	25.80
2025	197	52.39
Total	**376**	**100.00**

The publication pattern indicates three stages of development. The first stage, from 2017 to 2020, was an exploratory period in which research focused mainly on intelligent systems, AI adoption, automated educational support, and the general implications of AI for universities. The second stage, from 2021 to 2023, represented gradual expansion as researchers increasingly examined online higher education, institutional transformation, student acceptance, and systematic evidence concerning AI applications.

The third stage began in 2024 and was characterised by rapid growth. Publications from 2024 and 2025 accounted for more than three-quarters of the final dataset. This expansion coincided with the widespread use of generative AI and ChatGPT in higher education. Research attention consequently extended from specialised AI systems to readily accessible tools used in academic writing, feedback, programming, language learning, assessment, and research support. The sharp increase also reflects growing concern regarding academic integrity, reliability, institutional policy, and the educational consequences of generative AI.

4.2 Reference Co-Citation Network and Major Clusters

Reference co-citation analysis was conducted to identify the intellectual structure of the field. The final network contained 404 nodes and 1,305 links, with a density of 0.016. The modularity value was 0.7111, indicating that the network was divided into clearly differentiated clusters. The weighted mean silhouette value was 0.7551, demonstrating satisfactory internal consistency among the cluster members. The harmonic mean of modularity and silhouette was 0.7324. These indicators support the reliability of the clustering solution.

Figure 1 presents the reference co-citation cluster map. Nine major clusters were retained and labelled through the log-likelihood ratio method. The size of the nodes represents citation frequency, while the connections indicate co-citation relationships. Larger clusters represent broader and more established knowledge domains.

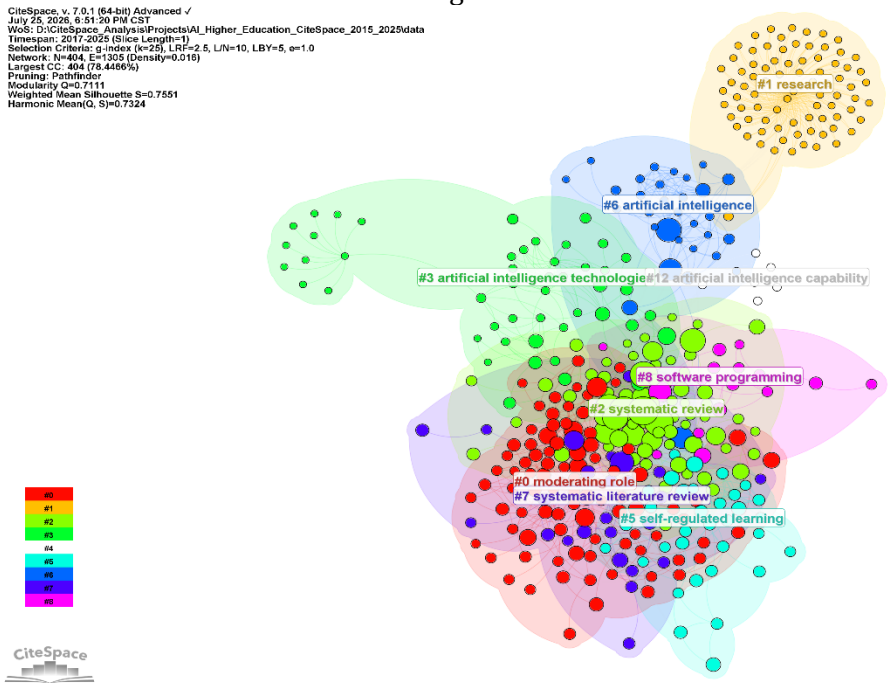

Figure 1. Reference co-citation cluster map of artificial intelligence applications in higher education

Table 2 summarises the size, silhouette value, LLR label, and average year of the nine major clusters.

