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TRENDS AND HOTSPOTS IN AI-FOCUSED TEACHER TRAINING FOR SCIENCE EDUCATION: A BIBLIOMETRIC REVIEW

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ABSTRACT

This study examines the publication landscape and scholarly impact of research on Trends and Hotspot in AI-focused teacher training in science education through a bibliometric analysis of leading journals and conference proceedings. The findings reveal that the field remains emerging and widely dispersed across a limited number of high-impact international sources, with no single dominant journal. Key contributors include Education and Information Technologies, Education Sciences, Frontiers in Education, Journal of Science Education and Technology, and Research in Science Education, each contributing two publications. Among these sources, Frontiers in Education demonstrated the highest citation impact, suggesting strong scholarly engagement and influence within the field. In contrast, some high-ranking journals showed lower citation counts, likely due to the recency of the publication within the 2021-2025 period. The results also highlight the global nature of research production, with major publishers based in Switzerland, the Netherlands, and the United States, indicating strong academic infrastructures supporting this emerging area. Although conference proceedings contributed fewer studies, they played a significant role in early knowledge dissemination, particularly in rapidly evolving topics at the intersection of artificial intelligence education. Particularly, certain conference publications demonstrated substantial citation influence, emphasizing their importance in shaping early discourse. The analysis suggests that AI-focused teacher training in science education is a multidisciplinary and evolving field situated at the intersection of educational technology, science education, and computer science. While still consolidating its core knowledge base, the field shows increasing scholarly attention, methodological diversity, and global participation. These findings provide a clearer understanding of current research trends and offer a foundation for guiding future studies, policy development, and the integration of AI in teacher professional development programs.

Keywords: Trends, Hotspots, Artificial Intelligence, Teacher Training, Science Education, Bibliometric Analysis

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INTRODUCTION

Artificial Intelligence (AI) continues to reshape educational systems across the world by influencing teaching practices, learning environments, and assessment methods. In science education, AI-powered tools such as intelligent tutoring systems, learning analytics, simulations, and virtual laboratories have demonstrated strong potential to support inquiry-based learning, improve conceptual understanding, and promote data-driven instruction (Luckin et al, 2016; Homes, Bialik, & Fadel, 2019). As classrooms become more technologically advanced, integrating AI is increasingly recognized as an essential component of educational innovation and reform.

Successful integration of AI in science education depends largely on how well teachers are prepared. Science educators are expected to possess not only strong pedagogical content knowledge but also competencies related to AI, including technological literacy, ethical awareness, and the ability to align AI tools with curriculum and instructional goals (OECD, 2021; UNESCO, 2022). This growing demand has led to the emergence of AI-focused teacher training as an important area of research and practice. Such initiatives emphasize professional development programs that equip both pre-service and in-service teachers with the skills needed to use AI effectively and responsibly in teaching science.

Research on AI-focused teacher training in science education has expanded significantly in recent years. Existing studies explore a wide range of topics, including teacher's AI literacy, competency frameworks, strategies for integrating AI into instruction, and educator's attitudes toward adopting AI technologies (Zawacki-Richter et al., 2019). Although this growing body of literature reflects increasing academic interest, it remains scattered across different disciplines, journals, and methodological approaches. This fragmentation makes it difficult to identify overall publication trends, key contributors, collaboration patterns, and emerging research themes within the field.

A limited number of comprehensive and large-scale syntheses currently exist to map the intellectual structure and development of AI-focused teacher training in science education, despite the increasing number of studies. Bibliometric analysis provides a systematic and objective approach to addressing this gap by examining publication trends, citation patterns, and thematic relationships within a research field (Donthu et al., 2021).

This study addressed this gap by conducting a bibliometric review of trends and hotspots in AI-focused teacher training for science education. The analysis focused on publication growth, leading authors, institutions, countries, journals, and keyword co-occurrence networks to provide a comprehensive understanding of the field's development and emerging directions. The findings were expected to guide future research, support evidence-based decision making in teacher education, and inform the design of effective AI-driven professional development programs in science education.

RESEARCH METHODOLOGY

This study adopted a bibliometric review design, a quantitative method used to analyze the academic literature and map trends, hotspots, and patterns in research. Bibliometric analysis is particularly useful in identifying key authors, institutions, countries, keywords, and research clusters within a defined topic area.

The Bibliometric Analysis model is shown in figure 1, it illustrates the systematic research flow of conducting a bibliometric analysis on trends and hostpots of AI-focused teacher training in science education. It was structured into four major components, namely: Process, Output, and Outcome. The

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Input consists of scholarly publications on AI-focused teacher training in science education, retrieved from reputable databases such as Scopus using relevant keywords. The Process involves Bibliometric methods (co-authorship analysis, keyword co-occurrence, citation analysis) using tools like VOSviewer and Bibliometrix in R. Bibliometric analysis includes performance analysis to examine publication trends, authorship, institutions, and journals. The Output of these analyses revealed research themes and patterns, emerging trends, research hotspots, influential authors and collaboration networks, and gaps in the existing literature. The Outcome of these, are acquired support from educational stakeholders including policymakers, researchers, and teacher educators in redesigning curriculum and implementing more responsive, equitable, and future-oriented training programs that align with the evolving demands of science education in the digital age.

