JURNAL ILMIAH EKONOMI DAN MANAJEMEN INDONESIA

eISSN3124-2197 & pISSN3124-2227

Vol. 2, No. 2, 2026
doi.org/10.63822/3knvef92
PP. 5399-5417

Transforming Teacher Competencies in the Era of Generative Artificial Intelligence: Mapping the Research Landscape and Future Research Agenda

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Received: 11 01, 2026 | Accepted: 11 05, 2026 | Published: 11 07, 2026

ABSTRACT

The rapid development of Generative Artificial Intelligence (GenAI) has reshaped educational practices and created new demands for teachers' professional competencies. This study aims to map the global research landscape on teacher competency transformation in the GenAI era through a bibliometric analysis of Scopus-indexed publications. A total of 383 open-access journal articles published between 2023 and 2026 were analysed using performance analysis and science mapping with VOSviewer version 1.6.21. The findings reveal a substantial increase in scientific publications, with approximately 89.3% published in 2025–2026. China emerged as the leading contributor, while Indonesia ranked fifth. The research landscape is primarily structured around artificial intelligence, AI literacy, professional development, teacher training, digital competence, and AI in education. Thematic evolution indicates a shift from foundational discussions of AI literacy and professional development toward empirical investigations of technology acceptance, behavioral intention, decision-making, and academic integrity. The findings highlight the need for comprehensive teacher competency frameworks, effective continuous professional development, and stronger institutional governance to support responsible AI integration. This study contributes to understanding the intellectual development and emerging priorities of research on teacher competencies in AI-enhanced educational environments.

Keywords: *Generative Artificial Intelligence; Teacher Competencies; AI Literacy; Professional Development; Bibliometric Analysis.*

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How to Cite:

Hadinata, M. . (2026). Transforming Teacher Competencies in the Era of Generative Artificial Intelligence: Mapping the Research Landscape and Future Research Agenda. Jurnal Ilmiah Ekonomi Dan Manajemen Indonesia, 2(2), 5399-5417. https://doi.org/10.63822/3knvef92

INTRODUCTION

The rapid advancement of Generative Artificial Intelligence (GenAI) has fundamentally transformed educational ecosystems, reshaping how knowledge is created, accessed, and disseminated across all levels of education. Since the public release of large language models such as ChatGPT in late 2022, educators have encountered unprecedented opportunities to redesign teaching practices while simultaneously facing new pedagogical, ethical, and professional challenges. Unlike earlier forms of educational technology, GenAI possesses the capability to generate human-like text, images, code, and instructional materials, enabling teachers to automate routine tasks, personalize learning experiences, support assessment, and facilitate collaborative knowledge construction. Consequently, GenAI has shifted educational discourse from the mere adoption of digital technologies toward the reconfiguration of teachers' professional roles within AI-enhanced learning environments (Kasneci et al., 2023; Tlili et al., 2023).

The transformative influence of GenAI extends beyond instructional efficiency to the very nature of teacher competence. Contemporary educational systems increasingly expect teachers not only to possess digital competence but also to demonstrate AI literacy, ethical judgment, critical evaluation of AI-generated content, prompt engineering skills, and the ability to design pedagogically meaningful interactions between learners and intelligent systems. These expectations signify a paradigm shift from technology integration toward AI-responsive professional competence, where teachers act as designers, facilitators, evaluators, and ethical mediators of AI-supported learning (Qi et al., 2026; Redecker, 2017). Recent empirical studies further indicate that successful implementation of GenAI depends heavily on teachers' AI competencies, self-efficacy, technology acceptance, and continuous professional development rather than on technological availability alone.

Consequently, scholarly interest in teacher competencies related to GenAI has expanded rapidly over the past three years. Research has investigated diverse themes, including AI literacy, digital competence, teacher attitudes, technology acceptance, ethical concerns, assessment practices, instructional design, professional learning, and curriculum transformation. The literature has also diversified across educational contexts, ranging from K–12 education and teacher education to higher education and lifelong learning. Nevertheless, this rapid expansion has resulted in a fragmented body of knowledge dispersed across multiple disciplines, including education, computer science, psychology, educational technology, and management. While individual studies provide valuable insights into specific aspects of teacher competence, the overall intellectual structure, thematic evolution, collaborative networks, and emerging research directions remain insufficiently synthesized.

Several review studies have attempted to summarize the educational implications of GenAI; however, most have focused broadly on AI applications in education, ChatGPT adoption, or digital transformation rather than specifically examining the evolution of teacher competencies. Likewise, existing bibliometric studies generally emphasize artificial intelligence in education as a whole or teacher digital competence without comprehensively analysing how teacher competencies have evolved in response to the emergence of GenAI. As a result, there remains limited understanding of who the leading contributors are, which institutions and countries drive the field, how conceptual themes are interconnected, and which research topics are emerging as future priorities. This gap limits the ability of researchers, policymakers,

and teacher educators to identify mature research areas, recognize underexplored themes, and formulate evidence-informed agendas for teacher professional development in the age of GenAI.

Bibliometric analysis offers a rigorous and systematic approach for addressing these challenges by quantitatively mapping the development of scientific knowledge. Unlike traditional narrative reviews, bibliometric methods enable researchers to identify publication trends, influential journals, productive authors, institutional and international collaborations, conceptual structures, and thematic evolution through science mapping techniques such as co-occurrence analysis, co-authorship networks, overlay visualization, and density visualization. Such approaches have become increasingly important for understanding rapidly evolving interdisciplinary fields characterized by high publication growth and conceptual diversification. By revealing both established research domains and emerging frontiers, bibliometric analysis provides a robust evidence base for guiding future research and informing educational policy and practice.

