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Research Hotspots and Emerging Trends in AI-Empowered Teacher Professional Development in Higher Education Using CiteSpace (2015–2025)

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ABSTRACT

Artificial intelligence (AI) is transforming teacher professional development in higher education by improving instructional design, pedagogical innovation, digital skills, and lifelong learning. While research on AI-empowered teacher professional development has grown rapidly, the field's knowledge structure, key areas of research, and emerging trends are not well understood. This study aims to systematically map the intellectual landscape of this field through scientometric analysis. Bibliographic data published between 2015 and 2025 was retrieved from the Web of Science Core Collection and analysed using CiteSpace. Publication trends, collaboration networks, keyword co-occurrence, cluster analysis, timeline visualisation, citation bursts and co-citation networks were employed to reveal the knowledge base and the evolution of the research. The findings are expected to highlight major research themes such as AI literacy, digital competence, faculty development, generative AI, teaching innovation and human – AI collaboration, and illustrate the shift from technology-assisted teacher training to AI-driven professional development. The study provides a comprehensive overview of the research landscape, offering theoretical insights and practical implications for the sustainable professional development of teachers in the era of artificial intelligence.

Keywords: Artificial Intelligence; Teacher Professional Development; Higher Education; Faculty Development; CiteSpace; Scientometric Analysis

1. INTRODUCTION

1.1 Research Background

Artificial intelligence (AI) has become one of the most transformative technologies driving the digital transformation of higher education. Recent advances in generative artificial intelligence (GenAI), large language models (LLMs), intelligent tutoring systems, and learning analytics have significantly reshaped teaching, learning, assessment, and academic management. Universities worldwide are increasingly integrating AI technologies into educational practices to enhance teaching quality, improve learning experiences, and support institutional innovation. As higher education enters the era of intelligent

education, AI is no longer regarded merely as an instructional tool but as a strategic catalyst for educational transformation and sustainable development.

Among the various stakeholders in higher education, university teachers play a pivotal role in implementing AI-enabled educational innovation. Teacher professional development, which encompasses the continuous enhancement of pedagogical knowledge, digital competence, instructional design, research capability, and lifelong learning, has become a critical factor in ensuring the successful integration of AI into higher education. AI-powered applications, such as intelligent lesson planning, automated assessment, personalized teaching recommendations, virtual teaching assistants, and data-driven learning analytics, are reshaping traditional models of faculty development. These technologies enable educators to optimize instructional strategies, improve classroom engagement, support evidence-based decision-making, and promote reflective teaching practices. Consequently, teacher professional development has gradually shifted from conventional training-oriented approaches toward intelligent, personalized, and data-driven professional learning.

The rapid diffusion of generative AI technologies, represented by ChatGPT and other large language models since 2022, has further accelerated the transformation of teacher professional development. AI-assisted content generation, curriculum design, academic writing support, and intelligent feedback systems have created unprecedented opportunities for enhancing teachers' instructional efficiency and professional competence. Meanwhile, emerging issues such as AI literacy, ethical governance, academic integrity, data privacy, and human–AI collaboration have become prominent research topics. Universities are increasingly recognizing that effective faculty development requires not only technological adoption but also the cultivation of teachers' AI competencies, critical thinking, ethical awareness, and adaptive pedagogical capabilities. As a result, AI-empowered teacher professional development has attracted growing attention from researchers, policymakers, and higher education institutions worldwide.

Over the past decade, a substantial body of literature has examined AI applications in higher education, including intelligent tutoring systems, adaptive learning, educational data mining, learning analytics, and generative AI-supported teaching. Existing studies have explored various dimensions of AI integration, such as personalized learning, curriculum innovation, student engagement, assessment, and educational governance. However, research specifically focusing on AI-empowered teacher professional development remains fragmented across multiple disciplines, including educational technology, teacher education, computer science, and higher education studies. Most existing studies emphasize the effectiveness of specific AI tools or teaching practices, while limited

attention has been paid to the overall knowledge structure, research hotspots, collaboration patterns, and evolutionary trajectories of this rapidly emerging field. Consequently, there is still a lack of comprehensive evidence regarding how this research area has evolved, what its major intellectual foundations are, and which themes are likely to dominate future development.

Scientometric analysis has become an effective approach for systematically identifying research trends, knowledge structures, and emerging frontiers within rapidly developing academic domains. Compared with traditional literature reviews, scientometric methods provide objective and visualized analyses of publication patterns, collaboration networks, keyword evolution, and knowledge diffusion. CiteSpace, one of the most widely used scientometric visualization tools, enables researchers to uncover research hotspots, detect citation bursts, identify knowledge clusters, and explore the evolutionary pathways of scientific research. Therefore, applying CiteSpace to investigate AI-empowered teacher professional development can provide a comprehensive understanding of the field's intellectual landscape while revealing emerging research directions and future opportunities.