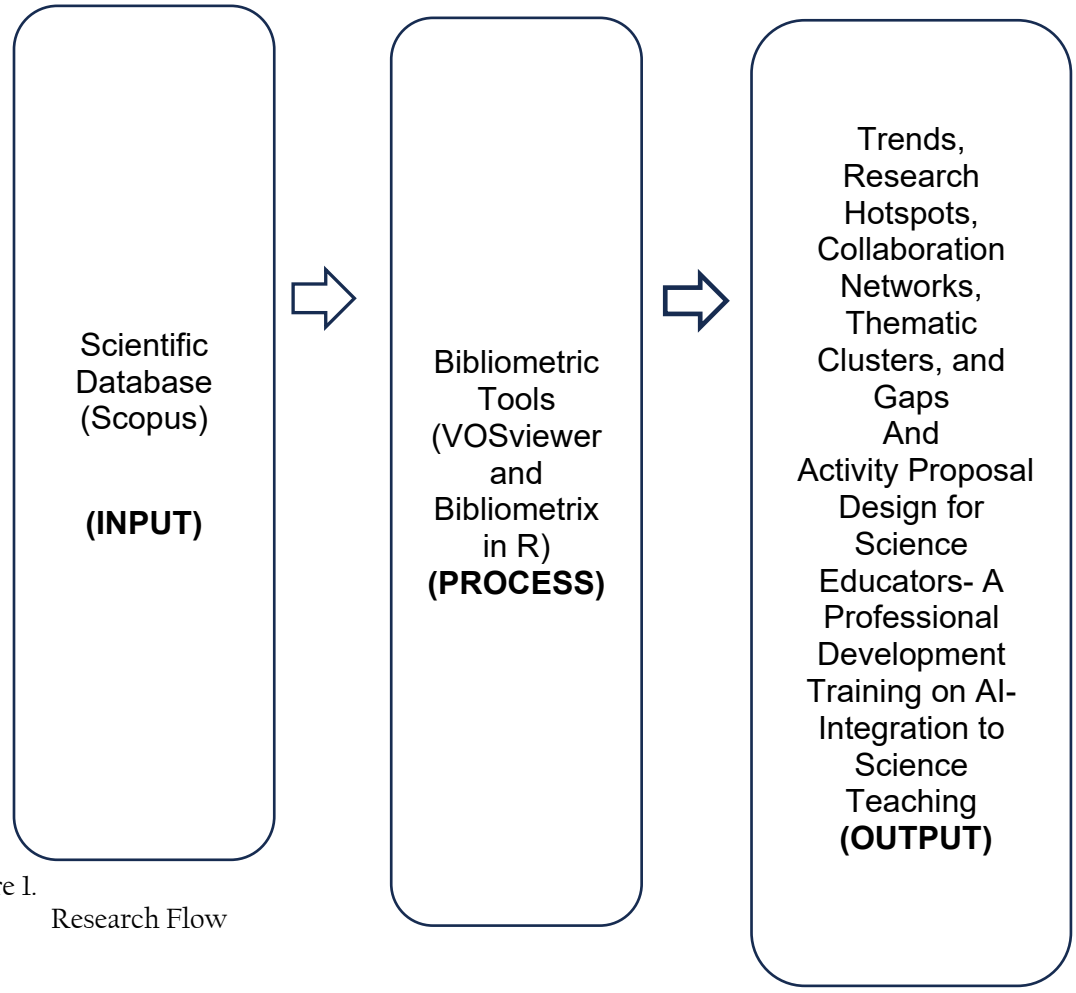

Figure 1.
Research Flow

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Since this study was a bibliometric review, it did not involve a physical or field-based environment like traditional experiment or survey research. Instead, the research environment was entirely digital, and data driven, involving the use of academic databases and analytical software.

In the context of a bibliometric review, the study did not involve human participants in the traditional sense like students, teachers, and interviewees. Instead, the participants of the study refer to the published academic works and their associated authors, institutions, and countries.

In a bibliometric review study, it did not use traditional instruments like surveys or interviews. Instead, the research utilized digital bibliometric tools and software as instruments for collecting, organizing, and analyzing data. The main instruments are Scopus Database, Microsoft Excel, VOSviewer Software and Bibliometrix and Biblioshiny (R Package).

The process of data collection of this study followed a systematic and structured approach to ensure the reliability and validity of the bibliometric analysis. The following steps were undertaken: First, is the identifying of the appropriate bibliographic database, second is developing search criteria, next is selecting suitable data analysis software tools, and lastly, conducting a comprehensive analysis and screening of the retrieved data.

Identifying the Appropriate Bibliographic Database

This bibliometric analysis utilized Scopus as the primary bibliographic database due to its extensive multidisciplinary coverage and comprehensive indexing of essential bibliographic metadata, including author affiliations, citations, abstracts, and keywords. These features support reliable bibliometric and science-mapping analyses and ensure compatibility with widely used analytical tools such as Bibliometrix/Biblioshiny and VOSviewer. Scopus was further selected because of its rigorous content selection and peer-review standards, ensuring that indexed journals, conference proceedings, and book series meet established criteria for originality, methodological rigor, and scholarly contribution. Its inclusion of both journal articles and conference publications is particularly relevant to interdisciplinary fields such as artificial intelligence in teacher training and science education, where emerging research is often disseminated through diverse publication channels.

Following the selection of Scopus as the data source, the study adopted the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) framework to guide the identification, screening, eligibility assessment, and inclusion of documents. The application of the PRISMA framework enhanced the transparency, consistency, and replicability of the document selection process. The PRISMA workflow employed in this study is presented in Figure 2, illustrating the procedures undertaken to identify and select the final dataset for analysis.