Against this background, the present study aims to map the global research landscape on teacher competency transformation in the era of Generative Artificial Intelligence (GenAI) through a bibliometric analysis of Scopus-indexed publications published between 2023 and 2026. Specifically, this study seeks to: (1) analyse publication growth and research trends; (2) identify the most productive journals, authors, institutions, and countries, as well as the distribution of publications across disciplinary areas; and (3) examine the conceptual structure and thematic development of the field through keyword co-occurrence analysis using network and overlay visualizations. By integrating performance analysis with science mapping, this study provides an overview of the development, distribution, and thematic evolution of research on teacher competencies in the GenAI era. The findings are expected to contribute to a better understanding of current research priorities and identify potential directions for future studies on teacher competency development in AI-enhanced educational environments.

METHODS OF RESEARCH

Research Design

This study employed a bibliometric research design to systematically map the development of scholarly publications concerning teacher competency transformation in the era of Generative Artificial Intelligence (GenAI). Bibliometric analysis is widely recognized as a quantitative approach for evaluating the intellectual structure, knowledge evolution, and publication performance within a scientific domain through statistical analysis of bibliographic metadata (Donthu et al., 2021; Zupic & Čater, 2015). Unlike traditional literature reviews, bibliometric analysis enables researchers to identify publication trends, influential contributors, collaborative patterns, and conceptual structures through science mapping techniques. Accordingly, this study combined performance analysis and science mapping to provide a comprehensive overview of the research landscape and to identify future research directions.

Data Source

The bibliographic data were retrieved exclusively from the Scopus database because of its extensive coverage of peer-reviewed international journals across education, social sciences, computer science, and interdisciplinary research. Scopus has become one of the most frequently used databases in bibliometric studies due to its broad journal coverage, standardized indexing system, and high-quality metadata suitable for citation and network analyses (Martín-Martín et al., 2021). The data collection was conducted in August

2026, ensuring that all retrieved publications represented the status of the database at the time of data extraction.

Search Strategy

The search strategy was developed to comprehensively capture publications related to teacher competency transformation in the context of Generative Artificial Intelligence. The search query combined five conceptual domains using Boolean operators ("AND" and "OR"), namely: Generative Artificial Intelligence; Teacher Professional Development; AI Literacy; Digital Competence; AI in Education. The complete search query was as follows:

> ("Generative Artificial Intelligence" OR "Generative AI" OR ChatGPT OR "Large Language Model*" OR LLM*) AND ("Teacher Professional Development" OR "Professional Development" OR "Continuing Professional Development" OR CPD OR "Teacher Learning" OR "Professional Learning") AND ("AI Literacy" OR "Artificial Intelligence Literacy" OR "AI Competenc*") AND ("Digital Competenc*" OR "Digital Literacy" OR "Digital Skill*" OR DigComp) AND ("AI in Education" OR "Artificial Intelligence in Education" OR AIED OR "Educational AI" OR "AI-assisted Learning")

The initial search identified 922 documents indexed in Scopus. To ensure consistency and relevance, several inclusion criteria were subsequently applied. Publications were limited to: Publication years: 2023–2026; Document type: Article; Source type: Journal; Language: English; Publication stage: Final; Open access status: All Open Access. After applying these criteria, the final dataset consisted of 383 journal articles, which constituted the basis for subsequent bibliometric analyses.

Data Analysis

The analysis consisted of two complementary stages: performance analysis and science mapping. The performance analysis examined the productivity characteristics of the retrieved publications, including: annual publication trends; leading journals (sources); productive authors; institutional affiliations; contributing countries/territories; and subject areas.

These descriptive indicators provide an overview of the growth and distribution of scientific production within the research field. The science mapping analysis was conducted using VOSviewer version 1.6.21 (van Eck & Waltman, 2010). VOSviewer is a widely used software application for constructing and visualizing bibliometric networks. The software applies the Visualization of Similarities (VOS) mapping technique to reveal relationships among bibliographic entities.

Specifically, this study employed keyword co-occurrence analysis based on Author Keywords to identify the conceptual structure of the research domain. Two visualization techniques generated by VOSviewer were analysed: Network Visualization, to identify thematic clusters and conceptual relationships among keywords; and Overlay Visualization, to examine the temporal evolution and citation patterns of research themes. The interpretation of these visualizations enabled the identification of major research themes, thematic evolution, conceptual linkages, and potential research gaps, thereby supporting the formulation of a future research agenda.

Research Workflow

The overall research procedure consisted of five sequential stages. First, identification of relevant publications through a structured Boolean search in Scopus. Second, application of inclusion criteria to refine the dataset. Third, export of bibliographic metadata in CSV format. Fourth, performance analysis of publication characteristics. Fifth, science mapping using VOSviewer version 1.6.21 to construct keyword networks and identify future research directions. The overall workflow of the bibliometric analysis is illustrated in **Figure 1**.

