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Mapping Teacher Competence in AI-Integrated School Education: A Bibliometric Study (2021–2025)

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ABSTRACT

The rapid integration of Artificial Intelligence (AI) into education has redefined teacher competence, requiring not only technical proficiency but also pedagogical adaptability and ethical awareness. However, existing literature lacks a comprehensive synthesis connecting these dimensions within school-based education. This study employed a bibliometric analysis of 288 Scopus-indexed research articles published between 2021 and 2025. Data were retrieved via ScienceDirect and validated through Scopus. VOSviewer was used to conduct keyword co-occurrence analysis, applying full counting and LinLog/modularity clustering to identify dominant themes. Seventy-six high-frequency keywords were grouped into seven thematic clusters: (1) student outcomes and engagement, (2) teacher development and TPACK integration, (3) AI literacy and readiness, (4) pedagogical innovation and AI systems, (5) generative AI tools and trends, (6) curriculum design and early AI education, and (7) emotional intelligence and institutional support. Key frameworks included TPACK, UNESCO's AI Competency Framework, and self-efficacy models such as TAICS. Findings reveal a multidimensional structure connecting cognitive, affective, and institutional aspects of teacher competence. The study highlights the need for holistic teacher education programs that integrate AI literacy, ethical reasoning, emotional resilience, and contextual pedagogy. Implications are discussed for curriculum developers, policymakers, and professional development initiatives, particularly in emerging contexts like Indonesia.

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1. INTRODUCTION

In the ideal 21st-century classroom, teachers are not only content experts but also facilitators of adaptive, personalized, and technology-integrated learning environments. The rapid advancement of Artificial Intelligence (AI) is transforming this vision into reality by enabling intelligent tutoring

systems, personalized learning pathways, and data-driven instructional decisions (Chen et al., 2020; Holmes et al., 2019). However, this transformation also brings forth new expectations and challenges for teachers, who must now possess the competence to critically adopt and apply AI in pedagogical contexts. Teacher competence in AI integration defined as the intersection of knowledge, digital skills, ethical awareness, and pedagogical sensitivity has thus emerged as a critical research and policy concern (Koehler, 2006; Zawacki-Richter et al., 2019).

Several studies have explored the benefits and controversies surrounding AI in education. On one hand, AI is lauded for democratizing access to learning, supporting differentiated instruction, and enhancing student engagement (Luckin et al., 2016). On the other hand, critical scholars argue that the rise of algorithmic systems in classrooms may reinforce socio-technical bias, depersonalize teacher-student interactions, and widen equity gaps (Knox, 2020; Selwyn, 2019). The field is further complicated by the proliferation of various frameworks, such as the TPACK model (Koehler, 2006), which emphasizes the integration of technology, pedagogy, and content, and UNESCO's AI Competency Framework for Teachers (AI CFT), which advocates a human-centred and ethical approach to AI adoption in education (Miao et al., 2021).

Despite the availability of these conceptual frameworks, there remains a lack of integrative synthesis in the existing literature that connects technological, pedagogical, ethical, and emotional dimensions of teacher competence in AI-driven education. Previous research has often examined isolated aspects such as digital literacy, AI literacy, or professional development without explaining how these competencies interact to shape effective and ethical teaching practices in AI-supported classrooms (Chiu et al., 2025; Zeng et al., 2022). Furthermore, most studies emphasize higher education contexts, while research focusing on school-level implementation and teacher preparation remains limited (Ahmad Rahmatika & Emilda Sulasmi, 2025; Istiarsyah et al., 2024). This analytical gap hampers the field's ability to develop a unified understanding of how AI can be pedagogically and ethically integrated to enhance teacher professionalism and student learning.

To address this gap, the present study applies a bibliometric analysis an established method for uncovering the intellectual and thematic structure of a research domain through citation and keyword analysis (Van Eck & Waltman, 2010). Drawing on 288 Scopus-indexed articles published between 2021 and 2025, this study maps keyword co-occurrences to identify thematic clusters and conceptual relationships in the literature on teacher competence in AI-integrated school education. Specifically, this study aims to:

1. Identify dominant research themes and clusters within the discourse on AI and teacher competence;
2. Interpret interconnections between technological, pedagogical, and affective dimensions of AI integration; and
3. Offer implications for teacher education programs, professional development, and educational policy reform.

Recent studies reaffirm the urgency of this analysis. For example, Ogunleye et al. (2024) emphasize the growing role of AI in reshaping teacher preparation and curriculum innovation, while Guechairi (2024) identifies new competency demands arising from generative AI applications. In Indonesia, research by Istiarsyah et al. (2024) and Syamdani et al(2025) illustrates how AI adoption improves instructional design and evaluation yet reveals teachers' limited readiness for sustainable implementation. Together, these studies highlight the need for continuous professional learning frameworks that combine TPACK's pedagogical structure with AI CFT's ethical foundation.

The findings of this study are expected to contribute to a more integrated theoretical understanding of teacher competence in AI-enhanced education, while offering practical insights for policymakers and teacher education institutions. By synthesizing emerging global and local perspectives, the research emphasizes the urgency of developing hybrid models that align pedagogical clarity, ethical awareness, and contextual adaptability for effective and equitable AI-based teaching practices.

