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Mapping Research Trends in Experiential Learning and Design Thinking for Science Teacher Education

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This study explores research trends in Experiential Learning and Design Thinking for science teacher education through a PRISMA-guided systematic review and bibliometric analysis. A total of 237 Scopus-indexed publications (2020–2025) were analyzed to identify thematic clusters, methodological developments, and scholarly collaboration. The findings highlight growing global interest in AI literacy, experiential pedagogy, and digital instructional innovation. Six thematic clusters emerged: AI education and computational thinking, digital curriculum platforms, experiential learning models, design-based pedagogy, teacher professional development, and AI ethics and digital competence. Bibliometric mapping illustrates a multidisciplinary convergence among education, computer science, and engineering. Furthermore, ethical considerations, platform equity, and empirical validation remain pressing research needs. By integrating qualitative synthesis and quantitative bibliometric insights, this study provides a conceptual foundation for advancing AI-enhanced science teacher education and guiding future research in innovative pedagogy. The thematic findings further offer insights for designing reflective, inclusive, and evidence-based teacher preparation programs.

Keywords: experiential learning, design thinking, digital learning ecosystems, science teacher education, PRISMA-Guided bibliometric analysis

INTRODUCTION

In the era of educational transformation, Experiential Learning and Design Thinking have emerged as vital pedagogical strategies for preparing science teachers to navigate

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the challenges of 21st-century education. Experiential Learning offers hands-on, reflective learning experiences that connect theory with practice, fostering deep engagement and critical thinking among pre-service teachers (Rahmi, 2024; Walling, 2025). Complementing this, Design Thinking provides a non-linear, user-centered framework that cultivates innovation, problem-solving, and empathy-driven teaching approaches (Dell'Era et al., 2025; Reddy & Reddy, 2023).

These pedagogies are increasingly situated within Digital Learning Ecosystems (DLEs)—integrated environments that utilize AI technologies, learning management systems (LMS), and collaborative digital tools to support flexible, data-informed, and personalized instruction (Rojas & Chiappe, 2024; Techakosit & Rukngam, 2024). The convergence of Experiential Learning, Design Thinking, and DLEs aligns with contemporary movements toward AI literacy, competency-based education, and interdisciplinary learning in science teacher education (Fonseca & Zegers, 2024; Nasharuddin et al., 2024).

Despite their growing adoption, the integration of these frameworks remains underexplored as a cohesive research domain. While previous studies have examined each component independently, few have systematically synthesized how these elements converge to shape science teacher education—particularly in the context of AI-enhanced learning and instructional innovation. Moreover, there is limited understanding of how the research landscape has evolved over time in terms of trends, networks, and methodological shifts.

The interconnection among experiential learning processes, design thinking approaches, and the development of AI literacy in science teacher education reveals a complex but crucial relationship. Experiential learning encourages direct engagement and reflective cycles (Kolb, 1984; Rahmi, 2024); design thinking introduces iterative, empathy-based problem solving (Galoyan et al., 2022; Dell'Era et al., 2025); and AI literacy equips future science teachers with essential digital competencies and ethical understanding (Nasharuddin et al., 2024; Sperling et al., 2024). Integrating these elements is fundamental to cultivating teachers who can navigate and innovate within AI-driven digital learning environments. Therefore, mapping the research trends at the intersection of these constructs is essential for identifying emerging themes, methodological practices, and collaborative networks that are shaping the future of science teacher preparation.

Given these gaps, a comprehensive and evidence-based mapping is needed to clarify the current state of scholarship and inform future directions. To fulfill this need, the present study undertakes a PRISMA-guided systematic review and bibliometric analysis of Scopus-indexed literature, focusing on the intersection of Experiential Learning and Design Thinking within the domain of science teacher education.

Research Questions and Research Objectives

Research Questions

RQ1: What are the developing research directions, thematic focuses, and key contributors, and methodological approaches in Experiential Learning and Design Thinking for science teacher education based on a PRISMA-guided systematic analysis?

RQ2: How has the research landscape, including publication growth, co-authorship networks, citation impact, and thematic evolution, on Experiential Learning and Design Thinking for science teacher education evolved over time, as revealed by bibliometric analysis?

Research Objectives

RO1: To systematically map and analyze research trends, thematic areas, and methodological developments through a PRISMA-guided systematic review of Experiential Learning and Design Thinking for science teacher education.

RO2: To conduct a bibliometric analysis to map the evolution of research, including publication trends, citation impact, and collaborative networks, in Experiential Learning and Design Thinking for science teacher education.

Theoretical Background and Literature Review

Experiential Learning

Experiential Learning is an active, hands-on educational approach that connects classroom theory with real-world applications. Grounded in Kolb's experiential learning cycle, it comprises four stages: experience, reflection, conceptualization, and active experimentation, fostering deep learning, critical thinking, and collaboration (Rahmi, 2024). This method is widely applied across disciplines, including STEM education and international organizations (Walling, 2025). Common practices, such as internships, service-learning, study abroad programs, and clinical education, facilitate knowledge acquisition through direct participation (Below, 2024; Salimon, 2022). Faculty play a crucial role in guiding reflective learning to ensure meaningful educational outcomes. However, challenges such as resource constraints and institutional readiness must be addressed for effective implementation (Rahmi, 2024).

Design Thinking

Design thinking is a non-linear, iterative problem-solving approach that fosters creativity and innovation across various contexts (Reddy & Reddy, 2023). It emphasizes user-centered design, encouraging deep understanding of user needs, challenging assumptions, and refining solutions through stages like ideation, prototyping, and testing (Dell'Era et al., 2025; Galoyan et al., 2022). Widely applied in fields such as education and product development, it engages learners and professionals in collaborative, solution-oriented processes (Madhav & Murthy, 2024).