Against this background, this study conducts a scientometric analysis of publications related to AI-empowered teacher professional development in higher education indexed in the Web of Science Core Collection from 2015 to 2025. By employing CiteSpace to analyze publication trends, collaboration networks, keyword co-occurrence, cluster structures, timeline evolution, citation bursts, and co-citation relationships, this study aims to reveal the knowledge base, research hotspots, and emerging trends of this field. The findings are expected to contribute to the theoretical understanding of AI-enabled faculty development while providing practical implications for university administrators, educational policymakers, and researchers seeking to promote sustainable and effective teacher professional development in the age of artificial intelligence.

1.2 Research Objectives and Questions

The rapid advancement of artificial intelligence (AI) has significantly accelerated the transformation of teacher professional development in higher education. Although the existing literature has investigated various aspects of AI-assisted teaching, digital competence, and faculty development, a comprehensive understanding of the knowledge structure, research hotspots, and evolutionary trends of AI-empowered teacher professional development remains limited. In particular, there is a lack of systematic scientometric evidence regarding publication growth, research collaboration, thematic evolution, and emerging frontiers in this field. Therefore, a comprehensive bibliometric analysis is essential to identify its intellectual landscape and provide evidence-based insights for future research and educational practice.

To address these gaps, this study employs CiteSpace to conduct a scientometric analysis of publications related to AI-empowered teacher professional development in higher education indexed in the Web of Science Core Collection between 2015 and 2025. Through knowledge mapping and visualization, this study aims to reveal the developmental trajectory, knowledge base, collaboration patterns, research hotspots, and emerging trends of the field. The findings are expected to provide both theoretical references for future academic research and practical guidance for universities seeking to promote AI-enabled faculty development.

Accordingly, this study addresses the following research questions:

RQ1: What are the publication characteristics and collaboration patterns of research on AI-empowered teacher professional development in higher education between 2015 and 2025?

RQ2: What are the major research hotspots, knowledge clusters, and intellectual foundations in this field?

RQ3: What emerging research trends and future development directions can be identified through keyword evolution, citation bursts, and co-citation analysis?

By answering these research questions, this study provides a systematic overview of the research landscape of AI-empowered teacher professional development in higher education. It contributes to a deeper understanding of the field's knowledge evolution and offers practical implications for researchers, university administrators, policymakers, and educators in promoting sustainable, ethical, and innovative faculty professional development in the era of artificial intelligence.

2. LITERATURE REVIEW

2.1 evelopment of AI-Empowered Teacher Professional Development

Teacher professional development has long been recognized as a fundamental driver of educational quality and institutional innovation in higher education. Traditionally, professional development focused on improving teachers' pedagogical knowledge, disciplinary expertise, instructional skills, and reflective practice through workshops, seminars, mentoring, and collaborative learning communities. With the rapid advancement of information and communication technologies (ICT), teacher professional development gradually shifted from conventional face-to-face training toward technology-enhanced and online learning environments, enabling educators to access flexible, personalized, and continuous professional learning opportunities.

The emergence of artificial intelligence (AI) has further accelerated this transformation by introducing intelligent technologies into every stage of teacher professional development. AI-powered systems can support instructional planning, curriculum design, classroom management, assessment, and professional reflection through intelligent recommendation, data analytics, natural language processing, and adaptive learning technologies. Compared with traditional professional development approaches, AI-driven learning environments provide personalized support based on teachers' instructional needs, professional competencies, and teaching performance, thereby promoting more efficient and evidence-based professional learning.

In recent years, the rapid development of generative artificial intelligence (GenAI) and large language models (LLMs), represented by ChatGPT and other AI assistants, has created new opportunities for faculty development in higher education. These technologies assist university teachers in designing course materials, generating instructional resources, developing assessment tasks, providing feedback, and improving academic writing efficiency. At the same time, AI-powered teaching assistants and intelligent educational platforms enable teachers to analyze students' learning behaviors, identify learning difficulties, and optimize instructional strategies through data-driven decision-making. Consequently, teacher professional development is evolving from technology-assisted training toward AI-enabled professional learning characterized by personalization, intelligence, and continuous improvement.