2. METHODS

This study employed a bibliometric analysis to map the intellectual and thematic structure of research on teacher competence in artificial intelligence (AI) within school-based education. Bibliometric methods allow systematic examination of the development, patterns, and conceptual relationships in scientific literature (Donthu et al., 2021).

2.1 Data Source and Search Strategy

Data retrieval was conducted in April 2025 using ScienceDirect as the search interface and Scopus as the bibliometric validation source. ScienceDirect was selected as the *initial search platform* because its full-text search capability returns broader and more sensitive early-stage results an approach frequently adopted in bibliometric studies. However, only articles verified as Scopus-indexed were included, ensuring the validity and compatibility of the dataset with VOSviewer and bibliometric standards.

The Boolean search query applied was:

Table 1. Boolean Search String

Component	Search Query
Initial search string	"teacher competence" AND "artificial intelligence" AND school
Database searched via interface	ScienceDirect (Elsevier)
Final indexing verification	Scopus-indexed only
Timespan	2021–2025
Document type	Article (research only)

The initial query on ScienceDirect yielded 1,743 records. After restricting the search to school-based educational contexts, 1,428 records remained. Refining document type to "article" (excluding editorials, conference papers, reviews, and book chapters) produced 1,066 articles.

2.2 Screening Procedures

Screening was conducted at the title level, a method commonly used in large-scale bibliometric research to ensure topical precision while maintaining feasibility (Donthu et al., 2021; Zupic & Čater, 2015). Two independent reviewers screened all records based on inclusion criteria:

- the title must explicitly address

a. teacher competence/readiness,
b. artificial intelligence or AI-related systems,
c. school-based educational settings (K–12, primary, secondary).

Inter-rater reliability analysis produced Cohen's Kappa = 0.86, indicating substantial agreement. Discrepancies were resolved through discussion. The final dataset comprised 288 Scopus-indexed articles.

2.3 Data Export and Bibliometric Analysis

All included articles were exported. RIS format and processed using VOSviewer (version 1.6.21). A co-occurrence analysis of author keywords was conducted to identify frequently occurring terms, thematic clusters, and interrelationships within the literature. The following parameters were applied:

Table 2. VOSviewer Configuration Parameters

Parameter	Specification
Counting method	Full counting
Minimum keyword occurrence	5
Type of analysis	Co-occurrence (author keywords)
Clustering technique	LinLog / Modularity
Visualization	Network, overlay, density maps

These settings allowed the identification of 76 high-frequency keywords and the generation of a bibliometric map representing seven major thematic clusters, which form the basis of the findings presented in Section 3.

2.4 Methodological Limitations

Several methodological considerations are acknowledged:

1. Title-only screening, while efficient, may exclude studies in which key concepts appear only in abstracts or full texts.
2. Using ScienceDirect as the search interface may yield initial records exceeding those found directly in Scopus; however, restricting inclusion to Scopus-indexed documents ensures bibliometric validity.
3. Full-text access limitations may affect manual verification of certain publications.
4. Keyword-based analysis may overlook conceptual nuances not captured in author keywords.

Despite these limitations, the methodological strategy aligns with best practices in bibliometric research and ensures a reproducible and transparent workflow.

3. FINDINGS AND DISCUSSION

This section presents the results of a bibliometric analysis using data extracted from 288 Scopus-indexed articles published between 2021 and 2025, focusing on the intersection of *teacher competence*, *artificial intelligence (AI)*, and *school education*. The analysis was conducted using VOSviewer, which identified 76 high-frequency keywords grouped into seven thematic clusters. These clusters reflect the prevailing focus areas and reveal how the literature has evolved in both technological and pedagogical dimensions.

All bibliometric patterns described in this section are based on the final Scopus-verified dataset. The clusters identified reflect results derived from a rigorously screened dataset independently reviewed by two coders (Cohen's Kappa = 0.86), ensuring high reliability in the inclusion of relevant publications. While the bibliometric map is constructed exclusively from empirical research articles, additional peer-reviewed conceptual and review studies are cited to contextualize and deepen the interpretation of each cluster.

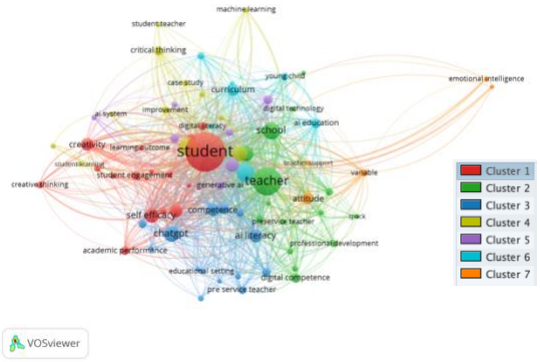

Figure 1. Visualization interrelationship of themes in the field of teacher competence, artificial intelligence, and school (https://tinyurl.com/2bsbve6q)

Figure 1, which is a bibliometric data visualization generated using VOSviewer, illustrates the interrelationship of themes in the field of *teacher competence*, *artificial intelligence*, and *school education*. The visualization is based on 288 Scopus-indexed articles published between 2021 and 2025. The analysis identified 76 frequently occurring keywords grouped into 7 clusters, with 1.324 total links and and total link strength 14.441 indicating the strength of co-occurrence relationships among items in the dataset. These 76 keywords met the minimum occurrence threshold of five, as specified in the VOSviewer configuration, and were clustered using the LinLog/modularity algorithm.