Digital Learning Ecosystems

Digital Learning Ecosystems (DLEs) are integrated digital environments that support flexible, collaborative, and personalized learning through AI, LMS platforms, and digital tools (Rojas & Chiappe, 2024; Pinto-Llorente & Izquierdo-Álvarez, 2024). In science teacher education, DLEs enable experiential learning and design thinking, fostering AI competencies and inquiry skills. Techakosit and Rukngam (2023) propose a constructionist model within DLEs that emphasizes artifact creation, problem-solving, and reflection, promoting self-directed learning. These ecosystems enhance engagement, feedback, and pedagogical innovation aligned with 21st-century skills (Fonseca et al., 2024).

Science Teacher Education

Science Teacher Education enhances educators' content knowledge, instructional strategies, and assessment methods to improve student learning. Active learning in professional development (PD) significantly strengthens teaching quality and student outcomes (You et al., 2024), while in-service training improves alternative assessment strategies essential for modern classrooms (Oliemat et al., 2025). Developing science literacy necessitates curriculum reforms in teacher education (Klemenčič et al., 2023). Effective primary science instruction integrates curriculum planning, authentic assessments, and interdisciplinary learning (Forbes, 2023), ensuring educators can foster scientific literacy and inquiry-based learning effectively.

PRISMA-Guided Bibliometric Analysis

PRISMA-Guided Bibliometric Analysis integrates the PRISMA framework with bibliometric techniques to examine publication trends, co-authorship networks, and thematic clusters, ensuring comprehensive and transparent literature synthesis (Prasetiyo et al., 2024). This approach systematically selects and evaluates studies, enhancing the identification of key research determinants and thematic gaps (Thaker et al., 2024). Widely applied in expert retrieval studies, it analyzes co-authorship patterns and thematic groupings across disciplines (Pham & Le, 2024). By combining quantitative bibliometric analysis with systematic review principles, this method strengthens research validity and supports evidence-based decision-making.

METHOD

The present research employs a systematic literature review approach, integrating PRISMA-guided systematic analysis and bibliometric analysis to investigate research trends in Experiential Learning and Design Thinking for science teacher education. The methodology is structured into two main phases, corresponding to the research objectives.

PRISMA-Guided Systematic Analysis

To address the first research objective, a systematic review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, consisting of four key stages.

Identification: Relevant publications are retrieved from Scopus using a structured search strategy with Boolean operators and predefined keywords related to Experiential

Learning, Design Thinking, and Science Teacher Education. The search is limited to peer-reviewed journal articles and conference proceedings (2020–2025) to ensure recent, high-impact research.

Screening: A rigorous screening process refines the dataset by applying inclusion criteria—studies must be published in open-access journals or academic conferences, explicitly examine Experiential Learning or Design Thinking for science teacher education, be written in English, and indexed in Scopus. Duplicates and non-relevant papers are removed to ensure data integrity and accuracy.

Eligibility: Abstracts and full texts are reviewed to ensure alignment with the research focus. Only studies explicitly examining the intersection of Experiential Learning and Design Thinking for science teacher education are retained, while articles lacking methodological transparency or empirical evidence are excluded.

Data Extraction and Synthesis: Key data from eligible studies, including publication details, research objectives, methodologies, findings, and thematic focuses, are extracted. A thematic analysis identifies emerging research trends, gaps, and methodological advancements in the field.

The final dataset is analyzed based on the following search criteria:

(TITLE-ABS-KEY ("artificial intelligence" OR "ai") AND PUBYEAR > 2019 AND PUBYEAR < 2026) AND (“design AND thinking” OR ”design”) AND (“competency” OR “competencies” OR “literacy”) AND (“experiential AND learning” OR “experiential”) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp")) AND (LIMIT-TO (SRCTYPE , "j") OR LIMIT-TO (SRCTYPE , "p")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (OA , "all"))

Bibliometric Analysis

To address the second research objective, a bibliometric analysis of Scopus-indexed publications examines research evolution, co-authorship networks, keyword co-occurrence patterns, and citation impact, following a structured process to ensure reliability and validity.

Data Collection and Processing: The bibliometric dataset, sourced from Scopus, is exported in RIS, EndNote, or RefWorks formats for compatibility with bibliometric analysis tools. A data-cleaning process removes duplicates and non-relevant entries to ensure high-quality publications. Inclusion criteria prioritize peer-reviewed journal articles and conference proceedings relevant to Experiential Learning and Design Thinking for science teacher education.

Co-Occurrence and Citation Analysis: A co-occurrence analysis using VOSviewer identifies key research themes based on keyword frequency and link strength. The analysis applies a full counting method, with a minimum occurrence threshold of four; selecting 77 relevant keywords from 1,628 analyzed keywords. To refine the dataset, the 39 most influential keywords are categorized into six thematic clusters, representing major research domains: Cluster 1 (9 items), Cluster 2 (7 items), Cluster 3 (7 items), Cluster 4 (6 items), Cluster 5 (6 items), and Cluster 6 (4 items).

Network Mapping and Visualization: The bibliometric network, visualized using VOSviewer, identifies collaborative relationships among authors, institutions, and thematic clusters. Co-authorship analysis determines key contributors and institutional collaborations, while citation analysis assesses the impact of influential works through h-index values and field-weighted citation impact (FWCI).