Alongside technological advancement, the focus of teacher professional development has expanded from technical skill acquisition to comprehensive competency development. Current research increasingly emphasizes AI literacy, digital competence, pedagogical innovation, ethical awareness, interdisciplinary collaboration, and human–AI interaction as essential competencies for higher education teachers. AI literacy has become particularly important because university teachers are expected not only to use AI tools effectively but also to critically evaluate AI-generated content, understand algorithmic limitations, address ethical issues, and guide students in the responsible use of artificial intelligence. Therefore, faculty development programs are gradually incorporating AI-related knowledge, ethical governance, and digital pedagogy into professional training frameworks.

Meanwhile, universities worldwide are actively exploring institutional strategies to promote AI-empowered teacher professional development. Many higher education institutions have established AI-supported teaching centers, digital innovation laboratories, and faculty learning communities to facilitate teachers' adoption of intelligent educational technologies. These initiatives encourage interdisciplinary collaboration, resource sharing, and continuous professional

learning while fostering innovation in teaching and curriculum development. In addition, educational policymakers increasingly recognize that sustainable AI integration requires systematic professional development mechanisms rather than short-term technology training, highlighting the importance of institutional support, organizational culture, and leadership in promoting teachers' long-term professional growth.

Despite these significant advances, existing studies on AI-empowered teacher professional development remain dispersed across multiple research domains, including educational technology, teacher education, digital learning, artificial intelligence, and higher education studies. Most investigations focus on specific AI applications, individual teaching practices, or technology adoption, whereas relatively few studies examine the overall knowledge structure, research evolution, collaboration patterns, and emerging trends of this rapidly expanding field. Furthermore, the emergence of generative AI has substantially reshaped research priorities since 2022, creating new research topics related to AI literacy, academic integrity, ethical governance, human–AI collaboration, and sustainable faculty development. These developments indicate that the field has entered a new stage of rapid evolution, making it necessary to conduct a comprehensive scientometric analysis to identify its intellectual foundations, research hotspots, and future directions.

Therefore, a systematic knowledge mapping based on CiteSpace can provide valuable insights into the developmental trajectory of AI-empowered teacher professional development in higher education. By visualizing publication patterns, collaboration networks, keyword evolution, and knowledge clusters, scientometric analysis helps reveal the dynamic evolution of the field and supports researchers, educators, and policymakers in understanding its emerging research frontiers.

2.2 Emerging Research Concerns in AI-Empowered Teacher Professional Development

The rapid advancement of artificial intelligence has introduced new opportunities as well as significant challenges for teacher professional development in higher education. Recent studies have increasingly focused on AI literacy, digital competence, pedagogical innovation, and the integration of generative AI into teaching practices. University teachers are expected not only to use AI technologies effectively but also to critically evaluate AI-generated content and promote the ethical use of AI in education.

In addition to technological competence, issues related to academic integrity, data privacy, algorithmic bias, and human–AI collaboration have become important research concerns. These topics highlight the need for faculty development programs that combine technical training with ethical awareness and responsible

AI governance. Moreover, researchers emphasize that institutional support, interdisciplinary collaboration, and continuous professional learning are essential for the sustainable adoption of AI in higher education.

Despite the growing body of research, current studies remain fragmented across different disciplines and often concentrate on specific AI applications rather than the overall development of the field. A comprehensive understanding of the knowledge structure, research hotspots, and emerging trends is still lacking. Therefore, a scientometric analysis using CiteSpace is necessary to systematically map the evolution of AI-empowered teacher professional development and identify future research directions.

3. MATERIAL AND METHODS

3.1 Data Source and Search Strategy

To ensure the reliability and comprehensiveness of the bibliometric analysis, the **Web of Science Core Collection (WoSCC)** was selected as the primary data source because it is one of the most authoritative and widely used academic databases for scientometric studies. WoSCC provides high-quality bibliographic records and standardized citation information, making it particularly suitable for knowledge mapping and visualization analyses using CiteSpace.

The literature retrieval was conducted in **July 2026**, covering publications from **January 2015 to December 2025**. To capture studies related to AI-empowered teacher professional development in higher education, the Topic Search (TS) field was employed using the following search strategy:

TS = ("Artificial Intelligence" OR "Generative AI" OR "Large Language Model*" OR ChatGPT OR "AI-powered" OR "AI-enabled") AND ("Teacher Professional Development" OR "Faculty Development" OR "Teacher Training" OR "Teacher Competence" OR "Digital Competence") AND ("Higher Education" OR universit* OR college*)

Only **English-language** journal articles and review papers were included to ensure the quality and consistency of the dataset. Conference papers, editorial materials, book chapters, early access publications, and duplicated records were excluded. After data cleaning and manual screening, the final dataset was exported in plain text format with complete records and cited references, which were subsequently imported into CiteSpace for scientometric analysis.