The clusters are as follows:

1. Cluster 1: academic performance; communication; creative thinking; creativity; digital literacy; further research; future research; higher education; instructional design; intrinsic motivation; learning outcome; self-efficacy; significant difference; student; student engagement; suggestion.
2. Cluster 2: digital competence; digital skill; digital technology; emotional engagement; ethic; framework; generative artificial intelligence; present study; preservice teacher; professional development; school; teacher; teacher educator; technology integration; TPACK.
3. Cluster 3: ability; AI literacy; AI technology; ChatGPT; competence; digital self-efficacy; educational practice; educational setting; practical implication; pre-service teacher; previous study; readiness; survey; teaching practice.
4. Cluster 4: AI assistance; AI system; case study; critical thinking; improvement; learning process; machine learning; pedagogical approach; skill; student learning; student teacher; teaching.
5. Cluster 5: AI tool; educator; generative AI; ICT; management education; pedagogy; trend.
6. Cluster 6: AI education; artificial intelligence; artificial intelligence education; computational thinking; curriculum; curriculum design; young child.
7. Cluster 7: attitude; big data; emotional intelligence; teacher support; variable.

Based on Figure 1, it is evident that the keyword "teacher" emerges as one of the most central and densely connected nodes, reaffirming its role as the thematic anchor in this field of study. The co-location of keywords such as *student*, *learning outcome*, and *academic performance* in Cluster 1 reflects strong research interest in how AI technologies affect student engagement and educational results.

Cluster 2 underscores the role of teacher professional development, digital competence, and the integration of models like TPACK, suggesting a strategic alignment of teacher training with emerging AI innovations. The appearance of ChatGPT and generative AI in Clusters 2 and 5 signals a growing shift toward analyzing how large language models are reshaping educational tools and practices.

Clusters 3 and 4 delve into teachers' AI readiness, digital self-efficacy, and the deployment of AI systems in real classroom contexts. Cluster 6 extends this to the curriculum level, particularly emphasizing early education and the incorporation of computational thinking and AI content. Finally, Cluster 7 reflects institutional and psychological dimensions such as attitude, teacher support, and emotional intelligence, which are increasingly recognized as influential variables in AI adoption.

The strength of associations between nodes represented by line thickness indicates the frequency and intensity of keyword co-occurrence in the literature. The greater the thickness, the stronger the thematic connection. This network visualization offers a structured overview for identifying dominant topics, emerging trends, and potential research gaps in AI-related teacher competence studies.

The following subsections provide a detailed explanation of each cluster. These analyses highlight the major themes, keyword relationships, and research directions that characterize the literature within each group. Understanding the nuances of each cluster is essential for interpreting the current knowledge landscape, identifying existing gaps, and proposing future pathways for AI-integrated teacher development.

These findings are consistent with previous studies that report a significant rise in interest and scholarly output related to the integration of AI in education. For example, Guechairi (2024) conducted a large-scale bibliometric study and found a notable publication spike in 2023, indicating an upward trend in AI-related educational research. Similarly, Zayimoglu Ozturk et al. (2025) highlighted the central role of teacher competence in addressing the pedagogical opportunities and technological challenges brought by AI. Ogunleye et al. (2024) further emphasized the growing relevance of generative AI in teaching practices, suggesting that understanding how educators engage with tools like ChatGPT is critical for shaping future instructional strategies.

These parallel findings reinforce the thematic clusters revealed in the present study, which collectively map the evolving discourse on teacher readiness, digital pedagogy, and AI-enhanced education.

3.1 Student Outcomes, Motivation, and Engagement

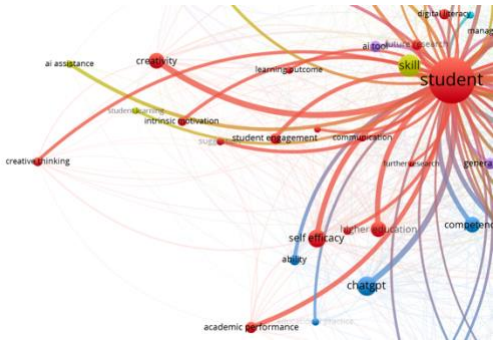

Figure 2. Cluster 1 Student Outcomes, Motivation, and Engagement

The title-screened dataset reveals a concentration of studies within this cluster, reflecting strong thematic coherence around student outcomes and learning engagement. Based on the VOSviewer visualization, Cluster 1 is centered around keywords such as *student*, *learning outcome*, *academic performance*, *creativity*, *student engagement*, and *self-efficacy*. This grouping indicates that a significant portion of the literature focuses on how AI technologies influence student-centered variables such as cognitive outcomes, motivation, and emotional engagement (Holmes et al., 2019; Luckin et al., 2016).

The strong co-occurrence of *creative thinking* and *instructional design* suggests that AI tools are increasingly used to foster higher-order thinking skills through adaptive and personalized learning systems. Pellas (2024) found that creativity significantly mediated the relationship between academic achievement and students' attitudes toward machine learning, while critical thinking and problem-solving served as significant moderators in the use of generative AI chatbots for learning.