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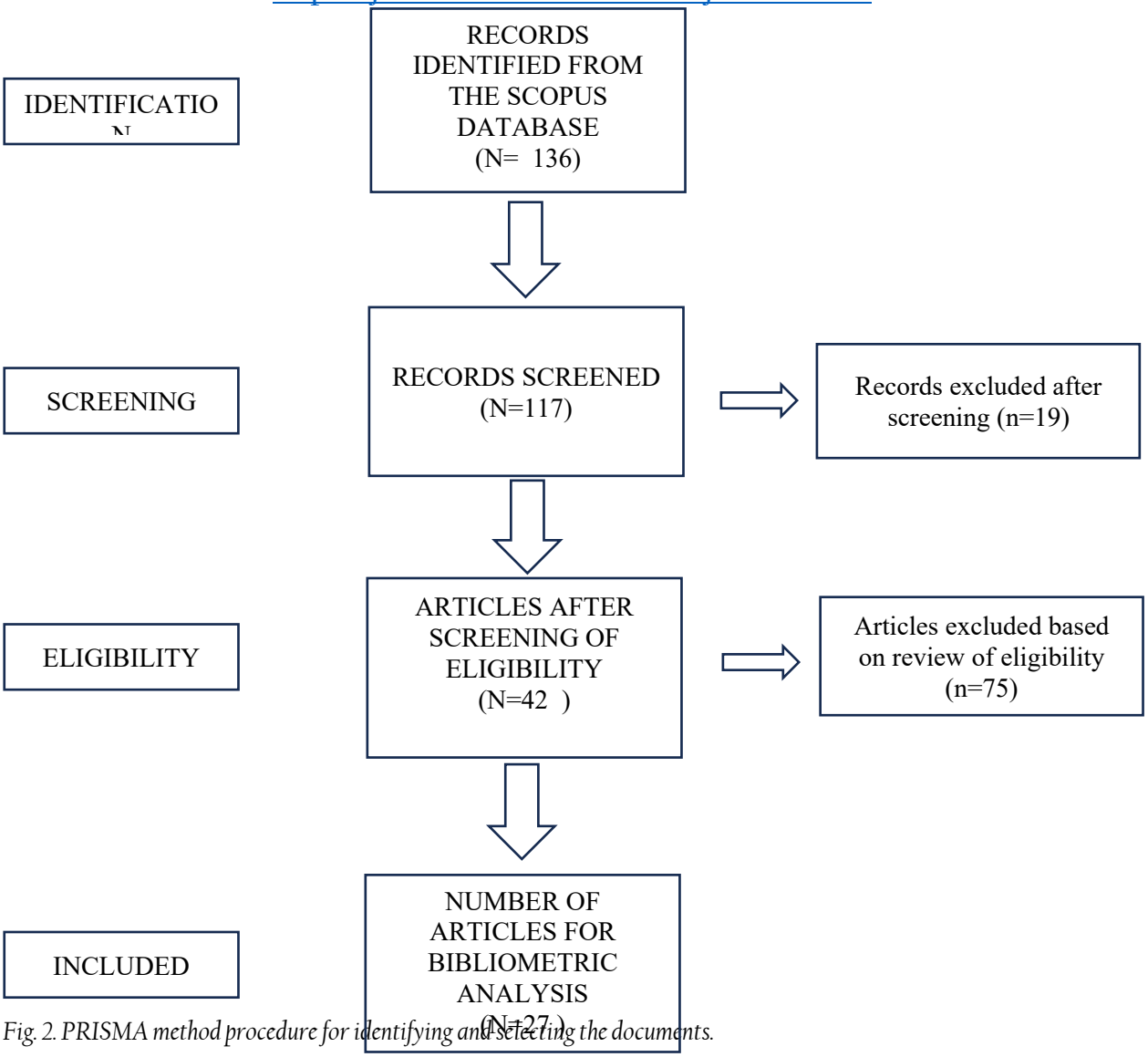

Fig. 2. PRISMA method procedure for identifying and selecting the documents.

Developing Search Criteria

The search strategy was systematically developed to retrieve literature closely aligned with the objectives of this bibliometric review while minimizing the inclusion of irrelevant publications (Table 1). Data collection was conducted using the Scopus Database, selected for its extensive coverage of high quality, peer-reviewed journals, conference proceedings, and comprehensive bibliographic metadata suitable for large-scale bibliometric analysis.

The search query was applied to the TITLE-ABS-KEY field, limiting retrieval to documents in which the search terms appeared in the title. Abstract, or author keywords. This approach enhanced conceptual relevance by ensuring that artificial intelligence and teacher training constituted the primary focus of the selected studies rather than being merely peripheral topics. The search string integrated three core thematic components: artificial intelligence, teacher training, and science education, which were

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linked using the Boolean operator "AND". Artificial intelligence-related terms (e.g., artificial intelligence, AI, machine learning, and deep learning) were combined with teacher training-related terms (e.g., science education, STEM education, and science teaching) to comprehensively capture relevant interdisciplinary research.

To ensure temporal relevance, a publication year filter was applied, limiting the results to studies published between 2015 and 2025. This period was selected to capture the rapid advancement of AI technologies and their increasing integration into teacher training practices. Moreover, substantial growth in scholarly publications was observed beginning in 2021, reflecting heightened academic and institutional interest driven by advances in machine learning, increased accessibility of AI tools, and the accelerated adoption of digital pedagogies in education.

Further refinement was achieved by limiting the subject areas to Social Sciences, Computer Science, Engineering, Mathematics, Psychology, Decision Sciences, and Earth and Planetary Sciences. These subject areas were selected to ensure alignment with both the pedagogical and technological dimensions of AI-focused teacher training. The document type filter restricted results to research articles, review articles, and conference papers, representing original and peer-reviewed scholarly contributions. Only publications written in English and indexed at the final publication stage were included to maintain consistency, accessibility, and methodological rigor.

No restrictions were imposed on source titles, affiliations, funding sponsors, countries or territories, source types, or open access status, thereby allowing the inclusion of a comprehensive and globally representative dataset. Collectively, these criteria ensured the retrieval of relevant and high-quality literature suitable for identifying publication trends, research hotspots, and emerging themes in AI-focused teacher training within science education.

Table 1. Search Strategy.

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Parameters	Criteria
Database	Scopus
Search String	TITLE-ABS-KEY(((“Artificial intelligence” OR “machine learning” OR “deep learning”)) and ((“teacher training” OR “teacher education” OR “professional development” OR “teacher preparedness”)) AND ((“science education” OR “STEM education” OR “science teaching”))) AND PUBYEAR>2014 AND PUBYEAR <2027 AND (LIMIT-TO (SUBJAREA, “ENGl”) OR LIMIT-TO (SUBJAREA, “MATH’) OR LIMIT-TO(SUBJAREA,”PSYC”) OR LIMIT- TO (SUBJAREA, “DECI”) OR LIMIT-TO (SUBJAREA, “MULT”) OR LIMIT-TO (SUBJAREA, “EART”)) AND (LIMIT-TO (DOCTYPE, “ar”) OR LIMIT-TO (DOCTYPE, “cp”)) AND (LIMIT-TO(LANGUAGE, “English”))
Time Span	2015-2025
Subject Area	Limited to Social Science, Computer Science, Engineering, Math, Psychology, Decision Science and Earth and Planetary Sciences
Document Type	Limited to original research articles, review articles, and conference papers or proceedings
Source Title	All
Publication Stage	Limited to final
Keyword	All
Affiliation	All
Funding Sponsor	All

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Country/Territory	All
Source Type	All
Language	All
Open Access	All

Selecting Suitable Data Analysis Software Tools

Bibliometrix, an R package designed for quantitative bibliometric analysis, and VOSviewer, a specialized software for bibliometric network visualization, were selected as the primary analytical tools for this study. Bibliometrix was utilized to perform descriptive bibliometric analyses, including annual publication trends, citation analysis, and the identification of the most productive authors, journals, institutions, and countries. In contrast, VOSviewer was employed to generate network visualization such as co-authorship, co-citation, citation, and keyword co-occurrence maps. These visualizations facilitated the identification of collaboration patterns, thematic clusters, and emerging research hotspots within the field of AI-focused teacher training in science education.