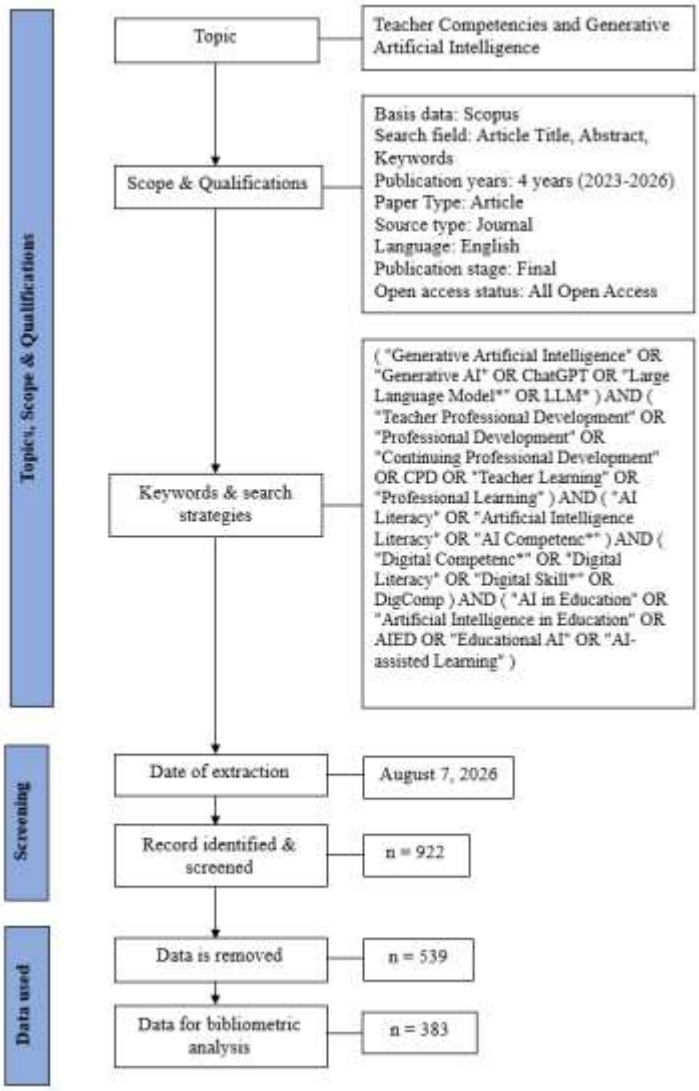


Figure 1. Search strategy flowchart

Figure 1 illustrates the systematic workflow employed to identify, select, and analyse the literature included in this bibliometric study. The process began with a structured search of the Scopus database using a Boolean query, which initially retrieved 922 publications related to Generative Artificial Intelligence,

teacher professional development, AI literacy, digital competence, and AI in education. Subsequently, predefined inclusion criteria were applied to ensure the relevance and consistency of the dataset. These criteria restricted the records to journal articles published in English, classified as final publications, indexed as open access, and published between 2023 and 2026. Following the screening process, 383 eligible articles remained and constituted the final dataset for analysis. The selected publications were examined using two complementary bibliometric approaches: performance analysis and science mapping. Performance analysis examined publication growth and research characteristics, including annual publication trends, leading journals, authors, institutional affiliations, contributing countries, and subject areas. Meanwhile, science mapping was conducted using VOSviewer version 1.6.21 to examine the conceptual structure and thematic development of the research field through keyword co-occurrence analysis, employing network and overlay visualizations. The integration of these approaches provided an overview of the global research landscape, highlighting publication patterns, major research themes, conceptual relationships, and the thematic evolution of research on teacher competency transformation in the era of Generative Artificial Intelligence.

Inclusion Criteria

To ensure the transparency and reproducibility of the bibliometric analysis, clear inclusion criteria were established for selecting the dataset. The criteria defined the scope of the search, publication characteristics, and analytical procedures to ensure that only high-quality and relevant publications were included. The complete inclusion criteria applied in this study are presented in **Table 1**.

Table 1. Inclusion Criteria for the Bibliometric Analysis

Criteria	Specification
Database	Scopus
Search Period	August 2026
Publication Years	2023–2026
Initial Records	922
Final Dataset	383
Language	English
Document Type	Article
Source Type	Journal
Publication Stage	Final
Open Access	All Open Access
Analysis Software	VOSviewer 1.6.21
Analysis Technique	Performance Analysis & Science Mapping

As shown in Table 1, the bibliometric dataset was retrieved exclusively from the Scopus database in August 2026. An initial search identified 922 records, which were subsequently refined using predefined inclusion criteria, including publication years (2023–2026), journal articles, English language, final publication stage, and open-access status. After applying these criteria, 383 articles were retained for analysis. The dataset was then examined using VOSviewer version 1.6.21 through a combination of performance analysis and science mapping, providing a comprehensive overview of publication

productivity, influential contributors, collaboration patterns, and the intellectual structure of research on teacher competency transformation in the era of Generative Artificial Intelligence.

RESULT AND DISCUSSION

This section presents the findings of the bibliometric analysis and discusses the research landscape of teacher competency transformation in the era of Generative Artificial Intelligence (GenAI). The analysis is organized into two complementary perspectives. First, performance analysis examines the growth and distribution of scientific publications by analysing annual publication trends, leading journals, productive authors, institutional affiliations, contributing countries, and subject areas. These indicators provide an overview of publication productivity, research development, and the geographical and disciplinary distribution of studies in this field. Second, science mapping analysis explores the conceptual structure and thematic development of the literature using VOSviewer version 1.6.21. Through Author Keyword co-occurrence analysis, supported by network and overlay visualizations, this analysis identifies major research themes, relationships among keywords, and changes in research focus over time. The integration of these two analytical approaches provides an overview of the development and thematic evolution of research on teacher competencies in response to the advancement of Generative Artificial Intelligence, while highlighting potential directions for further research.

The discussion does not merely describe bibliometric indicators but also interprets their implications for the development of knowledge in this emerging field. By linking publication performance with conceptual structures, this study seeks to reveal how scholarly attention has shifted from the adoption of digital technologies toward the transformation of teachers' professional competencies, including AI literacy, digital competence, pedagogical innovation, and continuous professional development. Consequently, the findings presented in this section contribute not only to understanding the current state of research but also to identifying knowledge gaps and promising avenues for future investigations aimed at supporting sustainable teacher competency development in AI-enhanced educational environments.