In addition, the presence of keywords such as *digital literacy* and *intrinsic motivation* within this cluster points to the growing demand for learner-centered AI curricula that support autonomy, self-regulation, and empowerment through technology (Bandura, 1997; Voogt & McKenney, 2017). Hu et al. (2025) emphasize that while generative AI tools can initially stimulate high levels of cognitive engagement such as analysis and evaluation students may become increasingly passive without intentionally designed, sustained interactive structures that promote ongoing critical thinking.

Recent research by Pahi et al. (2024) on the collaboration between human teachers and generative AI highlights how positioning AI as a classroom co-facilitator rather than a mere source of answers can enhance students' active learning. Their study demonstrates that when AI tools are integrated as dialogic partners that provide feedback during in-class activities, they help sustain students' engagement in higher-order thinking processes such as reflection, analysis, and self-regulation. This supports the growing perspective that generative AI, when thoughtfully designed and pedagogically framed, can serve as an inquiry companion that fosters deeper metacognitive engagement. Massaty et al. (2024) through a systematic review, examined how AI technologies contribute to the development of computational thinking and self-efficacy in various educational contexts. They found that AI supports personalized learning, adaptive feedback, and student agency factors that align closely with the cognitive outcomes and motivational constructs in this cluster.

Overall, Cluster 1 reflects a growing scholarly consensus that the integration of AI in education must go beyond efficiency or automation; it must intentionally promote student agency, engagement, and the development of complex cognitive skills. At the same time, it also reveals a critical gap: without continuous instructional innovation and monitoring, AI tools may risk diminishing rather than enhancing deep learning engagement, which encompasses students' cognitive effort, active behavioral participation, and emotional investment in the learning process over time.

3.2 Teacher Development and Digital Competence

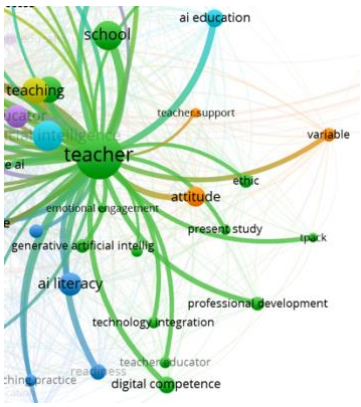

Figure 3. Cluster 2 Teacher Development and Digital Competence

The structure of this cluster reflects the modularity-based grouping generated through the LinLog layout in VOSviewer. Cluster 2 is defined by the keywords *teacher*, *professional development*, *TPACK*, *preservice teacher*, *school*, *digital competence*, and *technology integration*. This cluster underscores the importance of equipping educators with the necessary knowledge, digital skills, and pedagogical mindset to engage meaningfully with AI in classroom contexts. The frequent appearance of the TPACK framework Technological Pedagogical Content Knowledge reflects its widespread adoption as a conceptual foundation in teacher training programs aimed at digital transformation (Koehler, 2006).

However, while TPACK provides a strong foundation for general technology integration, it does not fully capture the competencies required for AI readiness. AI-specific teacher competence extends beyond technological literacy to include an understanding of data-driven systems, algorithmic reasoning, ethical awareness, and the ability to collaborate with intelligent technologies (Chiu et al.,

2025; Zawacki-Richter et al., 2019). This distinction is crucial, as teachers who master digital pedagogy may still lack the analytical and ethical fluency necessary to use AI responsibly in schools.

Recent studies have emphasized the complexity of preparing teachers for AI integration. Hava and Babayiğit (2025) revealed that while many teachers report high levels of digital proficiency, their competencies related to AI-specific TPACK remain relatively low. This gap suggests that digital literacy alone does not translate into readiness for AI-enhanced pedagogy, and targeted professional development programs are essential for bridging this divide.Yue et al. (2024) similarly found that although K–12 teachers often express positive attitudes toward AI education, their readiness to teach AI remains limited, underscoring the need for continuous training that merges technical knowledge with pedagogical and ethical reflection. In line with this, Runge et al. (2025) demonstrated that preservice teachers who had participated in AI-related teacher training courses showed significantly higher acceptance of AI tools and greater confidence in their classroom application.

Several emerging professional development (PD) models have attempted to address this gap. For instance, *AI teacher training initiatives in South Korea* have been shown to enhance educators' readiness for AI-integrated instruction through collaborative, practice-based approaches (Jik-Lee et al., 2024). Similarly, UNESCO's *AI Competency Framework for Teachers* emphasizes ethical decision-making and human-centered pedagogy (Miao & Cukurova, 2024). In Indonesia, national and local professional development initiatives such as digital literacy and AI introduction programs have begun to lay a foundation for teachers' digital competence (Fakhri et al., 2024). However, recent studies indicate that AI-specific content and ethical integration within teacher training remain limited, highlighting the need for more comprehensive AI-focused professional development models (Khosibah et al., 2025).

In addition, the presence of keywords such as *ethics* and *emotional engagement* in this cluster reflects growing attention to the affective and ethical dimensions of AI in education. This aligns with the human-centered orientation proposed by UNESCO's AI Competency Framework for Teachers, which emphasizes not only technical and pedagogical knowledge, but also the importance of developing critical awareness, empathy, and ethical judgment in the face of automated systems (Miao et al., 2021).

Together, the keywords and literature in this cluster highlight a multi-dimensional understanding of teacher competence one that integrates cognitive, technical, and affective capacities. This finding suggests that future research and policy should not only enhance teachers' digital skills but also foster professional identity and ethical reflection to support sustainable and responsible AI integration in schools.