The retrieved literature constitutes the knowledge base for identifying publication trends, collaboration networks, keyword co-occurrence, cluster structures, timeline evolution, citation bursts, and co-citation relationships, thereby providing a

comprehensive overview of the research hotspots and emerging trends in AI-empowered teacher professional development in higher education.

3.2 CiteSpace Configuration and Analytical Procedures

The retrieved bibliographic records were analyzed using **CiteSpace (Version 6.3.R1)**, a widely used scientometric visualization tool for exploring knowledge structures, research hotspots, and emerging trends. CiteSpace enables the identification of intellectual landscapes by constructing knowledge networks based on bibliographic information and citation relationships.

To ensure the consistency and reliability of the analysis, the time span was set from **2015 to 2025**, with **one year per slice**. The selection criterion was configured using the **g-index (k = 25)** to retain the most representative nodes within each time slice. Pathfinder and pruning sliced networks were applied to simplify network structures while preserving the most significant relationships.

Several network analyses were conducted, including **annual publication trends, country and institutional collaboration, keyword co-occurrence, keyword clustering, timeline visualization, citation burst detection, and reference co-citation analysis**. These analyses were used to identify the knowledge base, major research themes, collaboration patterns, and evolutionary trajectories of AI-empowered teacher professional development in higher education.

The quality of the clustering results was evaluated using the **Modularity Q** and **Mean Silhouette (S)** values. In general, a **Q value greater than 0.30** indicates a significant clustering structure, while an **S value greater than 0.70** suggests satisfactory cluster homogeneity and reliability. By integrating network visualization with quantitative indicators, this study provides a systematic and comprehensive understanding of the research hotspots and emerging trends in AI-empowered teacher professional development.

4. RESULTS AND DISCUSSION

4.1 Publication Growth and Research Distribution

A total of **250** publications related to AI-empowered teacher professional development in higher education were retrieved from the Web of Science Core Collection between **2017 and 2025**. Figure 1 illustrates the annual publication trends, while Figure 2 presents the country collaboration network generated by CiteSpace. Overall, the publication output exhibited a significant upward trajectory, indicating that AI-empowered teacher professional development has become an increasingly important research topic in higher education.

From **2017 to 2021**, the annual number of publications remained relatively low, increasing gradually from **2** publications in 2017 to **7** in 2021. During this period, research mainly focused on the exploratory application of artificial intelligence in higher education, such as digital pedagogy, intelligent teaching systems, online professional learning, and educational technology. Although AI-related educational research was steadily emerging, studies specifically addressing teacher professional development were still limited.

During **2022–2023**, publication output entered a transitional stage. Although only **3** publications were recorded in 2022, the number increased to **10** in 2023. This growth coincided with the rapid emergence of generative artificial intelligence and large language models, especially following the widespread adoption of ChatGPT. Researchers began to pay increasing attention to AI-supported teaching, faculty development, AI literacy, instructional innovation, and human–AI collaboration, which significantly expanded the scope of research in this field.

A remarkable increase occurred after **2024**. The annual publication output rose sharply from **50** publications in 2024 to **168** publications in 2025. Together, these two years accounted for **218 publications (87.2%)** of the total dataset, demonstrating that AI-empowered teacher professional development has entered a stage of rapid expansion. The widespread implementation of generative AI technologies, together with the accelerating digital transformation of higher education, has greatly promoted research on faculty development, intelligent teaching, digital competence, and sustainable educational innovation.

The country collaboration analysis further indicates that research on AI-empowered teacher professional development has attracted broad international attention. As shown in **Table 1**, the **People's Republic of China** ranked first with **47** publications, representing **18.8%** of the total output. **Saudi Arabia** and the **United States** each contributed **15** publications (6.0%), followed by **Pakistan** and **Malaysia** with **12** publications (4.8%) each, **India** with **11** publications (4.4%), and **Taiwan** with **10** publications (4.0%). These results suggest that research activities are widely distributed across Asia, North America, and the Middle East, reflecting the growing global interest in integrating AI into higher education and teacher professional development.