Conducting a Comprehensive Analysis and Screening of the Retrieved Data

The data retrieved from Scopus were systematically screened and analyzed to ensure the reliability and validity of the bibliometric findings. Relevant publications were exported in CSV format after applying the predefined inclusion and exclusion criteria based on publication year, document type, language, and subject area. The dataset was subsequently examined to identify and remove duplicate and irrelevant records. In addition, metadata were standardized to ensure consistency in author names, institutional affiliations, and keywords.The cleaned dataset was analyzed using Biblioshiny, the web-based interface of Bibliometrix in R, and VOSviewer. Biblioshiny was employed to conduct descriptive analyses, including publication trends, leading authors, journals, institutions, and countries.

This study employed bibliometric and science-mapping analyses to examine research trends, thematic evolution, and scholarly contributions in AI-focused teacher training for science education from 2021-2025. Bibliographic data was retrieved from the Scopus database, including publication years, authors, affiliations, countries, journals, citations, and keywords. The bibliometric analysis employed in this study are Publication and Citation Analysis, Contribution Analysis, Collaboration Network Analysis and Keyword Co-Occurrence and Hotspots Analysis.

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RESULTS OF THE STUDY

The bibliometric review of AI-focused teacher training in science education revealed significant developments in the field from 2021 to 2025. The analysis showed a steady increase in scholarly publications, indicating growing academic interest and recognition of the role of artificial intelligence in enhancing science teacher education. Early studies focused on foundational AI technologies such as machine learning, deep learning, and simulation-based learning, while more recent publications emphasized practical applications including Generative AI, ChatGPT, lesson planning, and instructional support. These findings suggest that the field is progressing from theoretical exploration toward classroom-oriented and pedagogical implementation.

The study further revealed that research productivity is concentrated in a few countries and institutions. Germany and the United States emerged as the leading contributors, supported by strong institutional collaborations, particularly among German universities and selected international partners. The author network demonstrated a collaborative and multidisciplinary nature, although no single researcher dominated the field. Core journals such as the *International Journal of STEM Education*, *Journal of Science Teacher Education*, and *Interactive Learning Environments* served as major venues for disseminating research on AI-focused teacher training.

Analysis of keyword co-occurrence and thematic clusters identified artificial intelligence as the central concept connecting multiple areas of inquiry. Frequently occurring keywords highlighted themes related to AI literacy, technology integration, teacher professional development, preservice teacher education, science education, STEM education, and ChatGPT-assisted instruction. Emerging research directions include evaluating AI-supported pedagogical practices, examining the long-term effects of AI integration on teaching, promoting interdisciplinary approaches, and addressing ethical considerations in AI use. These patterns indicate a shift toward more applied, context-sensitive, and practice-oriented research.

Citation analysis revealed that influential studies are distributed across several high-impact journals and conference proceedings. Publications in *Frontiers in Education*, *Education and Information Technologies*, *Education Sciences*, *Journal of Science Education and Technology*, and *Research in Science Education* have significantly contributed to shaping the field. Among these, *Frontiers in Education* demonstrated the highest citation impact, reflecting its strong influence on subsequent research. The presence of highly cited works from multiple countries underscores the global and multidisciplinary character of AI-focused teacher training research and highlights its growing importance in advancing science education.

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DISCUSSIONS

This study focused on the emerging publication trends over time regarding AI-focused teacher training in science education, contributions of countries, institutions, authors, and journals, frequently used keywords and emerging themes in the literature, and the most cited articles and the impact they have made in science education.

Publication and citation analysis by the emerging publication trends over time regarding AI-focused teacher training in science education

From 2021 to 2025, publications on AI-focused teacher training in science education showed an overall upward trend. Only one article was published in both 2021 and 2022, indicating that the field was still emerging. Publications increased to four in 2023, dipped slightly to three in 2024, and surged to 18 in 2025, reflecting growing interest driven by the widespread adoption of AI in education, stronger policy support for digital competencies, and increased emphasis on preparing teachers for AI-integrated learning environments.

Despite the rise in publication output, the mean total citations per year declined from 11.6 in 2021 to 2.0 in 2025. Earlier studies accumulated more citations because they had longer citation windows and served as foundational works in the field. As research expanded, citations became distributed across a larger number of publications, reducing the average citations per article. The slight increase in the 2025 citation rate suggests that recent studies are already attracting scholarly attention despite having limited time to accumulate citations. (See figure 3)

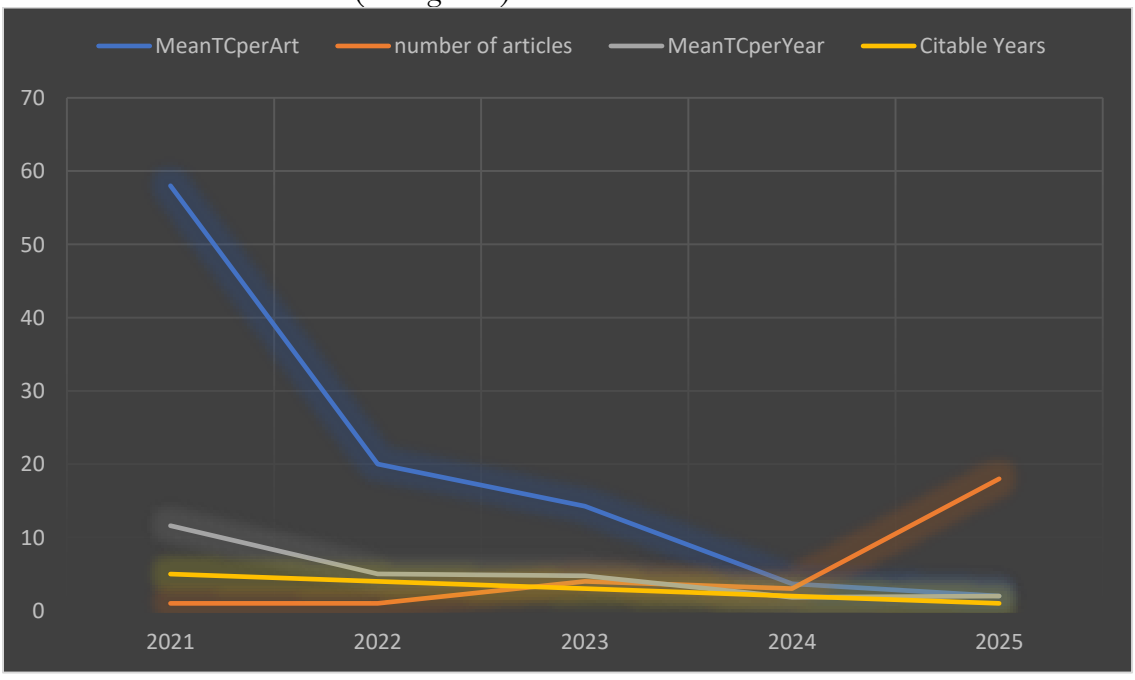

Figure 3. Annual number of publications and average citations per year and article from 2021 to 2025 on AI-focused teacher

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training in science education.

