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Mapping Teacher Competence in AI-Integrated School Education: A Bibliometric Analysis of Scopus Literature (2021–2025)

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ABSTRACT

The rapid advancement of Artificial Intelligence (AI) is transforming educational landscapes, prompting new demands for teacher competence in integrating AI into school settings. As AI technologies such as machine learning, generative AI, and intelligent tutoring systems become more prevalent, teachers are expected to possess not only technical skills but also pedagogical adaptability and ethical awareness. This study explores the evolving research landscape on teacher competence in AI-integrated school education through a bibliometric analysis of 288 Scopus-indexed articles published between 2021 and 2025. Utilizing VOSviewer, the analysis identifies 76 frequently occurring keywords grouped into seven thematic clusters, which include student learning outcomes, digital self-efficacy, professional development, AI literacy, curriculum innovation, generative AI tools, and emotional-institutional factors. The findings reveal a complex and multidimensional knowledge structure. While established frameworks such as TPACK and UNESCO's AI Competency Framework for Teachers offer valuable guidance, the literature still lacks an integrated model that bridges technological, pedagogical, and emotional domains. The study emphasizes the need for teacher education programs that incorporate ethical reflection, emotional intelligence, and practical AI readiness. Implications are offered for curriculum developers, policymakers, and researchers, particularly in developing hybrid competence frameworks and aligning institutional support with the real-world needs of pre-service and in-service teachers in the age of AI-enhanced learning.

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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).

However, despite the availability of these conceptual frameworks, there remains a lack of integrative synthesis in the existing literature that explores how key research themes such as professional development, AI literacy, curriculum design, and emotional intelligence are interrelated within the broader discourse on teacher competence in AI-driven education. This analytical gap hampers the field's ability to develop a unified understanding of what constitutes effective and ethical AI integration in teaching practices.

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, (2) interpret their interconnections, and (3) offer implications for future research, teacher training, and policy formulation. The findings emphasize the urgency of hybrid models that combine TPACK's pedagogical clarity with AI CFT's ethical orientation, while highlighting the need for standardization, contextualization, and longitudinal evaluation of AI-based teaching practices.

2. METHODS

This study employed a bibliometric literature review approach to explore global research developments related to teacher competence in the field of artificial intelligence (AI), particularly within the context of school-based education. The bibliometric method enables researchers to examine the intellectual, social, and conceptual structures of a scientific domain based on patterns in published literature (Donthu et al., 2021).

The bibliometric analysis procedure used in this study followed the five-stage model consisting of: Defining search keywords, Initial search result, Refinement of the search results, Screening for relevance, and Compilation and analysis (Fahimnia et al., 2015).

The data collection process was conducted in April 2025 using the ScienceDirect platform, which indexes peer-reviewed literature from Scopus. At the first stage, the keywords "teacher competence" and "artificial intelligence" were used in combination, yielding 1,743 initial documents. To narrow the focus specifically to school-based educational contexts, the term "school" was added, which refined the dataset to 1,428 documents.

In the third stage, refinement of article types was applied by limiting the selection to original research articles, excluding editorials, review papers, conference abstracts, and book chapters. This step resulted in 1,066 articles.

Next, during the screening phase, relevance was further enhanced by manually inspecting publication titles. Only articles whose titles explicitly addressed the intersection of teacher competence, artificial intelligence, and school-based educational settings were included. This pragmatic filtering strategy was applied to ensure topical precision, resulting in a final dataset of 288 articles.

All selected articles were exported in. RIS format and processed using VOSviewer (version 1.6.21). A co-occurrence analysis of author keywords was performed to examine the most frequently appearing terms, identify thematic clusters, and visualize the conceptual structure of the research landscape. The final bibliometric map revealed dominant research streams, interrelations among pedagogical and technological domains, and trends related to teacher competence in AI-integrated school education.

Due to the large volume of initial records and the thematic focus of this study, screening was limited to publication titles rather than full-text or abstract review. While this strategy enhanced efficiency and ensured clear topical relevance, it may have excluded studies in which relevant concepts appeared only in the abstract or body of the text. This methodological choice aligns with practices in prior bibliometric studies (Donthu et al., 2021; Zupic & Čater, 2015) and is acknowledged as a limitation of this research.