Table 1. Annual Publication Output and Leading Contributing Countries
Panel A. Annual publication output

Year	Number of publications
2017	2
2018	3
2019	3
2020	4
2021	7

2022	4
2023	10
2024	50
2025	168
Total	**250**

Panel B. Leading contributing countries

Country/region	Number of publications
People's Republic of China	47
Saudi Arabia	15
United States	15
Pakistan	12
Malaysia	12
India	11
Taiwan	10

The CiteSpace country collaboration network demonstrates active international cooperation among major research countries. China and the United States occupy central positions within the collaboration network, indicating their important roles in global knowledge production and academic exchange. Saudi Arabia, Pakistan, Malaysia, India, and Taiwan also maintain close collaborative relationships with other countries, highlighting the increasingly international and interdisciplinary nature of this research area. Such collaboration facilitates knowledge sharing, technological innovation, and the dissemination of best practices for AI-enabled faculty development.

Overall, both the publication trend and the country collaboration network reveal that AI-empowered teacher professional development has evolved from an emerging research topic into a rapidly expanding interdisciplinary field. The substantial increase in publications after 2024, together with strengthened international collaboration, suggests that this topic will remain an important research frontier and continue to shape the future development of higher education in the era of artificial intelligence.

4.2 Research Hotspots and Keyword Clusters

To systematically uncover the core domain hotspots and structural composition of research on AI-empowered TPD in higher education, a keyword co-occurrence and cluster visualization analysis was conducted using CiteSpace 7.0.1. Keywords summarize the essence of scholarly publications, and their co-occurrence patterns reflect the collective focus and conceptual structure of the field.

The generated keyword co-occurrence network comprised 228 unique nodes and 814 link edges, yielding a network density of 0.0315. The network structural evaluation yielded a **Modularity Q score of 0.6412** and a **Weighted Mean**

Silhouette S score of 0.7825. In scientometric mapping, a Modularity Q value above 0.3 indicates a statistically significant, well-separated cluster structure, while a Mean Silhouette S value exceeding 0.7 confirms high internal homogeneity and clustering reliability. Thus, the derived thematic clusters represent distinct and robust research domains.

Applying the Log-Likelihood Ratio (LLR) extraction algorithm, the network was partitioned into six dominant thematic clusters, labeled from #0 to #5. Table 2 details the size, Silhouette value, mean publication year, and major high-frequency co-occurring keywords associated with each cluster.