Growth Trajectory of Scientific Publications

To provide an overview of the temporal development of research on teacher competency transformation in the era of Generative Artificial Intelligence, publication trends were first analyzed based on the annual distribution of documents indexed in Scopus. Examining publication output over time helps identify the growth trajectory of the field, reveals periods of accelerated scholarly attention, and reflects the increasing academic interest in integrating Generative AI into teacher professional development. The annual publication trend is presented in **Figure 2**.

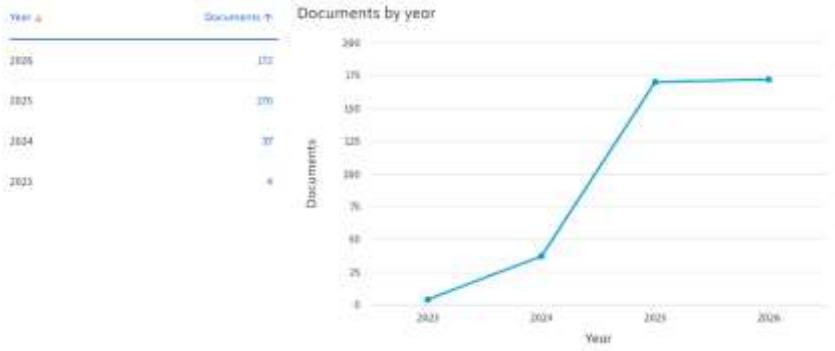


Figure 2. Annual Publication Trends on Teacher Competency Transformation in the Era of Generative Artificial Intelligence (2023–2026)

The annual publication trends reveal a substantial increase in research on teacher competency transformation in the era of Generative Artificial Intelligence (GenAI) during 2023–2026. Of the 383 articles analyzed, publications increased from 4 (1.0%) in 2023 to 37 (9.7%) in 2024, followed by a sharp rise to 170 (44.4%) in 2025 and 172 (44.9%) in 2026. Notably, approximately 89.3% of the publications appeared during 2025–2026, indicating rapidly accelerating scholarly interest in this emerging research field. This growth reflects the expanding academic focus on AI literacy, digital competence, teacher professional development, ethical AI integration, and pedagogical adaptation. The findings suggest that research has shifted beyond the technological adoption of AI toward a broader examination of the professional competencies required for teachers to navigate AI-driven educational environments. Nevertheless, the field remains relatively young, highlighting the need for further empirical and longitudinal studies, comprehensive AI competency frameworks, and sustainable professional development models to support responsible and effective GenAI integration in education.

Leading Publication Sources

Beyond examining the annual growth of publications, it is also important to identify the journals that have made the greatest contribution to advancing research on teacher competency transformation in the era of Generative Artificial Intelligence. An analysis of publications by source provides insights into the leading publication outlets, their productivity over time, and the extent to which they have shaped the development of this emerging research field. The distribution of documents by publication source and year is presented in **Figure 3**.

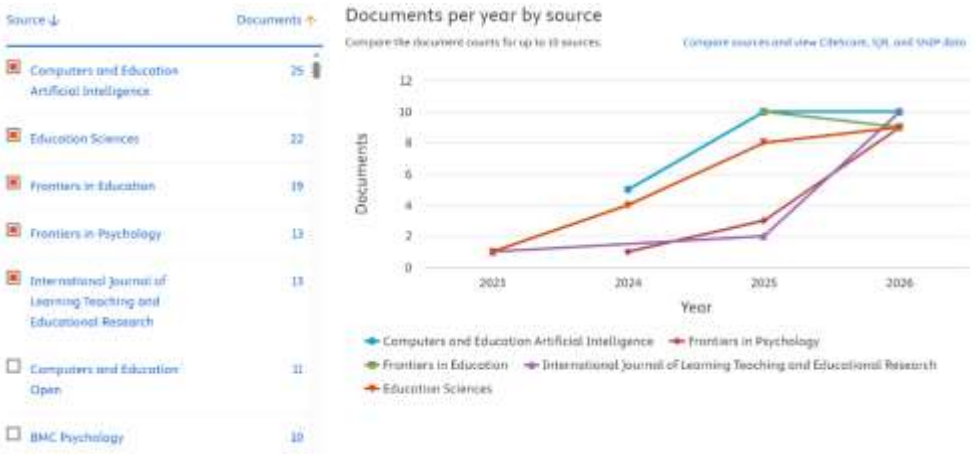


Figure 3. Annual Publication Distribution by Source (2023–2026)

The annual publication distribution across sources indicates that research on teacher competency transformation in the era of Generative Artificial Intelligence (GenAI) is increasingly disseminated through diverse international academic journals. Computers and Education: Artificial Intelligence leads with 25 publications, followed by Education Sciences (22), Frontiers in Education (19), Frontiers in Psychology (13), and the International Journal of Learning, Teaching and Educational Research (13). The temporal distribution reveals a marked increase in publication output during 2025–2026, with Computers and Education: Artificial Intelligence demonstrating relatively consistent productivity, while Frontiers in Psychology and the International Journal of Learning, Teaching and Educational Research exhibit substantial growth in 2026. This pattern reflects the expanding interdisciplinary character of the field, encompassing educational technology, pedagogical innovation, teacher professional development, and psychological dimensions of technology adoption. Overall, the findings suggest that scholarly attention has evolved beyond the functional application of GenAI toward a more comprehensive understanding of teacher competencies, particularly AI literacy, digital competence, pedagogical adaptation, self-efficacy, and ethical technology integration. The increasing contributions from journals across different disciplinary perspectives further highlight the importance of interdisciplinary research in developing adaptive, sustainable, and responsible teacher professional development frameworks in the era of Generative AI.