3.3 Competence and AI Readiness

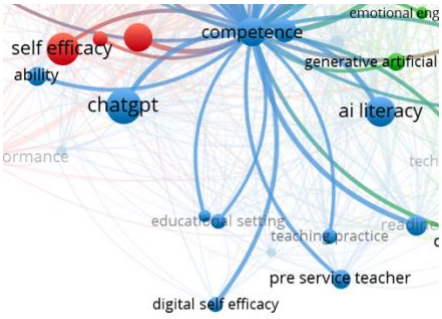

Figure 4. Cluster 3 *Competence and AI Readiness*

Cluster 3 is dominated by keywords such as *competence*, *AI literacy*, *readiness*, *digital self-efficacy*, and *teaching practice*. This cluster emphasizes the practical and psychological readiness of teachers to adopt AI-based tools in diverse educational settings. The strong link between *self-efficacy* and *educational practice* aligns with prior research that highlights confidence as a predictor of technology integration success (Zawacki-Richter et al., 2019; Zeng et al., 2022).

Recent studies have further explored these dynamics. For instance, a study by Yao an Wang (2024) found that digital literacy significantly impacts the self-efficacy of pre-service special education teachers, influencing their intention to use AI in education. This suggests that enhancing digital literacy can bolster teachers' confidence in integrating AI tools into their teaching practices.

Moreover, the development and validation of the Teacher Artificial Intelligence Competence Self-Efficacy (TAICS) scale by Chiu et al. (2025) provide a structured framework to assess teachers' AI competencies across various dimensions, including AI knowledge, pedagogy, assessment, ethics, human-centered education, and professional engagement. While the TAICS scale offers a robust and validated instrument, its development was situated primarily in East Asian contexts; therefore, future adaptations should incorporate local curriculum standards, digital access, and cultural attitudes to ensure contextual relevance in other regions, including Indonesia.

It is important to note that the majority of studies within this cluster originate from Asian countries, with a smaller proportion from European contexts. This geographical concentration reflects regions with more established AI education policies and teacher training infrastructures, which may limit the generalizability of findings to other parts of the world, particularly developing regions with differing levels of digital readiness and institutional support.

Finally, much of the existing research relies on self-reported data, as indicated by the prevalence of keywords such as *survey*, *pre-service teacher,* and *previous study.* Future investigations should include more classroom-based and longitudinal evidence to provide a comprehensive understanding of teachers' competence and readiness for AI integration.

3.4 Pedagogical Innovations and AI Systems

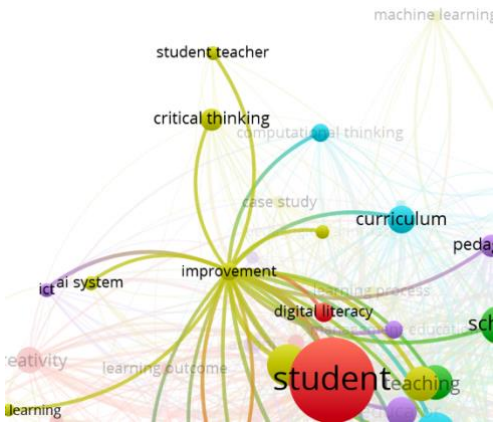

Figure 5. Cluster 4 *Pedagogical Innovations and AI Systems*

Cluster 4 is characterized by keywords such as *AI system*, *critical thinking*, *pedagogical approach*, *machine learning*, and *student learning*. This cluster underscores a growing research focus on leveraging AI to enhance pedagogical strategies and foster students' cognitive development.

Recent studies have demonstrated the potential of AI tools in promoting critical thinking skills among students. For instance, Lawasi et al. (2024) explored the use of AI in improving critical thinking skills among English Education students. Their findings indicated that while AI can aid in expanding ideas and providing deeper insights, its effectiveness largely depends on students' ability to critically interpret AI-generated content.

Furthermore, Melisa et al. (2025) investigated the impact of ChatGPT on developing critical thinking skills in higher education. The study revealed that while ChatGPT can enhance students' critical thinking by facilitating quick access to diverse perspectives, over-reliance on AI may hinder students' motivation for self-reflection and critical evaluation.

Similarly, Rios et al. (2025) through a systematic review, examined a range of AI-powered interventions aimed at fostering critical thinking skills. Their findings indicate that technologies such

as intelligent tutoring systems and machine learning algorithms can effectively promote critical thinking by delivering individualized feedback and assisting learners in evaluating arguments.

These findings suggest that while AI has the potential to enrich pedagogical approaches and improve student learning outcomes, it is imperative to integrate AI thoughtfully into educational settings. Educators should guide students in the responsible use of AI tools, ensuring that these technologies serve as facilitators of critical thinking rather than replacements for human judgment.

3.5 AI Tools and Technology Trends

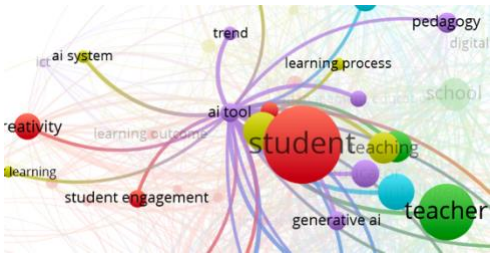

Figure 6. Cluster 5 *AI Tools and Technology Trends*

Cluster 5 includes terms such as *AI tool*, *ICT*, *generative AI*, *trend*, *pedagogy*, and *educator*. Although the frequency of these keywords is relatively lower than in other clusters, their presence reflects an emerging area of interest namely, the rapid development of generative AI technologies and their pedagogical implications. This cluster points to a growing scholarly effort to understand and conceptualize the transformative potential of tools like ChatGPT, DALL·E, and similar large language models in reshaping educational practices.