Keyword Trends and Thematic Analysis (Trend Analysis)

Figure 4 presents the overlay visualization of keywords, illustrating the evolution of research themes in AI-focused teacher training for science education. Node size represents keyword frequency, while color indicates the average publication year, with yellow denoting more recent terms and blue representing earlier ones.

Artificial Intelligence emerged as the central and most connected keyword, followed by Teacher Education and Science Education, highlighting their pivotal roles in the field. These core concepts are closely linked with Professional Development, STEM Education, Technology Integration, and Preservice Teachers, reflecting the interdisciplinary nature of the research.

The overlay also reveals a shift in research focus. Earlier studies emphasized foundational topics such as Machine Learning, Deep Learning, and Simulation, whereas more recent studies increasingly explore practical applications, including Generative Artificial Intelligence, ChatGPT, Lesson Planning, and Intelligent Tutoring Systems. This trend indicates a transition from foundational AI concepts toward pedagogical applications that support teacher training and classroom practice.

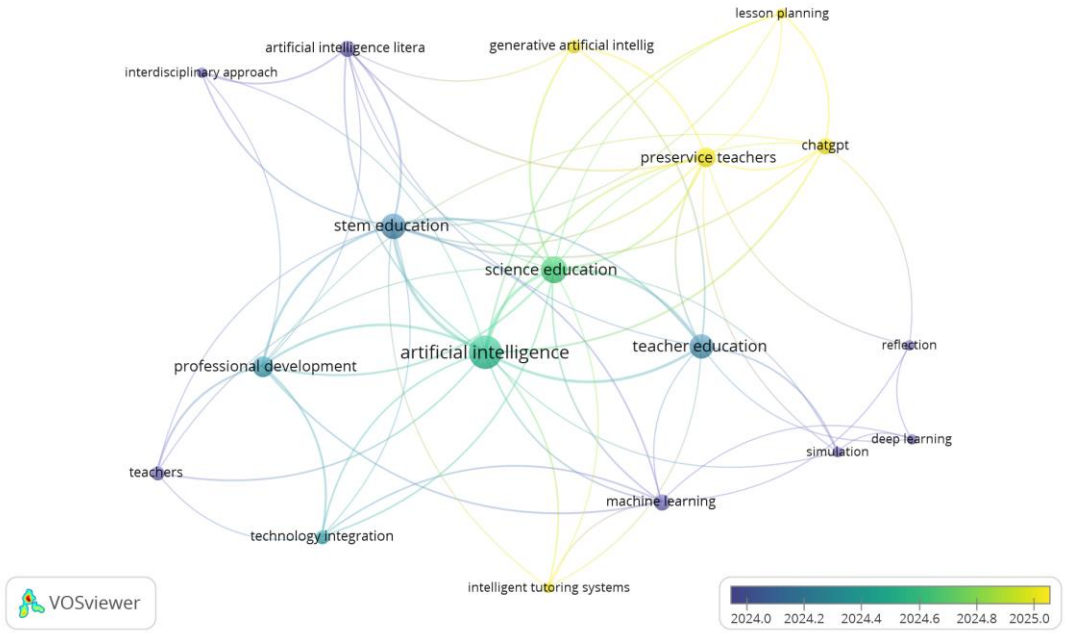

Figure 4. Overlay visualization (Trends) of keywords based on occurrence time with emphasis on the centrality and frequency of Artificial Intelligence and Teacher Education/Training.

Contribution Analysis by Countries, Institutions, Authors, and Journals

Figure 5 illustrates the global distribution of Scopus-indexed publications on AI-focused teacher

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training in science education, while Table 2 presents the top 10 contributing countries. Germany leads with 15 publications, followed by the United States with 11, highlighting Europe and North America as the primary research hubs. India and the Netherlands each contributed 4 publications, while Chile, Spain, Sweden, and Turkey produced 3 each. China and Israel, with 2 publications each, represent emerging contributors.

The findings show a geographically diverse research landscape, with Europe and North America dominating publication output and increasing contributions from Asia, South America, and the Middle East. This distribution indicates growing global interest in AI-focused teacher training and underscores opportunities for international collaboration to advance research, share expertise, and strengthen AI integration in science teacher education.