Table 1. Screening Prosses Summary

Criteria	Screening Result
Initial key words: teacher competence, artificial intelligence	1.743 articles
Refined with keyword "school"	1.428 articles
Filtered by article type: research only	1.066 articles
Screened by relevance in publication title	288 articles

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.

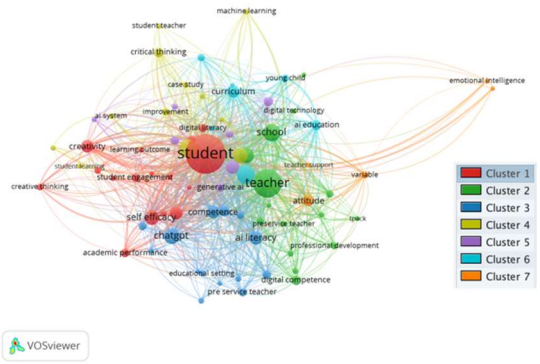

Figure 1. Visualization interrelationship of themes in the field of teacher competence, artificial intelligence, and school
(https://tinyurl.com/2bsbve6q)

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.

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

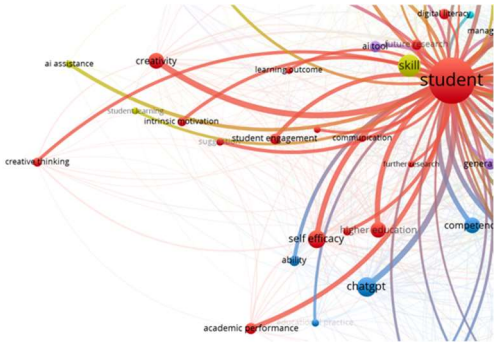

Figure 2. Cluster 1 Student Outcomes, Motivation, and Engagement

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 over time.

3.2 Teacher Development and Digital Competence

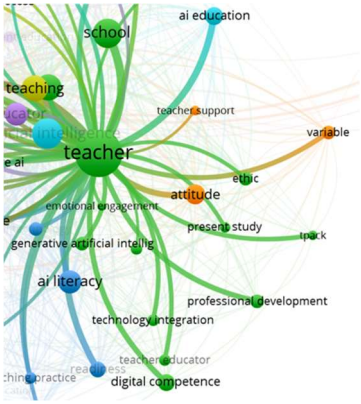

Figure 3. Cluster 2 Teacher Development and Digital Competence

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).

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.

Further supporting this view Yue et al. (2024) found that although K–12 teachers often express positive attitudes toward AI education, their TPACK readiness for teaching AI is limited, underscoring the need for continuous training that merges technical knowledge with pedagogical strategies. 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.

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

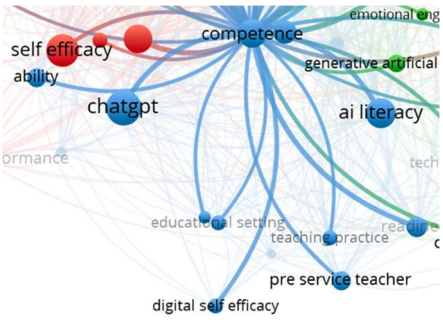

Figure 4. Cluster 3 *Competence and AI Readiness*

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. This tool aids in identifying specific areas where teachers may require further development to effectively integrate AI into their classrooms.

However, it's noteworthy that much of the existing literature relies on self-reported data, as indicated by the inclusion of keywords like *survey*, *pre-service teacher*, and *previous study*. This reliance points to a gap in evidence from classroom-based implementations. Future research should aim to include more empirical studies that observe and analyze the actual application of AI tools in teaching practices to provide a more comprehensive understanding of teachers' readiness and competence in this area.