A clear temporal trend appears when examining research associated with this cluster. Prior to 2023, studies on AI in education predominantly focused on adaptive learning, automated feedback, and personalized instruction supported by machine-learning systems, as illustrated in early work such as Pane et al. (2017). However, the period following the public release of ChatGPT in late 2022 marks a dramatic shift in scholarly attention. From 2023 onward, generative AI and large language models (LLMs) rapidly became the central focus of educational technology research. Analyses by Kasneci et al. (2023) and Lo (2023) highlight how LLMs began influencing pedagogical design, student inquiry, and metacognitive support, while raising new ethical and instructional design considerations. Simultaneously, concerns around academic integrity grew sharply, with studies such as Susnjak and McIntosh (2024) and Cotton et al. (2024) documenting how generative AI challenged existing assessment practices. Collectively, this timeline indicates a transition from pre-2023 adaptive systems to post-2023 dominance of generative AI in educational discourse.

A recent systematic review by Kildė (2024) examined the integration of generative AI in foreign language teacher education. The study revealed that while generative AI holds significant potential for enhancing digital and pedagogical competencies, challenges remain regarding training and curriculum alignment. Similarly, Haroud and Saqri (2025) explored the perceptions of students and lecturers on whether generative AI should serve as support, replacement, or a subject of digital literacy in higher education. Their findings highlighted the dual role of AI as both an enabler and a potential disruptor pointing to the need for increased digital literacy and critical awareness among educators.

In a bibliometric analysis, Întorsureanu et al. (2025) identified generative AI, particularly ChatGPT, as one of the most dominant trends in educational AI research. The study emphasized the need for a deeper understanding of its applications across diverse educational contexts and the ethical dilemmas that accompany its adoption. Furthermore, Sardi et al. (2025) in a systematic review of generative AI in education, cautioned that while such tools can enhance learner autonomy and critical thinking, excessive reliance may impede students' cognitive development.

Together, these findings underscore the importance of a balanced and reflective approach to the adoption of generative AI in teaching and learning. Educators and policymakers must weigh the benefits of automation and personalization against the risks of dependency and diminished human

agency. Cluster 5 thus signals a critical turning point in educational technology research one that demands thoughtful integration of emerging tools to complement, rather than replace, pedagogical intentionality and teacher expertise.

3.6 Curriculum Design and Early AI Education

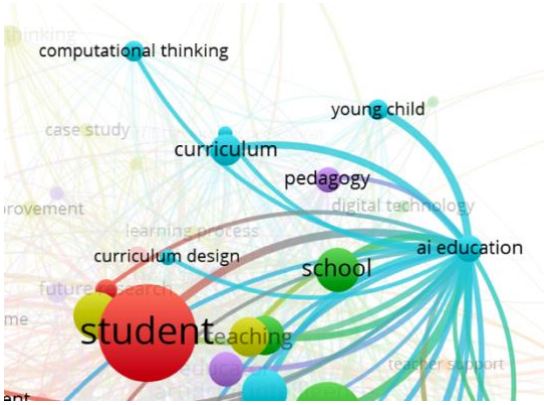

Figure 7. Cluster 6 *Curriculum Design and Early AI Education*

Cluster 6 is characterized by keywords such as *curriculum*, *computational thinking*, *AI education*, *young child*, and *curriculum design*. This cluster reflects ongoing efforts to embed artificial intelligence and computational thinking (CT) into early education systems, spanning from early childhood education (ECE) to the primary school level. In early childhood settings, previous studies such as Su and Zhong (2022) proposed curriculum frameworks structured around AI knowledge, AI skills, and AI attitudes, emphasizing tools like social robots to introduce AI concepts in developmentally appropriate ways. Similarly, Su and Yang (2022) found that integrating AI into early learning environments enhances children's creativity, emotion regulation, literacy development, and CT through interactive, play-based learning models.

However, transitioning AI education into the formal school system, especially at the primary level, presents several challenges. Su et al. (2023) noted persistent barriers such as teachers' limited AI knowledge, insufficient curricular guidelines, and the absence of pedagogical models tailored to early grades. Yim and Su (2025) further argued that although CT can motivate young learners, current approaches often lack interdisciplinary depth particularly in ethical reasoning and critical data literacy. Yim (2024) highlights that arts-based and transdisciplinary methods, including storytelling and visual design, can increase engagement and help young children intuitively explore AI concepts.

While these curriculum-focused insights are crucial, Cluster 6 also reveals that curriculum reform alone is insufficient without parallel investments in teacher preparation. Research in early AI literacy emphasizes that teachers require a foundational understanding of how AI works, how AI differs from traditional digital tools, and how to translate abstract AI concepts into playful, age-appropriate learning experiences. Williams et al. (2019) demonstrate that young children learn AI concepts most effectively when teachers integrate storytelling, embodied interaction, and social robots approaches that require specialized teacher training. Likewise, Long and Magerko (2020) emphasize that AI literacy involves not only conceptual understanding but also ethical awareness, human–AI interaction skills, and the ability to guide learners in reflecting on AI's role in daily life.