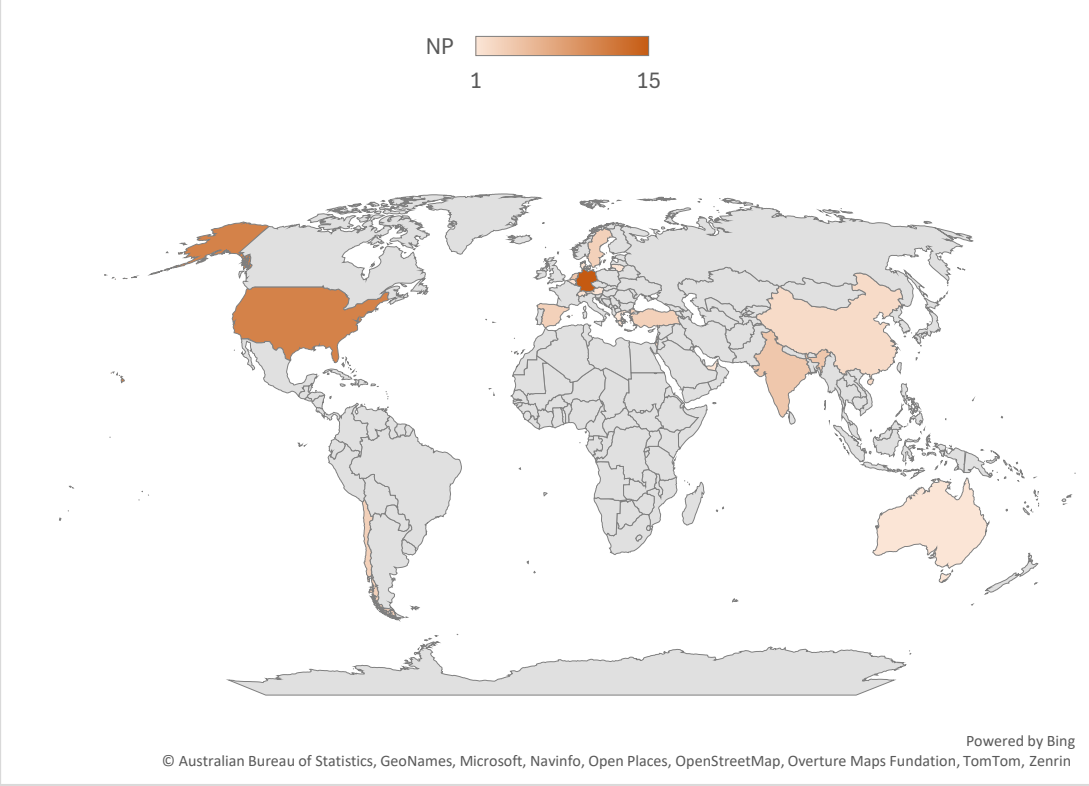

Fig 5. Scopus document distribution on AI-focused teacher training in science education contribution across the world.

Collaboration Network Analysis by Authors, Countries, and Institutions

Figure 6 presents the country-level collaboration network in AI-focused teacher training in science education. Node size represents publication output, while links indicate international research collaborations. The United States is the most prominent contributor, reflecting its leadership in research, supported by strong research infrastructure and investment in educational AI. Sweden and Israel occupy intermediate positions, demonstrating active collaboration and serving as important links between regional and international research efforts. Denmark, although contributing fewer publications, remains connected through collaborative partnerships, particularly within the Nordic region.

The network reveals a limited but meaningful pattern of international collaboration, with the United States serving as the dominant research hub. While the field is expanding globally, collaboration

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remains concentrated among a few countries. These findings highlight the need to strengthen international partnerships, particularly by engaging underrepresented regions, to promote knowledge sharing and advance AI-driven science teacher training worldwide.

Figure 6.

Collaboration network among nations with studies on AI-focused teacher training in science education.

Institutional Collaboration Network Analysis

Figure 7 shows a highly interconnected institutional collaboration network in AI-focused teacher training for science education, dominated by German-speaking institutions. Universities such as ***Technische Universität Darmstadt****,* ***Universität zu Köln****,* ***Technische Universität Dresden****,* ***Universität Konstanz****, and* ***Universität Leipzig*** *form the core of the network, reflecting strong and sustained collaboration in science education, biology education, and teacher training. Several institutions serve as collaboration hubs, linking research universities with teacher education institutions and promoting interdisciplinary research.*

The network also includes the ***University of Teacher Education Thurgau*** *(Switzerland) and the* ***University of Salzburg*** *(Austria), indicating cross-national collaboration within the German-speaking academic community. Overall, the findings reveal a cohesive and mature institutional research network characterized by strong national partnerships and selective international collaboration, supporting knowledge sharing and advancing AI integration in science teacher education.*

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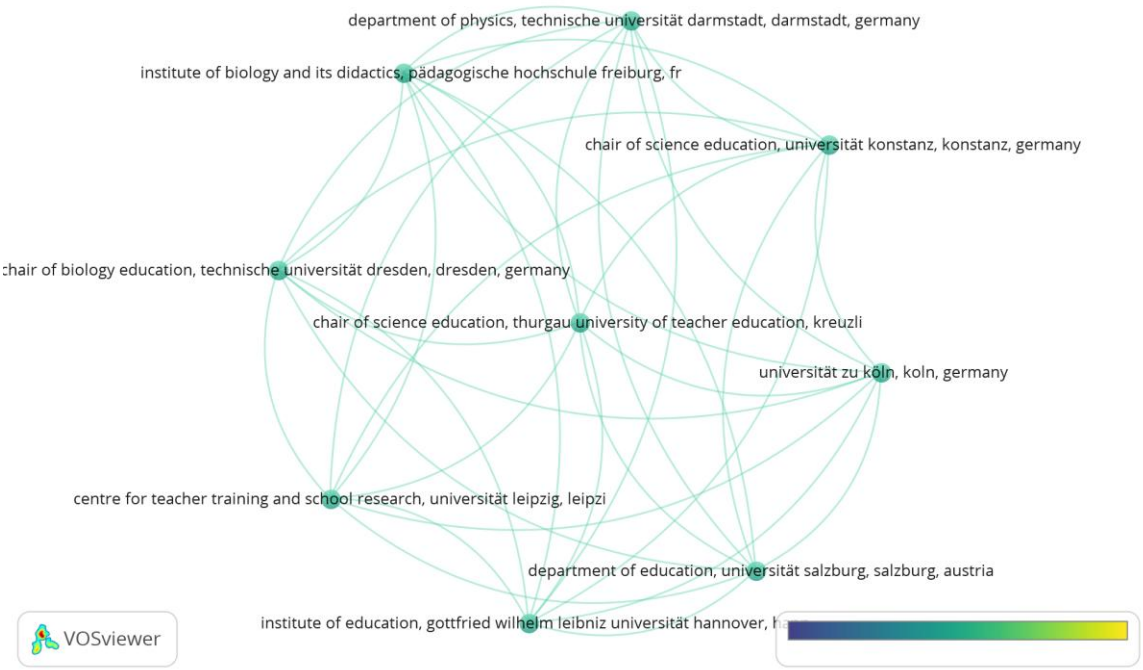

Figure 7. *Collaboration network among Institutions of authors with studies on AI-focused teachers training in Science Education*

Institutional Publication Output

Figure 8 presents the publication output of institutions engaged in AI-focused teacher training for science education. Universidad de Chile leads with three publications, followed by Arizona State University, Universidad Europea de Madrid, University of Georgia College of Engineering, Universität Hamburg, Universität zu Köln, and the Weizmann Institute of Science with two publications each. Other institutions, including the Arab American University, Bauman Moscow State Technical University, and the Chinese University of Hong Kong, contributed one publication, reflecting emerging participation from the Middle East, Russia, and Asia.