Data Analysis and Interpretation

Findings from PRISMA-guided systematic analysis and bibliometric analysis are synthesized to map research trends, integrating qualitative insights from the systematic review with quantitative bibliometric patterns. The study focuses on identifying key contributions and influential scholars, determining emerging themes and research clusters, and highlighting methodological advancements and research gaps.

Validity and Reliability Measures

Methodological rigor was ensured through a consensus coding process conducted by two researchers with expertise in science education and qualitative analysis. Both independently reviewed and coded the eligible studies based on predefined thematic categories.

After independent coding, they compared results, discussed discrepancies, and reached consensus through iterative dialogue. An inter-coder agreement rate of over 90% was achieved, reinforcing the reliability of thematic classification.

Additionally, the study employed cross-referencing with multiple indexing sources for data validation and incorporated PRISMA flow diagrams and bibliometric visualizations to enhance transparency and reproducibility.

Ethical Considerations

As this study relies solely on secondary data from published literature, no ethical approval is required; however, all sources are properly cited, and data collection follows academic integrity and reproducibility standards to ensure research transparency.

FINDINGS

This section presents findings from the systematic review and bibliometric analysis, aligning with the research objectives. The study identifies emerging trends, methodologies, and thematic developments in Experiential Learning and Design Thinking for science teacher education. The PRISMA-guided review explores research scope and key gaps, while the bibliometric analysis examines publication trends, researcher networks, and keyword distributions. Findings are structured into (1) PRISMA-Guided Systematic Analysis, highlighting core themes and research gaps, and (2) Bibliometric Analysis, mapping publication trends and collaboration patterns.

Research Trends in Experiential Learning and Design Thinking

To address the first research objective, a systematic review was conducted to analyze key research trends and methodological advancements, offering insights into the integration of Experiential Learning and Design Thinking for science teacher education.

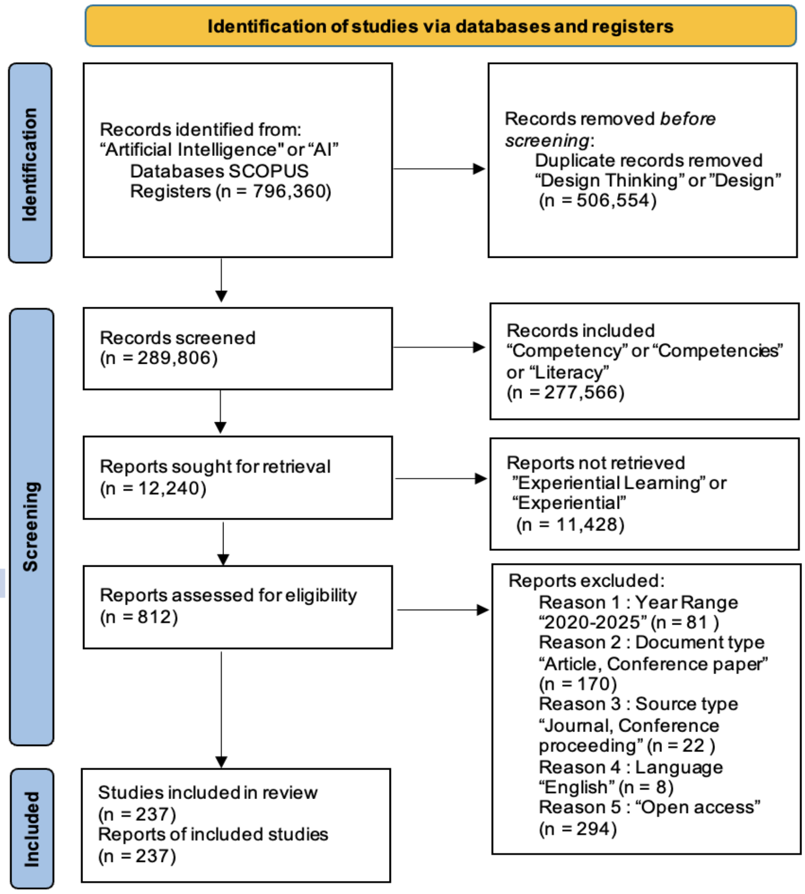

Figure 1
The PRISMA of experiential learning and design thinking for science teacher education

Figure 1 presents the PRISMA-guided systematic review process undertaken to map and analyze research trends in Experiential Learning and Design Thinking for science teacher education, in alignment with the first research objective. The figure illustrates a four-stage process—identification, screening, eligibility assessment, and inclusion—ensuring methodological rigor and transparency. In the identification phase, an initial SCOPUS search yielded 796,360 records related to "Artificial Intelligence" or "AI." Of these, 506,554 duplicate and irrelevant records, which did not explicitly relate to "Design Thinking" or "Design," were removed, narrowing the dataset to publications within the research scope.

During the screening phase, 289,806 records were assessed for the presence of keywords such as "Competency," "Competencies," or "Literacy." A total of 277,566 records met the criteria and advanced to the retrieval stage, while 11,428 were excluded for lacking explicit references to “Experiential Learning” or “Experiential.” In the eligibility assessment phase, 812 reports underwent full-text review based on predefined inclusion and exclusion criteria. Studies were excluded for the following reasons: temporal range (2020–2025): 81 studies; document type: 170 (non-journal articles or conference papers); source type: 22 (non-peer-reviewed sources); language: 8 (non-English); and open access: 294 studies. Further, articles were retained only if they explicitly examined the intersection between Experiential Learning and Design Thinking with the context of science teacher education. Those lacking this conceptual alignment or empirical rigor were excluded. In the final inclusion phase, 237 studies met all criteria and were included in the systematic review. These studies form the empirical foundation for mapping research trends, identifying core thematic areas, analyzing methodological developments, and exploring the intersection of Experiential Learning and Design Thinking within Digital Learning Ecosystems for science teacher education. By adopting a PRISMA-guided methodology, this study ensures a comprehensive, replicable, and evidence-based synthesis of the literature, contributing to a deeper understanding of the evolving research landscape in this domain.