Most Productive Authors

In addition to identifying the most productive publication sources, examining author productivity provides valuable insights into the individuals who have made the greatest scholarly contributions to this research field. An analysis of documents by author highlights the leading researchers, reveals patterns of individual scientific productivity, and identifies influential contributors shaping the development of knowledge on teacher competency transformation in the era of Generative Artificial Intelligence. The distribution of publications by author is presented in **Figure 4**.

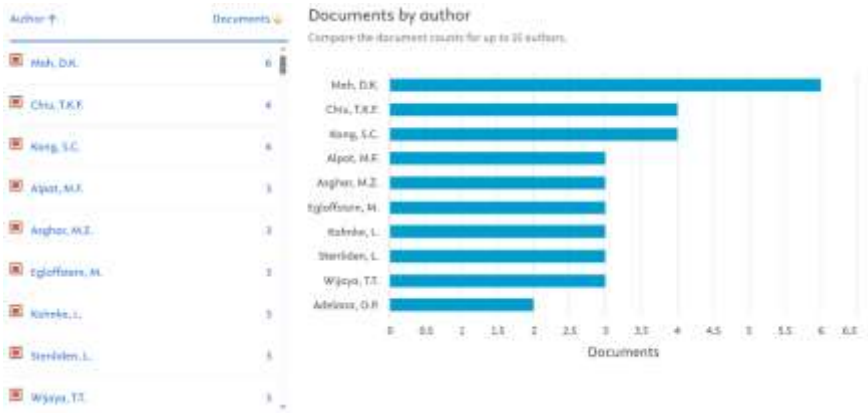


Figure 4. Documents by Author

The analysis of author productivity indicates that research on teacher competency transformation in the era of Generative Artificial Intelligence (GenAI) is still an emerging field, characterized by a relatively distributed pattern of scholarly contributions. Mah, D.K. ranks as the most productive author with six publications, followed by Chiu, T.K.F. and Kong, S.C. with four publications each. Meanwhile, Alpat, M.F., Asghar, M.Z., Egloffstein, M., Kohnke, L., Stenliden, L., and Wijaya, T.T. each contributed three publications, while Adelana, O.P. produced two. This distribution suggests that research productivity has not yet been concentrated among a small group of dominant scholars, reflecting the ongoing development of the field's conceptual and empirical foundations. The authors' research contributions encompass key themes such as AI literacy, digital competence, teacher professional development, technology acceptance, and the integration of ChatGPT and GenAI into education. These findings highlight considerable opportunities for strengthening international and interdisciplinary research collaboration to develop comprehensive teacher competency frameworks, validate AI-based professional development models, and establish a more integrated global research community capable of addressing the evolving demands of AI-driven education.

Leading Institutional Affiliations

Institutional productivity is another important indicator in bibliometric studies, as it reflects the organizational capacity to generate and disseminate scientific knowledge within a research field. Analyzing publications by affiliation helps identify the universities and research institutions that play leading roles in advancing studies on teacher competency transformation in the era of Generative Artificial Intelligence. This analysis also illustrates the geographical and institutional distribution of research activities, highlighting centers of excellence that contribute significantly to the development of AI-related educational research. The distribution of publications by institutional affiliation is presented in **Figure 5**.

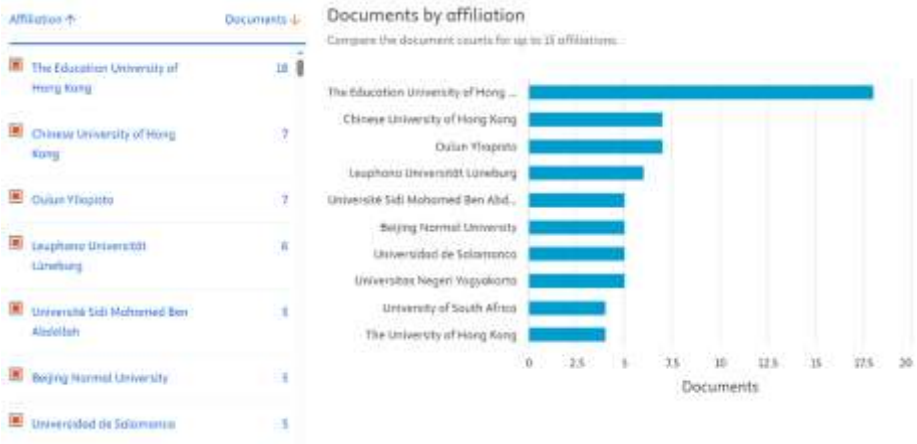


Figure 5. Documents by Affiliation

The analysis of publication output by affiliation reveals that research on teacher competency transformation in the era of Generative Artificial Intelligence (GenAI) is concentrated in several universities with strong research contributions in educational technology and innovation. The Education University of Hong Kong leads with 18 publications, followed by the Chinese University of Hong Kong and Oulun Yliopisto with seven publications each, and Leuphana Universität Lüneburg with six. Other notable contributors include Université Sidi Mohamed Ben Abdellah, Beijing Normal University, Universidad de Salamanca, and Yogyakarta State University, each with five publications. The geographical distribution reflects the growing global interest in GenAI-based teacher competencies, with significant contributions from institutions across Asia, Europe, and Africa. The prominence of Hong Kong institutions highlights their important role in advancing research on AI integration in education, while the participation of universities from developing countries demonstrates that this issue extends beyond technologically advanced nations. Nevertheless, the concentration of publications within a limited number of institutions suggests disparities in research capacity and institutional engagement. These findings underscore the importance of strengthening international research collaboration, expanding inter-institutional networks, and developing context-sensitive research initiatives to establish more inclusive, comprehensive, and sustainable frameworks for teacher competency development in the GenAI era.