The findings indicate that research is concentrated in a small group of leading universities while attracting contributions from a broader range of institutions worldwide. The collaboration network further highlights growing international engagement and underscores opportunities for stronger inter-institutional partnerships to promote knowledge exchange and advance AI-driven teacher training in science education.

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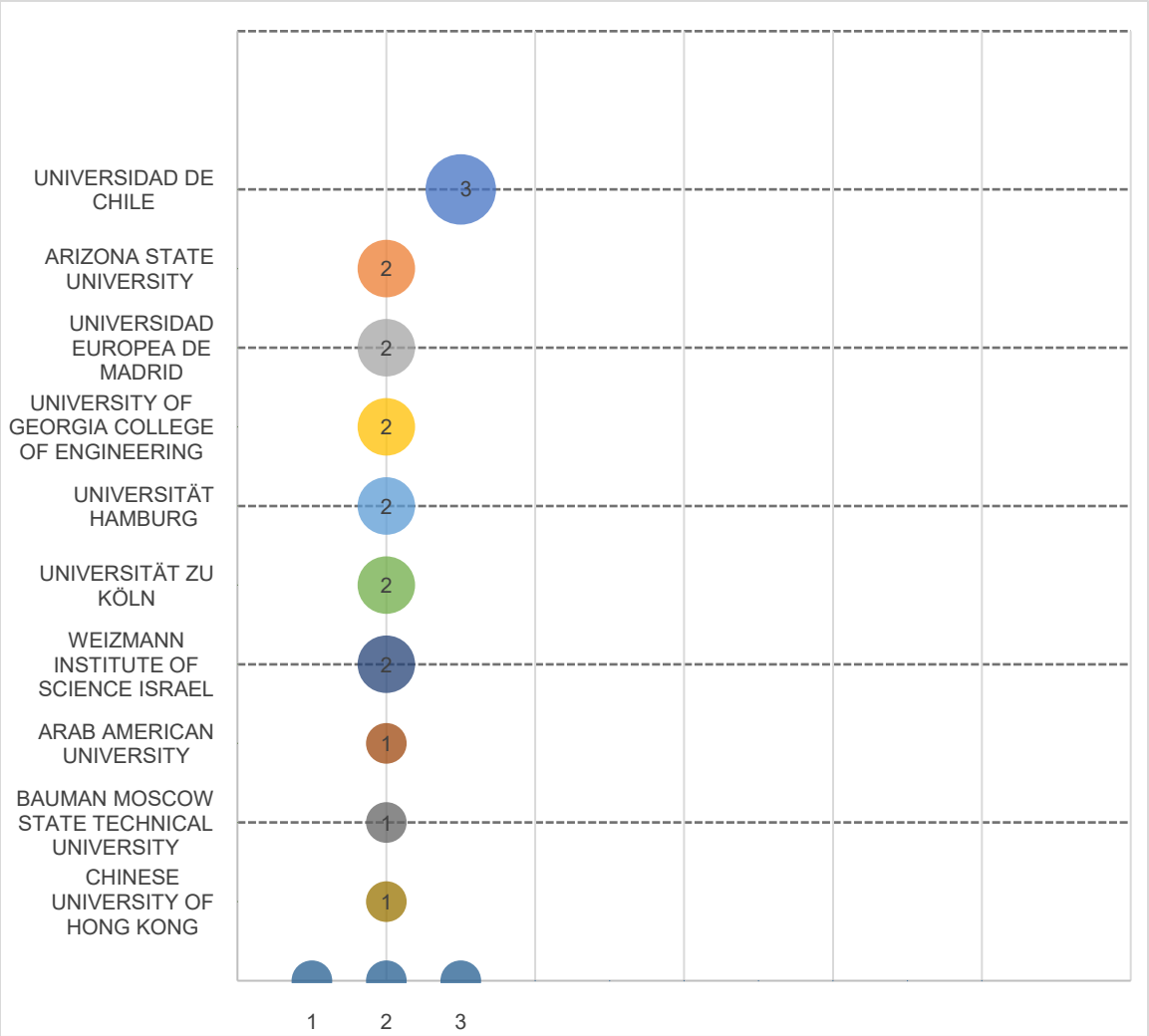

Figure 8. Top 10 institutions by number of publications on AI-focused teachers training for science education.

Figure 9 shows the collaboration network of authors involved in AI-focused teacher training in science education demonstrates a balanced and well-connected structure, with all authors such as Becker, Sebastian; Berber, Sandra; Bruckermann, Till; Bruckner, Mathea; Finger, Alexander; Huwer, Johannes; Kremser, Erik; Maurer, Nikolai; Meier, Monique; Thoms, Lars Jochen; Thyssen Christoph, are having an equal total link strength of eleven (11). This uniformity indicates that each author maintains a comparable level of collaborative engagement, suggesting a highly cooperative research community. The absence of dominance by any single author implies that expertise and contributions are shared equitably, promoting inclusivity in knowledge production.

Such a network structure also reflects a multidisciplinary and potentially international collaboration, as AI-focused teacher training in science education requires integration of educational research, technology, and subject-specific knowledge. The equal link strength facilitates efficient dissemination of ideas and findings, enhancing the collective impact of the network. Overall, the observed

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collaboration pattern indicates a cohesive scholarly community that is well-positioned to advance innovative strategies for AI integration in science teacher training.