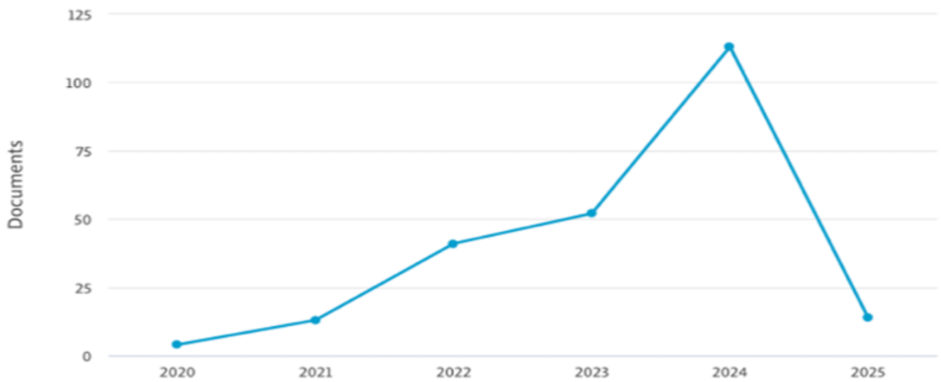

Figure 2
The documents by year of experiential learning and design thinking for science teacher education

Figure 2 presents the distribution of 237 included studies by publication year, aligning with the final inclusion phase of Figure 1 (PRISMA flow diagram). The trend reveals a significant increase in research publications on Experiential Learning and Design Thinking for science teacher education from 2020 to 2024, peaking in 2024 with 113 publications. This upward trajectory suggests growing scholarly interest in the topic, possibly driven by the increasing integration of AI, competency-based learning, and digital ecosystems in teacher education. The notable decline in 2025 (14 publications) may be attributed to data incompleteness or the lag in indexing recent publications. These findings, derived from the systematic review process in Figure 1, reinforce the evolving nature of research in this domain and highlight the importance of continued exploration into its pedagogical implications.

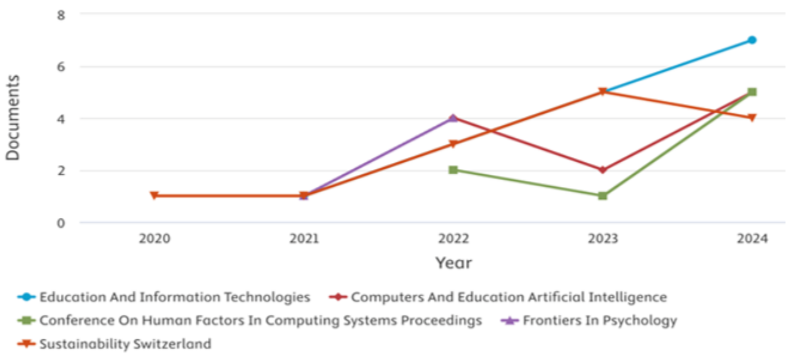

Figure 3
The documents per year by source of experiential learning and design thinking for science teacher education

Figure 3 presents the distribution of 237 included studies by publication source, providing further insights into the research landscape outlined in Figure 1 (PRISMA flow diagram). The figure illustrates the annual publication trends across key academic sources, highlighting journals and conference proceedings that contribute significantly to the discourse on Experiential Learning and Design Thinking for science teacher education. Notably, Sustainability Switzerland (14 documents), Computers and Education Artificial Intelligence (11 documents), and Conference on Human Factors in Computing Systems Proceedings (8 documents) emerge as leading sources. The trend indicates a diversification of publication venues, with an increasing presence in interdisciplinary journals that emphasize education, technology, and psychology. This distribution aligns with the systematic review process in Figure 1, reinforcing the rigor of source selection and validating the research trends identified in the study. The findings suggest that the integration of Experiential Learning and Design Thinking within AI-supported and digitally mediated educational environments, necessitating further bibliometric analysis to track evolving themes.

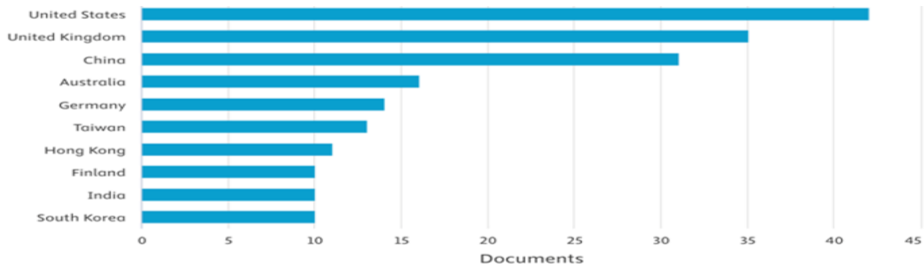

Figure 4
The documents by country or territory of experiential learning and design thinking for science teacher education

Figure 4 illustrates the geographical distribution of 237 included studies, aligning with the final inclusion phase of Figure 1 (PRISMA flow diagram). The data highlights the leading contributors to research on Experiential Learning and Design Thinking for science teacher education, with the United States (42 studies), United Kingdom (35 studies), and China (31 studies) emerging as the most prolific countries. Other significant contributors include Australia (16), Germany (14), Taiwan (13), and Hong Kong (11), reflecting a strong research presence across North America, Europe, and Asia. This distribution suggests that the integration of Experiential Learning and Design Thinking into teacher education is a global research priority, particularly in regions with well-established and AI-driven educational frameworks. These findings reinforce the systematic review process in Figure 1, demonstrating the international scope of scholarly discourse and the need for continued cross-regional collaboration to enhance the adoption of innovative pedagogical models in science education.