Global Distribution of Scientific Publications

A country-level analysis provides important insights into the global distribution of scientific productivity and identifies the nations that have contributed most significantly to research on teacher competency transformation in the era of Generative Artificial Intelligence. Examining publications by country or territory reveals patterns of international research activity, highlights regional leadership in AI-enabled education, and reflects the geographical diffusion of scholarly interest in this rapidly evolving field. The distribution of publications by country or territory is presented in **Figure 6**.

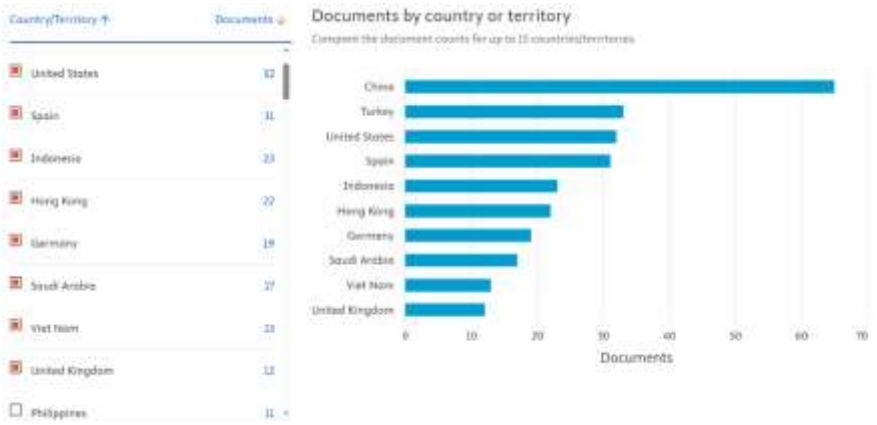


Figure 6. Documents by Country or Territory

The analysis of publications by country or territory reveals that research on teacher competency transformation in the era of Generative Artificial Intelligence (GenAI) has developed into a global research agenda, although scientific productivity remains concentrated in several countries. China leads with 65 publications, followed by Turkey (33), the United States (32), and Spain (31). Indonesia ranks fifth with 23 publications, followed by Hong Kong (22), Germany (19), Saudi Arabia (17), Viet Nam (13), and the United Kingdom (12). This distribution indicates that research on GenAI-based teacher competencies is no longer dominated exclusively by Western countries but increasingly involves diverse geographical regions, including developing economies. China's leading position reflects its prominent contribution to research on artificial intelligence and educational transformation, while Indonesia's presence among the five most productive countries demonstrates the growing participation of Indonesian scholars in the international discourse on AI integration in education. Overall, these findings highlight the importance of strengthening cross-national research collaboration, expanding international academic networks, and promoting knowledge exchange to develop teacher competency frameworks that are inclusive, context-sensitive, and sustainable across different educational systems.

Subject Area Distribution

In addition to identifying the geographical distribution of scientific productivity, it is important to examine the disciplinary composition of the literature to understand the breadth and diversity of research on teacher competency transformation in the era of Generative Artificial Intelligence. An analysis of publications by subject area reveals the academic disciplines that contribute most significantly to this field and illustrates the extent to which the topic has evolved into an interdisciplinary research domain. The distribution of publications across subject areas is presented in **Figure 7**.

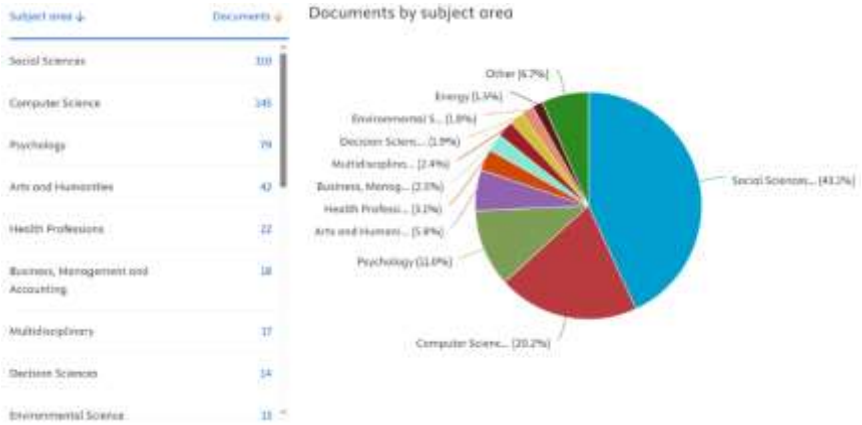


Figure 7. Documents by Subject Area

The analysis of publications by subject area reveals that research on teacher competency transformation in the era of Generative Artificial Intelligence (GenAI) is highly multidisciplinary, with Social Sciences dominating at 310 documents (43.1%), followed by Computer Science with 145 (20.2%) and Psychology with 79 (11.0%). These three disciplines account for more than 74% of the total publications, highlighting the intersection of educational transformation, technological innovation, and psychological factors in AI adoption. Other contributing fields include Arts and Humanities (5.8%), Health Professions (3.1%), Business, Management and Accounting (2.5%), Multidisciplinary (2.4%), Decision Sciences (1.9%), Environmental Science (1.8%), Energy (1.5%), and other areas (6.7%). This distribution indicates that teacher competency transformation is no longer exclusively a pedagogical concern but an increasingly complex issue involving technological, psychological, organizational, and societal dimensions. The prominence of Social Sciences reflects sustained scholarly attention to teacher professional development, educational policies, and pedagogical innovation, while contributions from Computer Science and Psychology emphasize the importance of AI integration, technological readiness, self-efficacy, motivation, and technology acceptance. Overall, these findings underscore the need for interdisciplinary research integrating pedagogical, technological, psychological, ethical, and organizational perspectives to develop comprehensive and adaptive teacher competency frameworks for sustainable education in the GenAI era.