UNESCO's *AI Competency Framework for Teachers* reinforces this perspective by positioning teacher readiness pedagogical, ethical, and socio-emotional as a prerequisite for implementing early AI education (Miao & Cukurova, 2024). According to the framework, teachers must develop competencies such as responsible AI use, safeguarding human agency, and designing inclusive learning environments where AI supports exploration rather than replaces creativity.

Taken together, the literature suggests that developing AI literacy for young children requires a systemic approach in which well-designed curricula are supported by robust teacher professional

development. Early childhood and primary educators need training that equips them with: (1) foundational AI and CT knowledge appropriate for young learners, (2) pedagogical strategies integrating AI through play, inquiry, storytelling, and project-based learning, (3) ethical and safety frameworks to ensure age-appropriate engagement, and (4) practical familiarity with child-friendly AI tools.

Overall, Cluster 6 underscores that fostering early AI literacy demands both curriculum innovation and a sustained commitment to preparing teachers with the knowledge, confidence, and pedagogical strategies necessary to introduce AI meaningfully in early childhood and primary education settings.

3.7 *Attitudes, Emotional Intelligence, and Institutional Support*

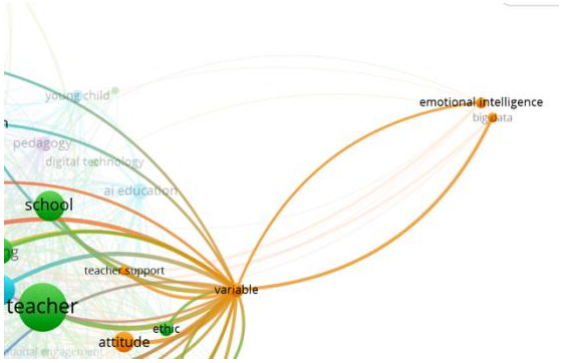

Figure 8. *Attitudes, Emotional Intelligence, and Institutional Support*

Cluster 7 comprises keywords such as *attitude*, *emotional intelligence*, *teacher support*, *big data*, and *variable*, indicating the prominence of psychological and institutional dimensions in shaping teachers' engagement with AI. As Goleman (1995) emphasized, emotional intelligence is fundamental to how individuals adapt to change and navigate innovations such as AI-driven instruction. This perspective is increasingly reflected in recent educational research. Fu (2025) found that emotional intelligence and psychological well-being significantly predict AI literacy among STEM teachers, explaining 71% and 61% of the variance, respectively. These findings suggest that emotional readiness is not peripheral but central to teachers' capacity to adopt AI tools.

Research also highlights the interplay between teachers' internal dispositions and the external support structures provided by schools. Bakhadirov et al. (2024) proposed a contextual model demonstrating that although self-efficacy strongly influences teachers' confidence in using AI tools, institutional support does not automatically translate into actual classroom integration. Their findings reveal a misalignment between formal support systems and the practical realities teachers face, such as limited time, rigid curricular structures, or inadequate training. Similarly, Zhi et al. (2024) showed that emotional intelligence and self-efficacy significantly shape technology adoption among EFL teachers, accounting for 89% and 63% of the variance, respectively. These studies collectively affirm that AI integration is not merely a technical or logistical process but a socio-emotional one.

To more clearly illustrate the distinction emphasized in Cluster 7, Figure X presents a matrix of internal and external factors that influence teachers' engagement with AI in education.

Table 3 . Internal and External Factors Influencing Teachers' AI Integration

Internal Factors (Teacher-Related)	External Factors (Institutional & Environmental)
Motivation to use AI	Technological infrastructure (devices, internet)
Emotional intelligence	School leadership support
Self-efficacy toward AI	Professional development availability
Attitudes and beliefs about AI	Institutional policies and guidelines
Psychological readiness (stress, resilience)	Time allocation and workload
Openness to innovation and AI-related pedagogical change	Organizational culture and institutional preparedness for innovation

This mapping demonstrates how AI adoption emerges from the interaction between teachers' individual dispositions and the institutional ecosystems in which they work. For example, strong infrastructure and policy frameworks (external factors) may have limited impact if teachers exhibit low self-efficacy or anxiety toward AI (internal factors). Conversely, teachers with high emotional intelligence and adaptive attitudes may still struggle if institutional support is weak or inconsistent.

Overall, Cluster 7 underscores that successful AI integration requires addressing both psychological/emotional readiness and institutional conditions. These insights highlight the need for professional development programs that foster emotional resilience, reflective practice, and confidence-building alongside supportive school leadership, targeted policies, and adequate technological resources. By cultivating both internal and external enablers, educational systems can support more equitable, sustainable, and human-centered AI integration.

Taken together, the seven clusters identified in this bibliometric analysis reveal a multidimensional research landscape surrounding teacher competence in AI-integrated education. Each cluster represents a distinct but interconnected domain: while Clusters 1 and 4 emphasize *student learning outcomes*, *critical thinking*, and *pedagogical enhancement* through AI, Clusters 2 and 3 focus on the *professional development*, *TPACK integration*, and *psychological readiness* of both pre-service and in-service teachers. Cluster 5 highlights emerging technological trends, particularly the role of generative AI, while Cluster 6 deals with *curriculum innovation* and the incorporation of AI into early and primary education. Finally, Cluster 7 adds a crucial affective layer by examining *emotional intelligence*, *teacher attitude*, and *institutional support* as enablers or barriers to successful adoption.