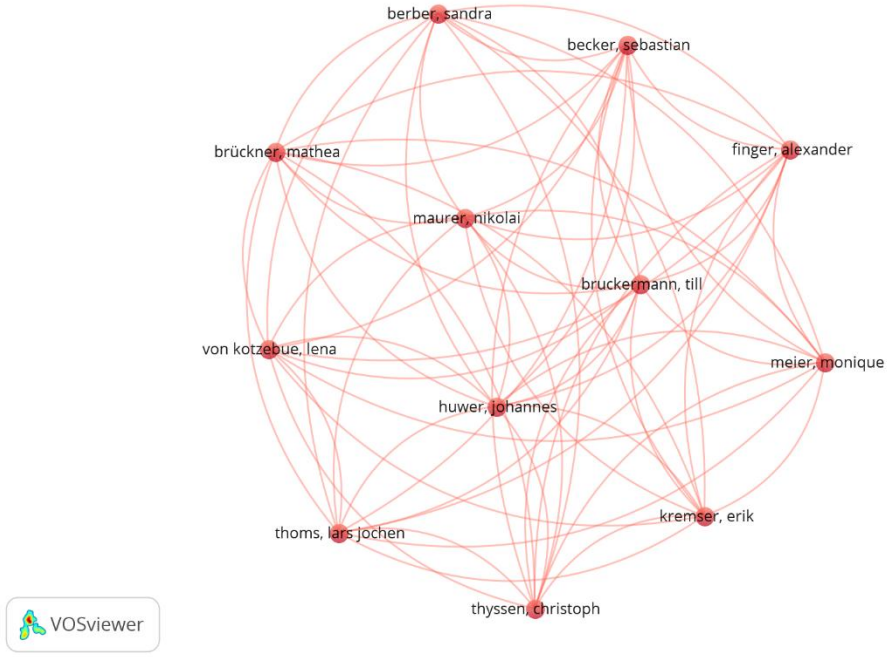

Figure 9. Collaboration network among authors with studies on AI-focused teachers training in Science Education

Keyword Co-occurrence and Hotspot Analysis

Figure 10 reveals a dynamic and evolving research landscape in AI-focused teacher education and training, organized into five interconnected thematic clusters. Artificial intelligence emerges as the central theme, with strong links to ChatGPT, lesson planning, technology integration, simulations, and professional development, reflecting a shift from conceptual discussions to practical classroom applications.

The analysis highlights several emerging trends. Teacher education and preservice teachers are increasingly recognized as key entry points for AI integration, supported by the growing use of generative AI, intelligent tutoring systems, and machine learning. AI literacy has also become a major research focus, emphasizing the need for teachers to develop conceptual, ethical, and pedagogical competencies for effective AI use. In addition, science education and STEM have emerged as important contexts for AI-enhanced teaching, particularly in lesson planning, inquiry-based learning, and student engagement.

The hotspot analysis suggests several future research directions, including the development of comprehensive AI literacy frameworks, evaluation of AI-assisted teaching strategies, interdisciplinary STEM–AI integration, longitudinal studies on preservice teacher development, and ethical frameworks for responsible AI implementation. Overall, the findings indicate that the field is rapidly expanding, with increasing emphasis on practical applications, teacher preparedness, and the effective and ethical integration of AI in science education.

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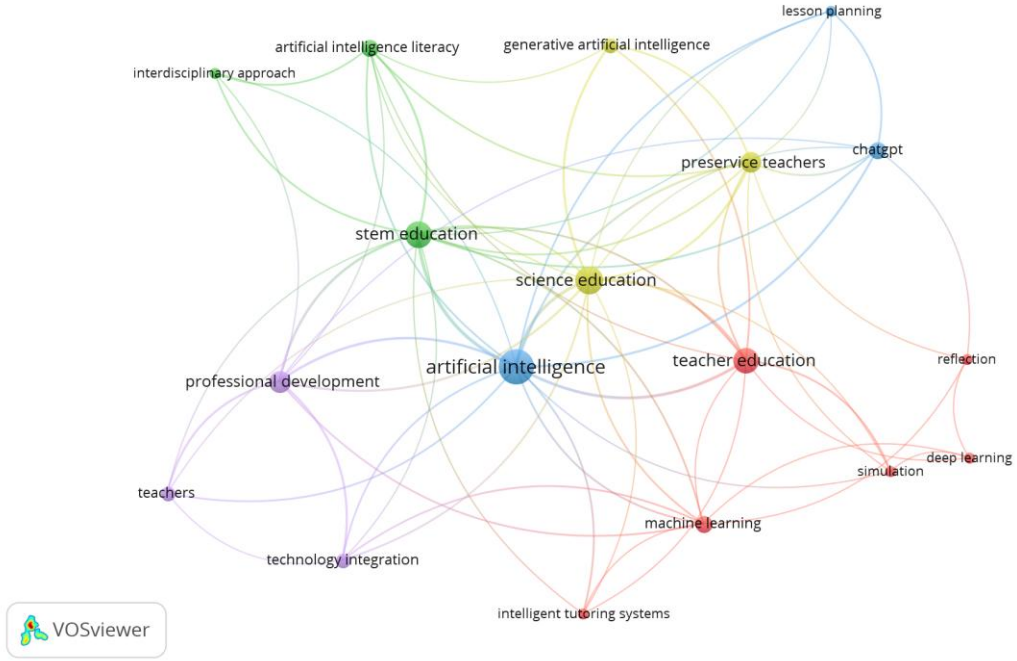

Figure 10. Network visualization (Hotspots) of keywords based on occurrence time with emphasis on the centrality and frequency of Artificial Intelligence and Teacher Education/Training.

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CONCLUSION

The study of AI-focused teacher training in science education reveals a rapidly evolving and increasingly application-oriented research field. Publication trends from 2021 to 2025 indicate clear growth, with early foundational studies (2021–2022) highly cited and a surge of publications in 2025 reflecting growing scholarly and practical interest. Despite lower mean citations for recent studies, early works have established conceptual and empirical anchors that guide current research trajectories.

Keyword co-occurrence and hotspot analyses highlight the centrality of artificial intelligence as both a conceptual and practical tool, with thematic clusters emphasizing teacher education, preservice training, AI literacy, and subject-specific applications in science and STEM. The research focus is shifting from foundational AI technologies toward applied, pedagogy-driven, and discipline-sensitive implementations, while emerging topics such as Generative AI, ChatGPT, and intelligent tutoring systems signal the field's forward-looking orientation.

Contributions are geographically diverse but concentrated in Europe and North America, particularly Germany and the United States. Institutional networks reveal strong national hubs complemented by selective international collaboration, while author networks demonstrate a cooperative, multidisciplinary scholarly community. Journals and conference proceedings, especially high-impact sources like Frontiers in Education, Education Sciences, and the ACM International Conference Series, provide rigorous and influential platforms for disseminating research.

In conclusion, the findings suggest that AI-focused teacher training in science education is maturing into a structured, globally relevant domain. The field is characterized by interdisciplinary collaboration, high-quality publications, and a growing emphasis on practical, ethical, and pedagogically meaningful integration of AI in teacher preparation and professional development. Future research should focus on AI literacy frameworks, effectiveness studies, interdisciplinary models, longitudinal impacts, and responsible implementation to sustain the field's growth and relevance.

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