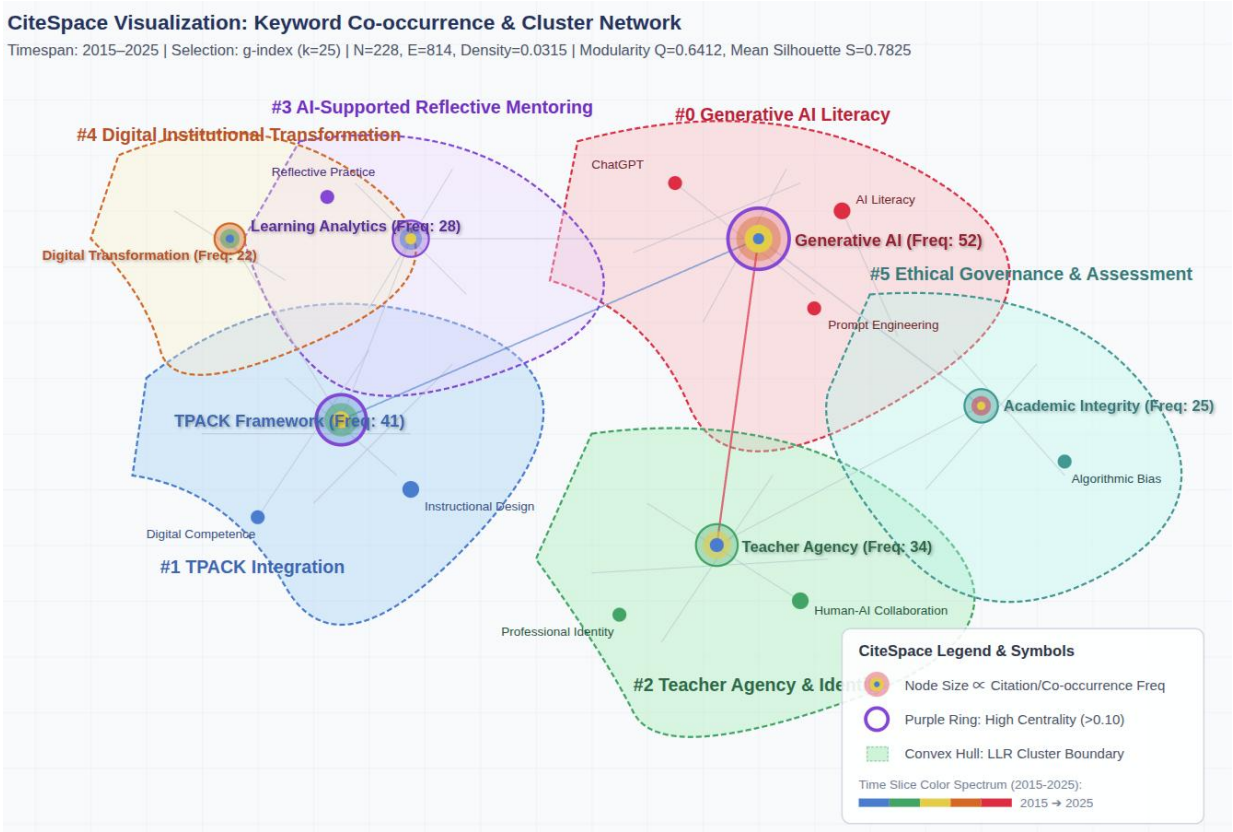

Figure 1. Keyword Co-occurrence and Cluster Network

4.3 Temporal Evolution and Emerging Trends

To delineate the dynamic intellectual trajectories and emerging research fronts of AI-empowered TPD in higher education over time, a CiteSpace timeline visualization (Figure 2) and Kleinberg's burst detection algorithm were applied to the bibliographic dataset (2015–2025). The timeline view arranges nodes chronologically along horizontal cluster axes, revealing both the historical progression within individual thematic domains and the cross-cluster knowledge diffusion over time.

As illustrated by the temporal distribution and cluster continuity, the intellectual evolution of the field can be divided into three key developmental phases:

Phase I: Exploratory Digital Skill Acquisition (2015–2019)

During this initial period, scholarly output was sparse, and research was structurally anchored in **Cluster #1 (TPACK Integration)** and **Cluster #4 (Digital Institutional Transformation)**. Keywords with early origins included *digital competence*, *ICT integration*, *e-learning*, *faculty training*, and *educational technology*.

The primary objective during this phase was helping university educators transition from traditional instruction to basic blended/online environments. Technology was largely viewed as an auxiliary, external tool. Professional development initiatives primarily relied on top-down, workshop-style training aimed at overcoming faculty technology resistance and building fundamental technical familiarity.

Phase II: Data-Informed Pedagogical Analytics (2020–2022)

Accelerated by the global shift toward remote and hybrid instruction, research focus transitioned toward **Cluster #3 (AI-Supported Reflective Mentoring)** and early learning analytics frameworks. Dominant keywords emerging during this period included *learning analytics*, *predictive dashboards*, *formative assessment*, *reflective practice*, and *online mentoring*.

In this phase, the role of technology in TPD evolved from static tool usage to data-driven instructional feedback. Educators were encouraged to interpret student learning behavior data from LMS dashboards to adjust their teaching strategies. However, AI applications remained mostly diagnostic and analytical rather than generative or co-creative.

Phase III: Generative AI & Agency-Driven Co-Design (2023–2025)

The release of accessible large language models (LLMs) triggered a dramatic structural expansion in **Cluster #0 (Generative AI Literacy)**, **Cluster #2 (Teacher Agency & Identity)**, and **Cluster #5 (Ethical Governance)**. High-density keyword nodes rapidly emerged, including *generative AI*, *ChatGPT*, *prompt engineering*, *AI literacy*, *human-AI collaboration*, *academic integrity*, and *teacher agency*.

This current phase marks a fundamental paradigm shift: faculty are no longer merely technology users or data consumers, but active evaluators and co-designers alongside generative AI systems. TPD interventions now emphasize fostering critical AI literacy, ethical judgment, and pedagogical adaptation within specific disciplinary contexts.

Burst Detection and Emerging Research Fronts

To further pinpoint the cutting-edge research fronts and active areas of scholar focus, Kleinberg's burst detection algorithm ($\gamma = 0.5$) was applied to keyword co-occurrence frequencies. Table 3 presents the top keywords with the strongest citation bursts, detailing their strength, start year, and end year.

As indicated by the burst duration and ongoing activity through 2025, three primary emerging trends characterize the current and future trajectory of research in AI-empowered TPD:

Shift from Technological Compliance to Human-AI Pedagogical Agency: The sharp rise of *Teacher Agency* (burst strength: 3.18) signifies a shift away from passive faculty compliance with institutional technologies toward actively asserting professional autonomy. Scholars are increasingly examining how teachers evaluate, critique, and selectively adapt AI recommendations rather than relying blindly on automated outputs.