3.4 *Pedagogical Innovations and AI Systems*

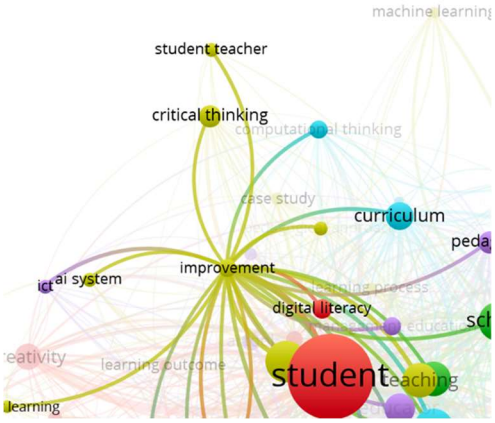

Figure 5. Cluster 4 *Pedagogical Innovations and AI Systems*

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*

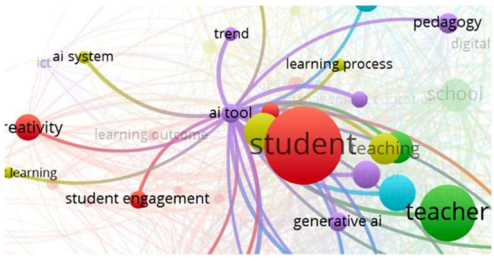

Figure 6. Cluster 5 *AI Tools and Technology Trends*

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 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

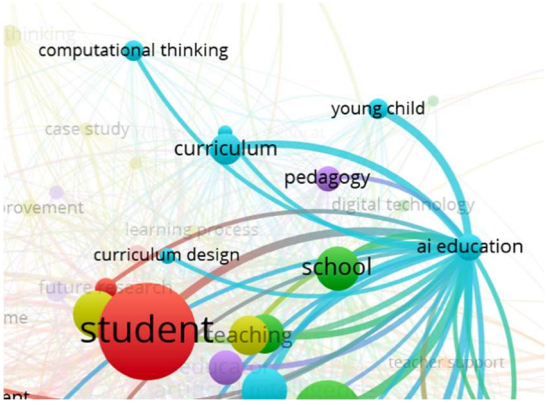

Figure 7. Cluster 6 *Curriculum Design and Early AI Education*

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, Su and Zhong (2022) proposed an AI curriculum framework for kindergarten based on three core competencies: AI knowledge, AI skills, and AI attitudes. Their study emphasized the use of social robots and age-appropriate tools to support children's understanding of AI concepts in a developmentally appropriate manner. Likewise, Su and Yang (2022) found that integrating AI into early learning environments can enhance young children's creativity, emotion regulation, literacy skills, and CT development through interactive and collaborative learning models.

However, transitioning AI education into the formal school system especially at the primary level presents additional challenges. Su et al. (2023) highlight barriers such as teachers' limited AI knowledge, insufficient curriculum frameworks, and a lack of pedagogical guidelines, especially for early-grade classrooms. Despite these constraints, momentum is growing to expand AI literacy beyond early childhood and into primary schooling.

Yim and Su (2025) examined AI literacy education in primary schools and noted that while computational thinking can effectively enhance students' motivation and technical proficiency, current approaches often lack interdisciplinary depth, such as ethical reasoning and critical data literacy. The study recommends a broader conceptualization of AI literacy that aligns with students' cognitive and moral development. In parallel, Yim (2024) demonstrated that integrating arts-based, transdisciplinary approaches such as storytelling and visual arts can promote creative engagement with AI content among primary-aged students.

Overall, Cluster 6 underscores the significance of curricular design in fostering foundational AI literacy from an early age. It highlights the need for scaffolded, ethically grounded, and developmentally appropriate pathways that introduce both young and primary school children to AI concepts. This aligns with global initiatives such as UNESCO's guidance on digital and AI competencies for children and educators, which stress the importance of inclusivity, safety, and human agency in early AI education.