The interconnections between these clusters underscore that effective AI integration in education is not merely a technical endeavor it is a complex interplay of pedagogy, psychology, infrastructure, and policy. For instance, the relationship between Clusters 3 (self-efficacy and competence) and Cluster 7 (attitude and emotional intelligence) suggests that teacher confidence is deeply influenced by both individual beliefs and institutional culture. Similarly, the co-occurrence of terms like "curriculum", "student", and "AI system" across Clusters 1, 4, and 6 illustrates how instructional design, learning outcomes, and curriculum planning are tightly interwoven in AI-enhanced classrooms. Keyword link strength patterns described across clusters correspond to VOSviewer's full-counting method, in which every co-occurrence contributes equally to the overall network structure.

These insights have direct implications for teacher education programs. First, they call for the design of holistic professional development (PD) frameworks that go beyond tool training to include ethical reasoning, emotional resilience, and pedagogical adaptation. Second, they suggest the value of interdisciplinary training models that combine AI literacy with curriculum design, reflective teaching, and socio-emotional learning. Lastly, the bibliometric map highlights areas of potential misalignment such as between available institutional support and teachers' real-world classroom challenges that must be addressed through targeted policy and school leadership interventions.

In summary, the literature converges on the idea that preparing teachers for the age of AI requires not only technical knowledge, but also affective readiness, institutional support, and curricular foresight. A future-ready teacher education system must therefore integrate these dimensions to ensure the ethical, effective, and equitable adoption of AI in schools.

In the context of Indonesian education, the findings from this bibliometric analysis can serve as a valuable reference for policymakers, teacher education institutions, and curriculum developers. Although the study focuses on global literature, the thematic clusters identified ranging from teacher self-efficacy and professional development to curriculum innovation and ethical concerns offer critical insights that align with Indonesia's current efforts to modernize its education system through digital transformation. These insights may support the refinement of national strategies, such as the *Strategi Nasional Kecerdasan Artifisial 2020–2045*, and inform the design of AI-responsive teacher training programs at both pre-service and in-service levels. Furthermore, the insights derived from this bibliometric analysis underscore the urgency of embedding AI-related teacher competence into the formal structure of teacher education programs at both undergraduate (S1) and graduate (S2) levels in Indonesia. Bachelor's programs in teacher education (S1 Pendidikan Guru) should begin incorporating foundational AI literacy, ethical frameworks, and pedagogical design principles aligned with digital innovation. Meanwhile, master's level programs (S2 Pendidikan Guru) must deepen this foundation by offering specialized modules on AI-integrated curriculum development, data-informed instructional strategies, and leadership in educational technology. Such integration would ensure that future educators and educational leaders are equipped not only with theoretical understanding but also with the adaptive skills necessary to respond to the evolving demands of AI-enhanced learning environments.

By contextualizing these global research trends, stakeholders in Indonesia can better prioritize areas such as AI literacy for teachers, emotional and institutional readiness, and the ethical implementation of generative AI tools ultimately enhancing the country's preparedness for AI-integrated education.

4. CONCLUSION

The findings of this study reveal a multidimensional landscape of teacher competence in AI-integrated education, showing that pedagogical knowledge, digital skills, emotional readiness, and institutional support form an interdependent ecosystem rather than separate domains. Beyond mapping thematic clusters, the study highlights that emotional intelligence, ethical awareness, and curriculum-oriented AI literacy play an equally critical role as technical proficiency an area often overlooked in earlier reviews. This makes the present study one of the first bibliometric syntheses to simultaneously connect pedagogical, emotional, and ethical dimensions within a unified framework of teacher AI competence.

The results indicate that preparing teachers for AI-enhanced schooling requires more than technological training. Teachers need support to develop adaptive pedagogical strategies, ethical judgment, emotional resilience, and confidence in navigating rapidly evolving AI tools, including generative AI. Institutional conditions such as leadership, infrastructure, and policy clarity remain decisive factors in shaping teachers' willingness and capacity to integrate AI meaningfully.

Several avenues for future research emerge. Empirical classroom-based studies are needed to examine how AI-supported instruction affects long-term learning outcomes, especially in primary education where evidence remains scarce. Longitudinal research should also explore how teachers' beliefs, self-efficacy, and emotional intelligence evolve with sustained AI exposure. Additionally, hybrid professional development models that combine TPACK principles with human-centered AI frameworks warrant further investigation to support teacher readiness at scale.

This study has several limitations. The reliance on title-based screening may have excluded conceptually relevant works, and the use of keyword co-occurrence analysis captures thematic patterns but not deeper theoretical nuances. Nevertheless, the approach provides a robust and transparent map of emerging research directions.

Overall, the findings underscore the urgency of developing teacher education programs that integrate AI literacy, ethical reflection, and socio-emotional competence. For contexts such as Indonesia,

these insights can guide policymakers and institutions in designing coherent strategies for AI-responsive teacher preparation aligned with the country's ongoing digital transformation.

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