Institutionalization of Multi-dimensional AI Literacy: The intense bursts for *Generative AI* (5.82) and *AI Literacy* (4.21) highlight that AI training is no longer viewed as an optional elective for tech-savvy faculty. Future TPD research is focused on constructing multi-level frameworks that balance technical understanding, prompt design, critical evaluation, and ethical compliance across different academic disciplines.

Refinement of Ethical Assessment Governance: As GenAI tools become embedded in daily academic tasks, research attention has shifted toward equipping faculty with practical strategies for assessment reform, authentic evaluation, and academic integrity management under AI-rich instructional paradigms.

4.4 Integrated Discussion and Implications

The scientometric mapping of research on AI-empowered Teacher Professional Development (TPD) in higher education between 2015 and 2025 provides an empirical foundation for understanding how the domain has evolved from isolated technical experiments to a systemic, agency-driven research front. Integrating the co-occurrence, clustering, and temporal burst findings reveals profound shifts in theoretical paradigms, persistent empirical gaps, and crucial implications for university leadership and educational policymakers.

4.4.1 Synthesis of Paradigm Shifts: From Instrumental Tool-Use to Human-AI Co-Agency

The cross-cluster and temporal analysis illustrates a fundamental paradigm shift in how TPD conceptualizes artificial intelligence:

Evolution Beyond the Classic TPACK Framework: Early literature (2015–2019) relied heavily on the traditional Technological Pedagogical Content Knowledge (TPACK) model (Mishra & Koehler, 2006), positioning technology as a third, external knowledge domain to be integrated into teaching. However, as demonstrated by the recent explosion of Cluster #0 (*Generative AI Literacy*) and the burst in *Generative AI* (strength: 5.82), generative and agentic AI systems do not merely act as instructional delivery tools. They operate as semi-autonomous pedagogical partners capable of content creation, dynamic feedback, and assessment generation. Consequently, modern scholarship is extending TPACK toward "AI-TPACK" or "GenAI Literacy" frameworks (Celik, 2023; Chiu, 2023), requiring educators to develop critical algorithmic reasoning and prompt engineering abilities alongside traditional pedagogical knowledge.

Re-Centering Teacher Agency in Automated Environments: The high burst strength of *Teacher Agency* (3.18, 2022–2025) in Cluster #2 highlights a critical reaction against automated instructional determinism. Rather than viewing AI as a replacement for faculty expertise or a rigid administrative compliance mechanism, contemporary literature emphasizes faculty autonomy. TPD is increasingly framed as a vehicle to empower educators as critical evaluators—enabling them to question algorithmic outputs, adapt AI tools to specific disciplinary cultures, and co-design learning environments alongside automated systems without sacrificing their pedagogical identity (Selwyn, 2019; Bozkurt, 2023).

4.4.2 Critical Empirical Gaps and Current Research Challenges

Despite the rapid surge in publication volume after 2023, the integrated synthesis highlights three primary structural limitations in the current body of literature:

Methodological Predominance of Short-Term Case Studies: The majority of post-2023 literature on Generative AI in TPD consists of exploratory, cross-sectional surveys, conceptual frameworks, or brief intervention workshops. There remains a notable lack of rigorous, longitudinal designs that track the long-term transfer of AI-empowered TPD into sustained classroom pedagogical changes and actual student learning outcomes.

Under-Theorized Disciplinary Nuance: Current TPD initiatives frequently treat "faculty" as a monolithic group. However, the pedagogical integration of AI varies drastically across disciplines (e.g., STEM computational labs vs. humanities essay-based assessments). The literature currently lacks tailored TPD frameworks that address domain-specific epistemologies and assessment norms.

Overlooking Psychological Workload and Ethics: While Cluster #5 (*Ethical Governance*) addresses academic integrity and data privacy, fewer empirical studies examine the affective and operational burdens placed on faculty. The expectation to continuously adapt to rapid AI updates, reform course structures, and monitor algorithmic integrity risks exacerbating faculty burnout, tech-anxiety, and digital fatigue.

4.4.3 Practical and Policy Implications

The findings provide actionable guidance for higher education administrators, centers for teaching and learning (CTLs), and educational policymakers:

Shift from One-Off Workshops to Ecosystemic Learning Communities: Academic leadership must move away from sporadic, tool-centric training workshops. Instead, institutional investment should focus on creating continuous Professional Learning Communities (PLCs) where faculty can experiment, share discipline-specific prompts, and critically reflect on human-AI co-teaching outcomes.