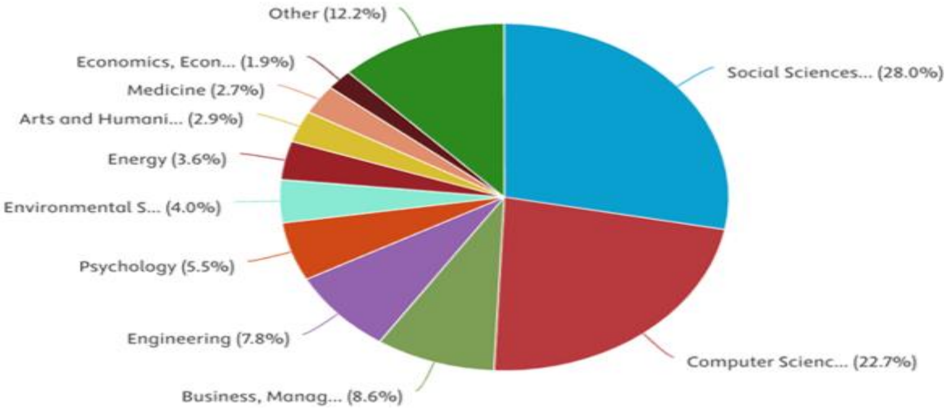

Figure 5
The documents by subject area of experiential learning and design for science teacher education

Figure 5 presents the distribution of 237 included studies by subject area, aligning with the final inclusion phase of Figure 1 (PRISMA flow diagram). The data reveals that research on Experiential Learning and Design Thinking for science teacher education spans multiple disciplines, with Social Sciences (133 studies, 28.0%) and Computer Science (108 studies, 22.7%) as the dominant fields. The prominence of Social Sciences underscores the pedagogical and cognitive aspects of experiential learning, while Computer Science's substantial contribution reflects the role of digital technologies, artificial intelligence, and human-computer interaction in modern teacher education. Other significant domains include Business, Management and Accounting (41 studies, 8.6%), Engineering (37 studies, 7.8%), and Psychology (26 studies, 5.5%), indicating an interdisciplinary approach that integrates educational methodologies, technological advancements, and psychological perspectives. The presence of Environmental Science, Energy, Arts and Humanities, and Medicine further suggests the applicability of these frameworks beyond education, highlighting their broader impact. These findings, derived from the systematic review process in Figure 1, reinforce the multidisciplinary nature of this research domain, emphasizing the importance of cross-sector collaboration to advance innovative, technology-enhanced pedagogical models in science teacher education.

Bibliometric Analysis of Experiential Learning and Design Thinking

To address the second research objective, a bibliometric analysis was conducted to examine publication trends, citation impact, and scholarly collaborations, offering insights into the evolution of research on Experiential Learning and Design Thinking for science teacher education.

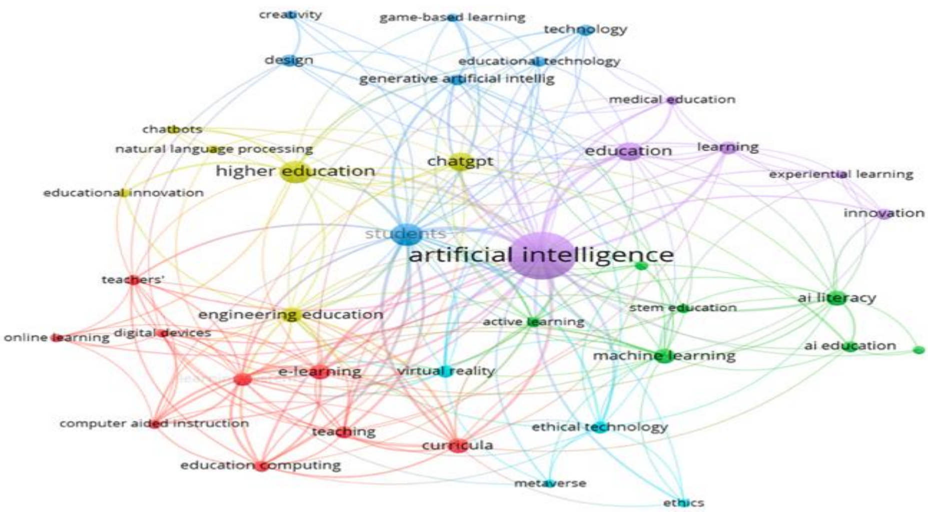

Figure 6
The bibliometric analysis of research related to experiential learning and design thinking for AI competency development in science teacher education

Figure 6 presents the bibliometric analysis results, following the structured process outlined in Section 4.2. This network visualization, generated using VOSviewer, illustrates the co-occurrence of keywords extracted from Scopus-indexed publications, offering insights into the evolution of research trends, scholarly collaborations, and thematic areas in Experiential Learning and Design Thinking for AI Competency Development in Science Teacher Education. The analysis identifies 77 relevant keywords—meeting a minimum occurrence threshold of four—out of a total of 1,628 analyzed keywords. These are organized into six thematic clusters, each representing a distinct research domain: Cluster 1 (9 items) focuses on e-learning, education computing, online learning, and digital devices, highlighting the technological infrastructure supporting AI-driven education; Cluster 2 (7 items) includes engineering education, higher education, educational innovation, and chatbots, underscoring AI's role in facilitating interactive and automated learning; Cluster 3 (7 items) centers on machine learning, AI education, STEM education, and AI literacy, reflecting the expanding integration of AI competencies in science teacher training; Cluster 4 (6 items) features experiential learning, active learning, and innovation, reinforcing the pedagogical underpinnings of design thinking methodologies; Cluster 5 (6 items) comprises virtual reality, curricula, metaverse, and ethical technology, pointing to the emergence of immersive and ethically oriented AI education; and Cluster 6 (4 items) highlights game-based learning, creativity, and educational technology, illustrating the engagement-centric aspects of developing AI competencies.