3.7 *Attitudes, Emotional Intelligence, and Institutional Support*

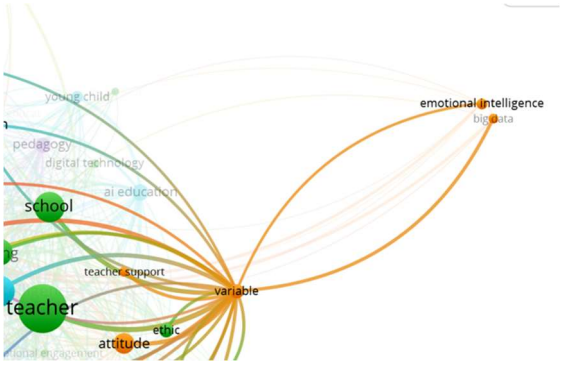

Figure 8. *Attitudes, Emotional Intelligence, and Institutional Support*

Cluster 7 comprises keywords such as *attitude*, *emotional intelligence*, *teacher support*, *big data*, and *variable*. The presence of *attitude* and *emotional intelligence* highlights the psychological and emotional dimensions of teachers' engagement with artificial intelligence (AI) technologies. As Goleman (1995) famously argued, emotional intelligence plays a crucial role in how individuals adapt to innovation and change.

Recent research further reinforces this perspective, Fu (2025) demonstrated that emotional intelligence and psychological well-being significantly predict AI literacy among STEM teachers, accounting for 71% and 61% of the variance, respectively. This suggests that supporting teachers' emotional readiness is essential for effective AI integration in classrooms.

Bakhadirov et al. (2024) proposed a contextual model that accounts for both internal factors (such as teacher motivation and self-efficacy) and external variables, including school support and technological infrastructure. Their findings revealed that while teachers' self-efficacy was positively associated with their confidence in using AI tools for instruction, institutional support did not always guarantee actual integration of AI into teaching practices. This indicates a possible misalignment between the formal availability of support systems and the practical, context-specific needs of teachers in real classroom environments. The study underscores the importance of not only equipping educators with technical resources but also tailoring professional support structures to their pedagogical realities.

In a study focused on EFL teachers, Zhi et al. (2024) found that emotional intelligence and self-efficacy significantly influenced technology adoption, accounting for 89% and 63% of the variance, respectively. These findings reaffirm that beyond technical skills, emotional and psychological factors are pivotal in shaping teachers' openness to educational innovation.

Overall, Cluster 7 underscores that AI integration in education is not solely a technical or infrastructural challenge but also a human one. Addressing emotional readiness, fostering supportive

institutional environments, and building teachers' confidence are critical steps toward more equitable and sustainable adoption of AI in schools.

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.

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

This bibliometric study mapped the evolving landscape of teacher competence in AI-integrated school education by analyzing 288 Scopus-indexed articles published between 2021 and 2025. Through co-occurrence analysis using VOSviewer, seven thematic clusters were identified, encompassing student learning outcomes, teacher professional development, digital self-efficacy, curriculum innovation, generative AI trends, and emotional-affective factors. These clusters reveal a multidimensional and interconnected body of research that highlights not only the technical and pedagogical aspects of AI adoption, but also psychological readiness, institutional support, and ethical considerations.

The findings confirm that while frameworks such as TPACK and UNESCO's AI Competency Framework provide a foundation, the field still lacks an integrated approach that bridges pedagogical, technological, and emotional domains. The thematic connections between clusters suggest that effective AI integration requires more than tool proficiency it demands the development of emotionally competent, ethically aware, and curriculum-oriented teachers who are supported both institutionally and professionally.

Future research should address several critical gaps. First, more empirical studies are needed to examine how AI-enhanced instruction influences long-term student outcomes in real classroom settings. Second, the field would benefit from longitudinal research on how teacher beliefs, self-efficacy, and emotional intelligence evolve with sustained AI exposure. Third, there is a growing need for developing and validating hybrid training models that combine the strengths of TPACK and human-centered AI frameworks to prepare future teachers for a rapidly evolving educational ecosystem.

Ongoing studies may also explore how generative AI particularly large language models is reshaping teacher roles, assessment strategies, and classroom dynamics, especially in primary education. Given the multidimensional nature of AI integration highlighted in this bibliometric study, future research should empirically examine the impact of teacher AI literacy particularly when grounded in the TPACK framework on both pedagogical practice and student learning outcomes at the elementary level. Such investigation would not only address the current gap in classroom-based evidence but also offer practical insights for designing teacher training models that foster ethical, effective, and student-centered AI adoption. This direction is especially urgent in the Indonesian context, where digital transformation efforts are accelerating but empirical studies linking teacher AI competence and student achievement remain limited.

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