Table 2. Characteristics of the major reference co-citation clusters

Cluster ID	Size	Silhouette	LLR label	Average year
#0	93	0.513	Moderating role	2023
#1	81	0.978	Research	2016
#2	71	0.595	Systematic review	2022
#3	48	0.855	Artificial intelligence technologies	2020
#5	33	0.875	Self-regulated learning	2023
#6	31	0.942	Artificial intelligence	2019
#7	25	0.817	Systematic literature review	2023
#8	16	0.913	Software programming	2022
#12	6	0.996	Artificial intelligence capability	2019

Cluster #0, labelled moderating role, was the largest cluster, containing 93 members and having an average year of 2023. Its citing literature examined ChatGPT adoption, student perceptions, stakeholder engagement, academic well-being, and the mechanisms through which generative AI affects educational outcomes. The cluster indicates that recent research has increasingly employed behavioural and explanatory models rather than merely describing the functions of AI tools. However, its silhouette value of 0.513 was lower than those of the other clusters, suggesting that it contained several related but comparatively diverse research themes.

Cluster #1, labelled research, contained 81 members and had the earliest average year, 2016. Its high silhouette value of 0.978 indicates strong thematic consistency. The cluster was closely associated with the systematic review by Zawacki-Richter et al. (2019), which organised AI research in higher education into major application areas and highlighted the limited participation of educators. This cluster represents the early knowledge foundation of the field, when researchers attempted to define its boundaries, application categories, and research priorities.

Cluster #2, labelled systematic review, contained 71 members and represented one of the most active recent knowledge domains. Its major references addressed ChatGPT, authentic assessment, generative AI, student reactions, opportunities and challenges, and future research agendas. The prominence of this cluster shows that the rapid introduction of generative AI created an immediate need to synthesise a large and fragmented body of research. However, the coexistence of many reviews also suggests that the field is developing faster than stable empirical evidence can be accumulated.

Cluster #3, labelled artificial intelligence technologies, comprised 48 members and had an average year of 2020. It connected studies on AI adoption, online higher education, extended reality, AI-based robots, and the ethical and social consequences of intelligent technologies. The cluster reflects an intermediate stage in which research shifted from describing AI systems to examining their integration into educational institutions and learning environments.

The remaining clusters represent more specialised applications and outcomes. Cluster #5, self-regulated learning, focused on the effects of generative AI on learning outcomes, academic skills, student engagement, and independent learning processes. Cluster #8, software programming, captured the growing use of ChatGPT and related tools in programming, language learning, retrieval-augmented systems, and technology-supported academic work. Cluster #12, artificial intelligence capability, examined institutional AI capability, university support, student self-efficacy, creativity, and participation in intelligent teaching. Together, these clusters show that the field has moved beyond general discussions of AI toward more specific questions concerning how AI affects learners, disciplines, and institutional capacity.

4.3 Thematic Evolution

Figure 2 presents the timeline view of the nine major clusters. The horizontal position of each node represents the year of the cited reference, while each horizontal line represents a knowledge cluster. The size of a node indicates its co-citation frequency, and the links illustrate the continuity of the intellectual relationships across time.