The largest node, "Artificial Intelligence," is the central hub of research discussions, with strong interconnections to "machine learning," "AI literacy," "education technology," and "STEM education." The prominence of "chatGPT" and "generative artificial intelligence" suggests a recent shift toward AI-driven automation in teaching and assessment.

Research Evolution and Citation Impact: The bibliometric analysis also tracks the temporal evolution of research themes, showing a transition from early AI-assisted instruction to advanced AI-driven pedagogy, machine learning applications, and human-AI collaboration in education. The presence of "ethics," "AI governance," and "responsible AI" in the network highlights ongoing concerns regarding the ethical implications of AI in teacher education. The citation impact analysis reveals that publications focusing on "AI education," "curricula design," and "experiential learning methodologies" have received higher citation counts, signifying their influence in shaping educational policies and AI competency frameworks.

Co-Authorship Networks and Interdisciplinary Collaboration: The co-authorship analysis demonstrates strong interdisciplinary collaboration among researchers in education, computer science, psychology, and engineering. The high connectivity among terms such as "teaching," "higher education," and "students" suggests a focus on AI-enhanced instructional design, adaptive learning environments, and competency-based assessment strategies.

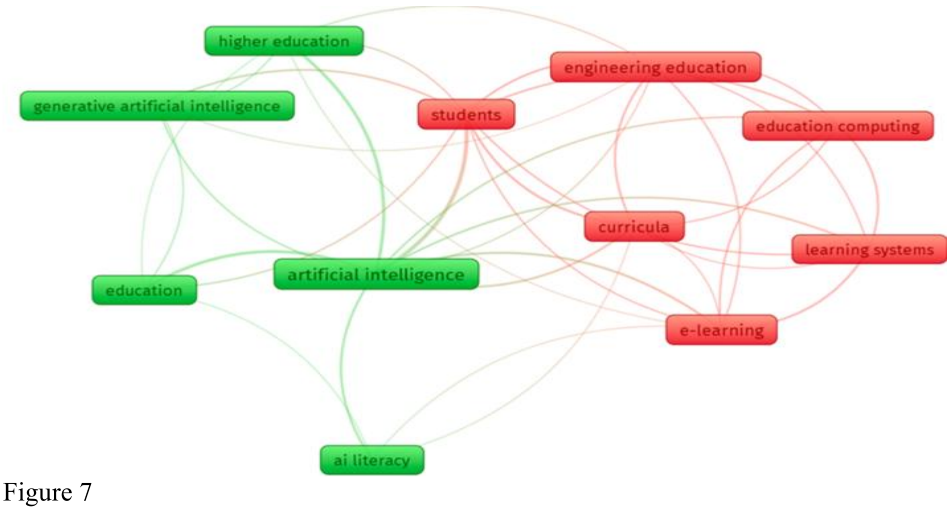

Figure 7
Clustering frames of keywords in titles and abstracts of experiential learning and design thinking for AI competency development in science teacher education

Figure 7 presents the clustering frames of keywords extracted from the titles and abstracts of research focusing on Experiential Learning and Design Thinking for AI Competency Development in Science Teacher Education. This network visualization, generated using VOSviewer, categorizes keywords into two primary clusters (green and red), each representing distinct thematic domains within the research landscape.

Cluster Analysis and Thematic Distribution: The green cluster encompasses research themes associated with Artificial Intelligence (AI) and AI literacy, with an emphasis on their integration into educational contexts. The central node, “Artificial Intelligence,” is closely linked to terms such as “education,” “AI literacy,” “higher education,” and “generative artificial intelligence.” These associations reflect a concentrated research focus on AI-driven pedagogical frameworks, digital literacy development, and competency-based instruction within teacher education. In contrast, the red cluster centers on technology-enhanced learning environments, incorporating keywords such as “e-learning,” “education computing,” “learning systems,” and “curricula.” Notably, the node “students” serves as a semantic bridge between AI-focused research and digital innovation in learning, underscoring the importance of student-centered approaches in developing AI competencies. The presence of “engineering education” within this cluster further highlights the interdisciplinary integration of AI, computational thinking, and science teacher education.

Keyword Interconnections and Research Implications: The strong interrelationships between clusters suggest that the development of AI competencies in science teacher education is shaped by the integration of AI literacy, curriculum design, and experiential learning methodologies. The linkage between “students” and “AI literacy” underscores the increasing demand for AI-related skill development among future educators. Additionally, the connections among “curricula,” “learning systems,” and “e-learning” reflect ongoing discourse surrounding the transformation of digital learning environments in science teacher education.

Moreover, the emergence of "generative artificial intelligence" highlights the increasing impact of large language models, AI-powered learning tools, and automated assessment systems in teacher training programs. The network also reinforces the role of design thinking and experiential learning approaches in shaping adaptive, competency-based AI education.