Intellectual Structure of the Research Field

To examine the intellectual structure of the research field, a keyword co-occurrence network analysis was conducted using VOSviewer. Network visualization identifies the principal research themes, their interrelationships, and the conceptual clusters that constitute the knowledge base of teacher competency transformation in the era of Generative Artificial Intelligence. By mapping the frequency of keyword co-occurrence and the strength of their connections, this analysis provides insights into the dominant research topics and the overall organization of scholarly knowledge within the field. The resulting keyword co-occurrence network is presented in **Figure 8**.

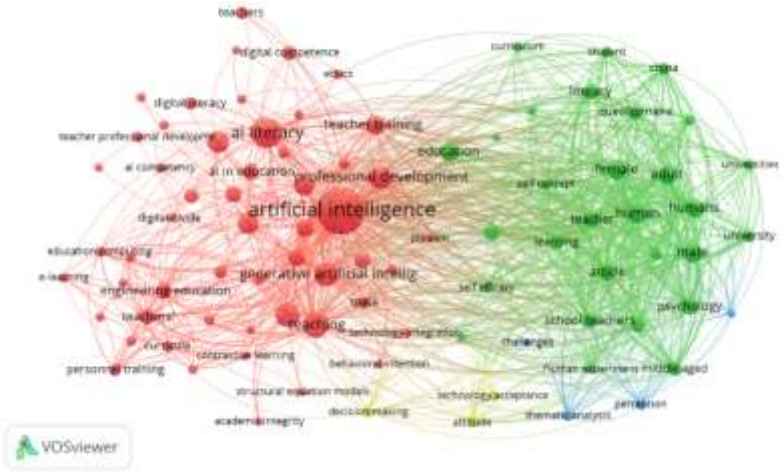


Figure 8. Network Visualization of Keyword Co-occurrence in Teacher Competency Transformation Research in the Era of Generative Artificial Intelligence (2023–2026**)**

The VOSviewer network visualization reveals that research on teacher competency transformation in the era of Generative Artificial Intelligence (GenAI) is structured around several interconnected thematic clusters, with artificial intelligence emerging as the largest and most central keyword. The red cluster primarily encompasses AI literacy, professional development, teaching, teacher training, Generative AI, and AI in education, highlighting the central research focus on developing teachers' competencies to integrate AI into educational practices. The strong connections among AI literacy, digital competence, and professional development indicate that AI-related knowledge and skills are increasingly recognized as essential dimensions of teachers' professional competencies. Meanwhile, the green cluster, comprising humans, teachers, school teachers, students, curriculum, literacy, and learning, reflects the emphasis on human-centered perspectives, particularly teachers' and students' experiences, perceptions, and readiness to adopt AI. The blue and yellow clusters further demonstrate growing scholarly interest in technology acceptance, attitudes, perceptions, psychological factors, and decision-making processes. Overall, the interconnected clusters illustrate the multidisciplinary nature of this research field, integrating educational, technological, psychological, and behavioral perspectives. Nevertheless, relatively underexplored areas, including AI-related educational leadership, institutional governance, long-term evaluation of professional development, and comprehensive teacher competency frameworks, represent important opportunities for future research. These findings suggest that research should move beyond technological adoption toward developing holistic, ethical, and sustainable models of teacher professional development that respond to the evolving demands of AI-enabled education.

Temporal Evolution of Research Themes

To further examine the temporal evolution of research themes, an overlay visualization based on the average publication year was generated using VOSviewer. Unlike the network visualization, which illustrates the structural relationships among keywords, the overlay visualization reveals when specific topics emerged and how the research focus has evolved over time. This analysis enables the identification of established themes as well as newly emerging research directions, providing valuable insights into the dynamic development of teacher competency transformation in the era of Generative Artificial Intelligence. The results are presented in **Figure 9**.

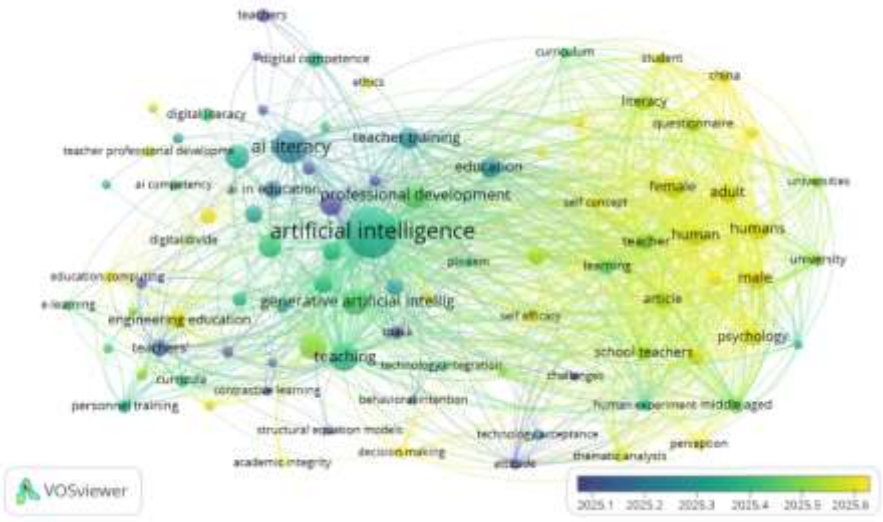


Figure 9. Overlay Visualization Based on Average Publication Year

The overlay visualization based on average publication year reveals the temporal evolution of research on teacher competency transformation in the era of Generative Artificial Intelligence (GenAI), highlighting a gradual shift from foundational themes toward more recent empirical and practical investigations. The earlier research themes, represented by purple–blue and greenish colors, primarily include artificial intelligence, AI literacy, professional development, teacher training, digital competence, and AI in education, indicating an initial scholarly focus on developing teachers' foundational competencies and integrating AI into educational practices. As the research landscape evolves, newer themes represented by yellow nodes, including technology acceptance, behavioral intention, decision-making, academic integrity, digital literacy, and engineering education, become increasingly prominent. This temporal development suggests that scholarly attention is expanding beyond the acquisition of AI-related competencies toward understanding the factors influencing the effective adoption and responsible implementation of GenAI in educational environments. The growing emphasis on technology acceptance, behavioral intention, and academic integrity further indicates a shift from exploring how AI can be used toward examining how it can be integrated effectively, ethically, and sustainably. These findings highlight important opportunities for future research, particularly in developing contextualized AI literacy frameworks, evaluating the effectiveness of continuous professional development programs, strengthening