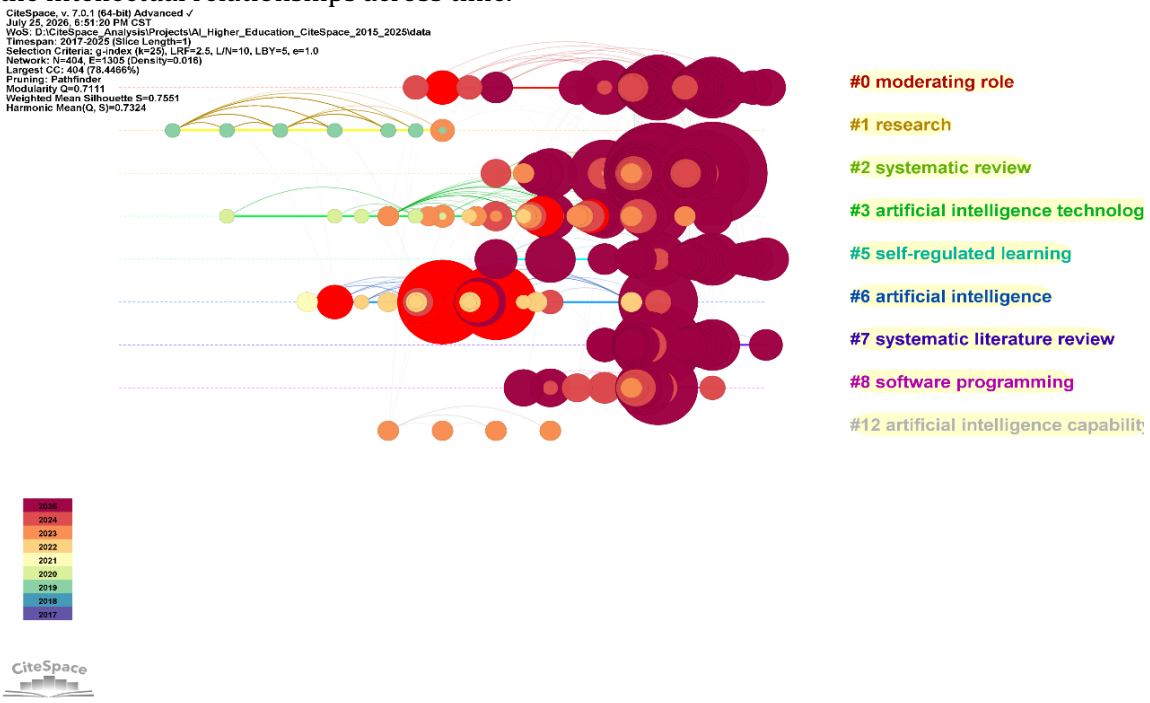

Figure 2. Timeline view of the major reference co-citation clusters

The timeline reveals a transition from foundational AI research to educational integration and, more recently, to generative AI-related learning outcomes. Cluster #1 formed the earliest and longest-running knowledge base. Its references provided general definitions, technical foundations, and systematic classifications that supported subsequent studies. Cluster #6, artificial intelligence, and Cluster #12, artificial intelligence capability, emerged around 2019 and focused on AI adoption, systems approaches, institutional readiness, and students' participation in intelligent teaching.

From 2020 onward, Cluster #3 expanded the focus toward specific AI technologies and their integration into online and institutional environments. This period was characterised by increasing attention to technology adoption, educational transformation, intelligent services, and the social implications of AI. These studies created an important bridge between earlier technical research and later learner-centred investigations.

The period from 2022 to 2025 was dominated by Clusters #0, #2, #5, #7, and #8. The large nodes concentrated near 2023–2025 demonstrate the rapid consolidation of research after the emergence of generative AI. Systematic reviews became especially prominent because researchers needed to clarify the rapidly expanding evidence concerning ChatGPT, assessment, student perceptions, academic integrity, and institutional adoption.

At the same time, self-regulated learning and learning outcomes emerged as central themes. This development indicates a shift from evaluating the availability and acceptance of AI tools to examining whether they improve learning, creativity, engagement, academic skills, and student autonomy. The growth of the software programming cluster further shows that generative AI is being examined within particular disciplinary and task-based contexts rather than only as a general educational technology.

Overall, the timeline suggests a progression through three intellectual orientations. The first was technology-centred, focusing on intelligent systems and technical possibilities. The second was adoption-centred, examining user acceptance and institutional integration. The third is increasingly learner- and outcome-centred, investigating how generative AI influences learning processes, student behaviour, academic performance, and responsible educational practice.

4.4 Influential References and Emerging Knowledge Fronts

Citation frequency, burst strength, betweenness centrality, and Sigma were examined to identify influential publications. Cotton et al. (2024) recorded the highest co-citation count of 53. Kasneci et al. (2023) and Chan and Hu (2023) each received 51 co-citations, followed by Dwivedi et al. (2023) and Rudolph et al. (2023), each with 46. Most of these highly cited publications belonged to Cluster #2, confirming that recent discussions of generative AI, assessment, opportunities, risks, and student perceptions have become the most active shared knowledge base.