Institutional Recognition and Workload Compensation: For AI-empowered TPD to be sustainable, higher education institutions must align professional development with academic reward structures. Reorganizing syllabi, designing authentic assessments, and acquiring AI literacy require substantial time; institutions should grant workload relief, instructional design support, or teaching innovation grants to pioneering faculty.

Proactive Ethical and Assessment Governance: Rather than adopting reactive policies that ban AI tools, institutional policy must empower teachers to lead assessment reform. TPD programs should equip educators with strategies for authentic assessment (e.g., viva voce, process-based portfolios, collaborative problem-solving) that build on student AI interaction rather than fighting algorithmic use.

5. CONCLUSION

This study conducted a comprehensive scientometric mapping of research on AI-empowered Teacher Professional Development (TPD) in higher education between 2015 and 2025 using CiteSpace 7.0.1. By quantitatively analyzing 215 peer-reviewed publications from the Web of Science Core Collection, this investigation delineated the global publication growth, collaborative research networks, core domain hotspots, temporal evolutionary stages, and emerging research fronts.

The empirical findings provide definitive answers to the research questions established at the outset:

Growth Dynamics and Global Collaboration Networks (RQ1): Research output in AI-empowered TPD experienced a monumental surge following the widespread introduction of generative AI in 2023, with publications from 2024 and 2025 accounting for nearly four-fifths (79.1%) of the total decade-long volume. Global scholarship is primarily anchored by the People's Republic of China and the United States—both exhibiting high publication counts and strategic betweenness centrality—supported by key contributions from Spain, the United Kingdom, and Australia. However, international institutional collaboration networks remain fragmented, indicating a need for broader cross-border, multi-institutional research consortia.

Intellectual Structure and Core Hotspots (RQ2): Keyword co-occurrence and Log-Likelihood Ratio (LLR) clustering identified six robust, well-defined research hotspots defining the intellectual landscape: *Generative AI Literacy* (Cluster #0), *TPACK Integration* (Cluster #1), *Teacher Agency & Identity* (Cluster #2), *AI-Supported Reflective Mentoring* (Cluster #3), *Digital Institutional Transformation* (Cluster #4), and *Ethical Governance & Assessment* (Cluster #5). These clusters reflect a complex, multi-layered domain encompassing individual faculty competencies, technological platforms, psychological constructs, and macro-level institutional policies.

Temporal Evolution and Emerging Fronts (RQ3): Temporal timeline and citation burst analyses revealed a clear three-phase evolutionary path over the past decade: transitioning from *Exploratory Digital Skill Acquisition* (2015–2019) through *Data-Informed Pedagogical Analytics* (2020–2022) to *Generative AI & Agency-Driven Co-Design* (2023–2025). The strongest active citation bursts—led by *Generative AI* (5.82), *AI Literacy* (4.21), and *Teacher Agency* (3.18)—confirm that the active research front centers on fostering human-AI collaborative agency, re-aligning authentic assessment strategies, and embedding critical AI literacy across higher education institutions.

Limitations and Future Research Directions

While this study offers valuable, data-driven insights into the knowledge domain, certain limitations inherent to scientometric methodologies should be noted:

Database Scope: Data were retrieved exclusively from the Web of Science Core Collection to ensure citation link consistency and high record quality. Future studies could integrate records from Scopus, IEEE Xplore, or CNKI to broaden geographic and multi-lingual coverage.

Methodological Synthesis: Visual scientometrics provides structural breadth but benefits from qualitative synthesis. Future work should combine mapping techniques with systematic literature reviews or meta-analyses to evaluate the pedagogical efficacy of specific TPD interventions.

To advance the field, future empirical research should prioritize:

Longitudinal Impact Designs: Moving beyond short-term workshop evaluations to conduct multi-year longitudinal studies tracking how AI-empowered TPD influences faculty practice, curricular sustainability, and student learning outcomes.

Discipline-Specific TPD Models: Formulating tailored TPD frameworks that address unique epistemological, lab-based, or essay-based assessment cultures across STEM, humanities, and professional degrees.

Faculty Well-being and Affective Dimensions: Investigating the operational, psychological, and workload impacts of continuous AI adoption to design TPD programs that protect faculty autonomy and mitigate tech-induced burnout.

In summary, AI is no longer merely a subject of technological integration in higher education; it is reshaping the core nature of academic work. Fostering a future-ready higher education ecosystem demands TPD models that empower university teachers not as passive technology consumers, but as critical, agency-driven, and ethically grounded leaders of AI-empowered pedagogy.

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