Although not all keywords in Table 1 appear as high-frequency terms in Figure 7, each term was selected based on its conceptual importance, frequency in broader bibliometric analysis (Figure 6), and its centrality in the theoretical framework of the study. The inclusion of “Design Thinking” and “Experiential Learning,” for instance, reflects their foundational role in both the research objective and literature review, despite not being central nodes in the network visualization of Figure 7.

Table 1
Keywords of mapping research trends in experiential learning and design thinking for AI competency development in science teacher education

Keywords	Description	Reference
Artificial Intelligence	a transformative force in science education, enabling personalized learning, real-time feedback, and adaptive instruction. While it enhances teaching and assessment practices, concerns such as content accuracy, teacher readiness, and ethical use call for robust training, infrastructure, and responsible integration strategies.	Almasri, (2024); Nugroho et al., 2024; Mustofa et al., 2025
AI Literacy	The competency of science teachers in AI principles, data literacy, ethical AI use, and pedagogical integration. It encompasses theoretical knowledge (episteme), practical application (techne), and professional judgment (phronesis) to ensure equitable and effective AI-driven instruction in the digital age.	Nasharuddin et al., 2024; Sperling et al., 2024; Valenzuela, 2025
Education	A digital and student-centered learning process supported by technology, where learners actively construct knowledge through self-directed inquiry, artifact creation, and interaction within a digital learning ecosystem. It emphasizes personalized learning, constructionist pedagogy, and 21st-century skill development in science education.	AlKanaan, 2022; Techakosit & Rukngam, 2024; Maphalala & Ajani, 2025
Engineering Education	The integration of AI-driven tools in STEM and engineering education enhances creativity, project development, and personalized learning. It incorporates intelligent tutoring, automated grading, and predictive analytics while addressing ethical concerns such as academic integrity, data privacy, and algorithmic bias to ensure responsible and innovative AI implementation.	Sun et al., 2024; Zhang & Chang, 2024; Rebelo, 2025
e-Learning	A technology-enhanced learning approach that provides flexibility and resource accessibility through online and blended models. It supports diverse teaching strategies but requires improvements in interaction, skill development, and integration of real-life scenarios to enhance teaching competencies and foster effective virtual learning environments.	Punzalan, 2023; Mahdiannur et al., 2024; Nuhoğlu et al., 2024
Learning Systems	AI-powered adaptive environments that personalize instruction through machine learning, intelligent tutoring, and gamification. They enhance engagement, motivation, and comprehension by aligning with learners' cognitive and emotional needs, while addressing challenges such as ethical use, data quality, and social interaction.	Duong et al., 2024; Rasmitadila et al., 2021; Senanayake et al., 2024
Design Thinking	A collaborative, iterative problem-solving approach that integrates empathy, ideation, prototyping, and testing. When combined with AI, it enhances creativity, efficiency, and human-machine synergy in addressing complex challenges, fostering innovation in education, assessment, and user-centered system development.	Galoyan et al., 2022; Kamnerddee et al., 2024; Twabu & Nakene-Mginqi, 2024
Experiential Learning	A hands-on, interactive approach that integrates real-world applications, AI-driven tools, and adaptive feedback to enhance learning outcomes. It fosters personalized learning, collaboration, and reflection, allowing learners to engage with AI technologies through immersive experiences and practical applications.	Alghowinem et al., 2024; Rathika et al., 2024; Fauzi et al., 2025
STEM Education	An interdisciplinary approach that integrates AI to enhance personalized learning, automate assessments, and support teacher development. AI-driven science and technology education fosters innovation, real-time feedback, and tailored instruction while addressing ethical concerns such as data privacy, inclusivity, and algorithmic bias.	Asrifan et al., 2024; Zhai, 2024; Zhai & Krajcik, 2024

The keywords summarized in Table 1 align with the thematic clusters identified through bibliometric analysis. They serve as conceptual anchors for understanding how core ideas such as AI literacy, experiential pedagogy, and digital ecosystems converge to support AI competency development, as further discussed in the following section.

DISCUSSION

This study aimed to map research trends in Experiential Learning and Design Thinking within science teacher education through a PRISMA-guided systematic review and bibliometric analysis. The findings revealed six distinct thematic clusters, each representing key priorities, conceptual frameworks, and emerging research gaps in the evolving field. Following the reviewers' suggestions, this section presents an expanded thematic discussion, supported by literature examples and implications for future inquiry.

Cluster 1: AI Education and Computational Thinking

This cluster highlights the integration of artificial intelligence (AI), computational thinking, and machine learning in teacher preparation. Galoyan et al. (2022) and Nasharuddin et al. (2024) emphasize the need for foundational AI literacy and critical understanding of algorithmic systems in science classrooms. The reviewed studies reflect a growing effort to embed AI-supported tools into science instruction. However, empirical investigations on the long-term impact of these integrations are limited, underscoring a need for experimental and longitudinal research.

Cluster 2: Digital Platforms and Curriculum Innovation

This cluster centers on redesigning science curricula using digital technologies, such as learning management systems (LMS), online simulations, and adaptive learning platforms. Reddy and Reddy (2023) demonstrated how design thinking can drive STEM curriculum transformation, while Rahmi (2024) integrated experiential learning into digital environments. Although innovations are evident, there is little discussion on issues of access, inclusivity, or digital equity. Future research should explore socio-technical challenges of digital learning ecosystems in teacher education.

Cluster 3: Experiential Learning and Active Experimentation

Research in this cluster draws heavily on Kolb's experiential learning cycle, emphasizing reflection, hands-on learning, and real-world application. Rahmi (2024) applied experiential models in AI-integrated classrooms, promoting active experimentation. Despite strong interest, cross-cultural comparisons and mixed-method evaluations are scarce, suggesting an opportunity to test experiential models across diverse educational contexts.