Zawacki-Richter et al. (2019) recorded the strongest citation burst, with a burst strength of 13.67. The study also achieved the highest Sigma value of 3.79, indicating that it combined strong citation growth with an important structural position in the network. Its influence reflects its role in consolidating earlier fragmented studies and establishing a widely used classification of AI applications in higher education.

Other notable burst references included Chen et al. (2020), Popenici and Kerr (2017), Bates et al. (2020), Hinojo-Lucena et al. (2019), and Kuleto et al. (2021). These studies addressed the changing role of AI in education, institutional transformation, technical development, and emerging pedagogical implications. Their citation bursts indicate that the foundations of the field were established before the recent generative AI expansion.

Betweenness centrality further identified publications that connected otherwise separate knowledge domains. Kaplan and Haenlein (2019) had the highest centrality value of 0.28, followed by Dwivedi et al. (2023) at 0.25. Zawacki-Richter et al. (2019) and Hinojo-Lucena et al. (2019) each recorded a centrality of 0.10. These publications served as bridges between general AI research, educational technology, institutional adoption, and the emerging generative AI literature.

The combined results show that the field's intellectual centre has shifted rapidly. Earlier influential studies defined AI applications and examined their institutional implications, whereas recent high-impact references concentrate on generative AI, ChatGPT, assessment, academic integrity, student perceptions, and learning outcomes. The next stage of research is therefore likely to require more longitudinal and experimental evidence concerning educational effectiveness, as well as stronger attention to institutional capability, educator roles, responsible use, and the conditions under which AI genuinely supports learning.

5. CONCLUSION

This study mapped the knowledge structure and thematic evolution of artificial intelligence applications in higher education from 2015 to 2025. Based on 376 English-language articles and reviews indexed in the Web of Science Core Collection, the analysis identified a field that developed slowly before 2021 but expanded rapidly in 2024 and 2025. This growth reflects the increasing accessibility of generative AI and ChatGPT and their widespread application in teaching, learning, assessment, academic writing, programming, and student support.

The reference co-citation network demonstrated a clear and reliable cluster structure, with a modularity value of 0.7111 and a weighted mean silhouette value of 0.7551. Nine major clusters were identified, including artificial intelligence technologies, artificial intelligence capability, self-regulated learning, software programming, systematic reviews, and moderating mechanisms. The

timeline analysis showed that the field has moved through three broad stages: early technology-centred research, subsequent attention to adoption and institutional integration, and recent learner- and outcome-centred investigation. Current research increasingly examines how generative AI affects student perceptions, academic skills, learning outcomes, self-regulated learning, and institutional capability.

The analysis also identified several publications that shaped the development of the field. Zawacki-Richter et al. (2019) recorded the strongest citation burst and the highest Sigma value, confirming its importance in organising the early intellectual foundations of AI research in higher education. More recent studies by Cotton et al. (2024), Kasneci et al. (2023), Chan and Hu (2023), and Dwivedi et al. (2023) formed a prominent knowledge base concerning generative AI, academic integrity, student perceptions, opportunities, and educational risks. These findings indicate that the intellectual centre of the field has shifted rapidly toward the educational consequences and responsible implementation of generative AI.

Several limitations should be acknowledged. The dataset was restricted to English-language articles and reviews indexed in the Web of Science Core Collection, which may have excluded relevant studies from other databases, languages, and publication types. The title-based search strategy improved thematic precision but may also have omitted publications that discussed AI applications primarily in their abstracts or keywords. In addition, recently published studies have had limited time to accumulate citations, which may affect their visibility in the co-citation network.

Future research should therefore combine multiple databases and examine the field through broader comparative analyses. Greater attention is also needed to longitudinal and experimental evidence concerning learning effectiveness, student dependence, educator roles, institutional readiness, and ethical governance. As AI becomes increasingly embedded in higher education, the main research challenge is no longer simply whether these technologies can be used, but under what conditions they can enhance learning while preserving academic integrity, human judgement, and educational responsibility.

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