AI governance and educational leadership, and formulating policies that support inclusive and responsible AI integration in education.

Citation Impact of Research Themes

Beyond illustrating the temporal evolution of research themes, it is equally important to examine their scientific impact. To achieve this, an overlay visualization based on average citations was generated using VOSviewer. This visualization highlights the relative citation impact of keywords by assigning colors according to the average number of citations received by publications associated with each keyword. Consequently, it enables the identification of research themes that have attracted the greatest scholarly attention and have exerted the strongest influence on the development of knowledge concerning teacher competency transformation in the era of Generative Artificial Intelligence. The results are presented in **Figure 10**.

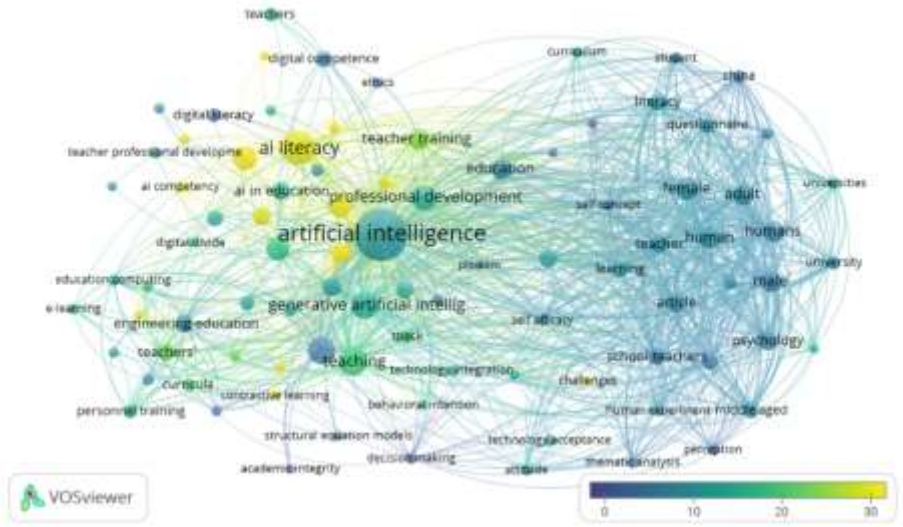


Figure 10. Overlay Visualization Based on Average Citations

The overlay visualization based on average citations illustrates the relative scientific impact of research themes concerning teacher competency transformation in the era of Generative Artificial Intelligence (GenAI). The yellow and greenish-yellow nodes, particularly AI literacy, professional development, teacher training, AI in education, and engineering education, indicate themes associated with higher average citation levels, highlighting their significance in shaping scholarly discussions on teacher competency development and AI integration in education. Although artificial intelligence remains the largest and most central keyword, its green coloration suggests an intermediate average citation impact. Meanwhile, keywords related to respondent characteristics and empirical studies, such as humans, male, female, adult, psychology, student, and questionnaire, tend to appear in blue or turquoise, indicating relatively lower average citation levels. This pattern does not necessarily imply lower research quality, as these themes may represent more specialized empirical investigations or recently published studies that

have had less time to accumulate citations. Similarly, generative artificial intelligence and teaching remain at an intermediate citation level, suggesting that their scholarly influence is still developing. Overall, the visualization indicates that research with relatively high citation impact is concentrated on AI literacy, teacher professional development, and AI integration in education, while empirical investigations of practical implementation, user behavior, and learning outcomes offer considerable opportunities for further scholarly contributions. Future research could therefore strengthen the connection between established conceptual frameworks and empirical evidence through longitudinal studies, evaluations of professional development effectiveness, and the development of context-sensitive teacher competency models applicable across diverse educational settings.

CONCLUSION

This study provides a bibliometric overview of 383 Scopus-indexed open-access articles published between 2023 and 2026, revealing the rapid growth and increasingly interdisciplinary nature of research on teacher competency transformation in the era of Generative Artificial Intelligence (GenAI). The findings show that scholarly attention is primarily concentrated on artificial intelligence, AI literacy, teacher professional development, teacher training, digital competence, and AI in education, with China emerging as the leading contributor and Indonesia ranking fifth. The science mapping analysis also indicates a thematic shift from foundational discussions of AI literacy and professional development toward empirical investigations of technology acceptance, behavioral intention, decision-making, and academic integrity, reflecting growing concerns about the effective and ethical implementation of GenAI in education. Despite this progress, further research is needed to develop and validate comprehensive teacher competency frameworks, evaluate the long-term effectiveness of professional development programs, and examine the roles of institutional leadership, governance, and educational context in AI integration. Overall, transforming teacher competencies requires more than access to AI tools; it demands continuous and holistic professional development that equips teachers to become critical users, innovative learning designers, and ethical facilitators of AI-enhanced education. Ultimately, the sustainable integration of GenAI into education depends not only on technological advancement but also on teachers' and educational institutions' capacity to use it meaningfully, responsibly, and effectively.

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