Cluster 4: Design Thinking and Creative Pedagogy

This cluster explores the application of design thinking—empathize, define, ideate, prototype, test—as a strategy to enhance creativity, innovation, and student-centered learning among pre-service teachers. Dell'Era et al. (2025) and Kamnerddee et al. (2024) provide compelling cases of integrating design thinking with AI for instructional planning. However, the field lacks evidence on the sustained impact of such approaches on teaching practice, presenting a critical direction for future studies.

Cluster 5: Professional Development and Reflective Teaching

Studies in this cluster focus on professional learning communities, AI-assisted mentorship, and reflective teaching frameworks. Rojas and Chiappe (2024) and Techakosit and Rukngam (2024) emphasized the value of digital ecosystems in building teacher autonomy and inquiry-based learning cultures. Most of the reviewed studies used self-report surveys without behavioral data, calling for rigorous mixed-method approaches to measure professional growth. Kamnerddee et al. (2024) conducted a quasi-experimental study involving AI-enhanced instructional design workshops for pre-service science teachers. The findings revealed a significant improvement in their reflective thinking, instructional planning, and collaboration scores as measured by a validated rubric. These results suggest that experiential professional development initiatives incorporating AI can strengthen teacher agency and practical readiness.

Cluster 6: AI Literacy, Ethics, and Digital Competence

This cluster responds to increasing concerns around AI ethics, digital citizenship, and responsible innovation in science teacher preparation. Prior studies by Sperling et al. (2024) and Sun et al. (2024) emphasized the need for ethical guidance in AI use. In this study, we propose two conceptual dimensions of AI competency—AIknowSense and AIethiGuard—to promote foundational AI awareness and ethical responsibility. However, standardized tools for evaluating ethical and digital behavior remain underdeveloped, indicating a pressing need for assessment innovation. In particular, Sperling et al. (2024) conducted a quasi-experimental study assessing the impact of an AI ethics module on teacher candidates. Their findings showed significant improvement in participants' ability to identify ethical dilemmas and articulate responsible AI use scenarios. Such evidence supports the structured inclusion of AI ethics in teacher education programs beyond theoretical discussion.

In sum, the thematic clusters demonstrate a growing convergence between experiential learning, design thinking, and AI integration in teacher education. The review confirms that while conceptual models are evolving, empirical validation remains limited. Addressing this gap requires co-creative research designs with educators, cross-national studies, and validated tools to assess AI ethics, creativity, and digital fluency in science teacher preparation programs. These future directions are essential for building resilient, ethical, and innovation-ready science teachers for the AI era. To strengthen science teacher education, universities should not only emphasize AI-related competencies but also embed structured opportunities for lesson planning and project-based pedagogy, as evidenced in recent AJE findings (Brilliananda et al., 2025; Sutarto et al., 2022). These approaches support holistic development and ensure readiness for dynamic classroom environments.

Recent studies underscore the importance of targeted lesson planning and project-based frameworks in pre-service teacher development. For instance, Brilliananda et al. (2025) revealed that while preservice teachers possess foundational knowledge, many still struggle with complex curriculum elements such as differentiated instruction and Pancasila learner profiles under Indonesia's Merdeka Curriculum. These findings echo the need for structured guidance in curriculum adaptation and pedagogical design.

Similarly, Sutarto et al. (2022) emphasized the efficacy of project-based learning in enhancing critical thinking and collaboration skills among preservice biology teachers, suggesting the integration of experiential approaches to develop broader professional competencies.

IMPLICATIONS

The findings of this study suggest that the integration of Experiential Learning and Design Thinking within science teacher education is a powerful driver of AI competency development, digital pedagogy, and instructional innovation. The emergence of Digital Learning Ecosystems (DLEs) as an underlying framework indicates a shift toward dynamic, data-informed environments that support reflective practice, student-centered learning, and interdisciplinary collaboration. Given these insights, science teacher education programs should prioritize curriculum reform that incorporates design thinking stages and experiential learning strategies into AI-enhanced instructional models. Teacher preparation must also address ethical concerns related to AI use, including algorithmic bias, data privacy, and responsible integration. Future research should investigate the long-term impacts of DLEs on teacher professional growth, the scalability of AI-enhanced experiential pedagogies across diverse educational contexts, and the development of robust assessment tools to evaluate AI literacy and pedagogical innovation among pre-service and in-service science educators.

CONCLUSION

The present research systematically mapped research trends and methodological developments in Experiential Learning and Design Thinking for science teacher education using a PRISMA-guided systematic review and bibliometric analysis. The findings reveal increasing scholarly attention from 2020 to 2024, with AI literacy, digital pedagogy, and student-centered learning emerging as dominant themes. Co-authorship and citation analyses highlight interdisciplinary collaboration, particularly across education, engineering, and computer science. Notably, the integration of Experiential Learning and Design Thinking within Digital Learning Ecosystems (DLEs) serves as a key framework to foster AI competencies, reflective practice, and pedagogical innovation. These results not only address the research questions and objectives but also provide an empirical foundation for advancing theory-informed and evidence-based practices in science teacher education.

Author Contribution

Somsak Techakosit conceptualized the research framework, designed the study methodology, and supervised the systematic review and bibliometric analysis. Teerapop Rakngam led data collection, analysis, and interpretation, ensuring methodological rigor and consistency. Jarumon Nookong contributed to literature synthesis, thematic categorization, and manuscript drafting. Panita Wannapiroon provided critical insights into digital learning ecosystems, assisted in result validation, and refined the discussion and conclusion. All authors contributed to manuscript revisions and approved the final version for submission

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