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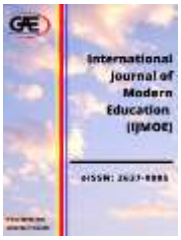

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MAPPING GLOBAL RESEARCH TRENDS ON COMPUTATIONAL THINKING IN PRE-SERVICE TEACHER EDUCATION: A BIBLIOMETRIC ANALYSIS (2015-2025)

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Abstract:

Computational Thinking (CT), which involves systematic, algorithmic problem-solving processes, is widely known as a critical 21st-century skill, making its incorporation into pre-service teacher education vital for preparing future educators. However, many teacher training programs worldwide have yet to fully integrate CT, and a comprehensive mapping of the field's development is needed to understand its evolution and inform curriculum enhancements. This research bridges that gap via a bibliometric analysis of 439 Scopus-indexed publications from 2015 to 2025 on CT in pre-service teacher education. Relevant literature was identified via advanced Scopus search queries combining keywords such as "computational thinking," "pre-service teacher," and "teacher education," filtered to English-language documents. The dataset was analyzed using Scopus Analyzer for descriptive statistics, cleaned with OpenRefine, and visualized via VOSviewer for co-occurrence mapping of keywords and co-authorship networks. Results indicate a steady growth in publications over the past decade, peaking in 2022, reflecting escalating global scholarly interest in this area. Citation analysis identified the most cited papers and prolific authors, and the United States, Turkey, and Germany emerged as the leading countries in publication output. Keyword co-occurrence mapping revealed dominant research themes such as "computational thinking," "teacher education," and "educational robotics," while co-

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authorship analysis showed robust international collaborations among scholars and institutions. In conclusion, this bibliometric mapping provides a comprehensive overview of the field's trajectory and reveals trends, influential works, geographical contributions, thematic focus, and collaboration patterns. Additionally, it offers future research directions to support the strategic development of CT curricula and training frameworks in pre-service teacher education.

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Keyword:

Computational Thinking (CT), Bibliometric Analysis, Educational Robotics and STEM Integration, Pre-Service Teacher Education, Teacher Preparation and Training

Introduction

Computational Thinking (CT) is a fundamental skill that involves problem-solving processes akin to those used by computer scientists, such as problem decomposition, pattern recognition, algorithmic thinking, and abstraction (Hoić-Božić et al., 2019; Oliveira et al., 2022; Putra et al., 2025). In the 21st century, CT has become increasingly recognized as essential for navigating a technology-driven society, making it a critical component of modern education (Das & Mitra, 2024; Hoić-Božić et al., 2019; Voon et al., 2023). The integration of CT into educational curricula is seen as vital for preparing students to tackle complex problems and fostering analytical and creative thinking (Angeli, 2022; Bers, 2021; Das & Mitra, 2024). Despite the widespread enthusiasm for CT, research reports that its effective integration into K-12 education still poses challenges, notably concerning the preparedness of teachers, particularly pre-service teachers (Angeli & Jaipal-Jamani, 2018; Chan, 2020; Oliveira et al., 2022).

Although CT is gaining increasing attention, many teacher education programs have yet to fully incorporate CT training into their curricula (Angeli & Jaipal-Jamani, 2018; Chan, 2020; Walton et al., 2020). This gap presents a challenge, as pre-service teachers often lack the necessary knowledge and experience to effectively teach CT concepts (Angeli & Jaipal-Jamani, 2018; Chan, 2020; Walton et al., 2020). Addressing this issue requires a concerted effort to develop comprehensive training programs that equip pre-service teachers with both theoretical understanding and practical skills in CT (Dong et al., 2024; Rodrigues et al., 2024, 2025). This study explores the research landscape of CT in pre-service teacher education from 2015 to 2025, focusing on identifying the most influential articles, leading countries by publication output, key thematic keywords, and international collaboration patterns through co-authorship

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networks, aiming to provide an insightful overview that informs future research and supports the development of effective training programs for future educators.

Literature Review

The importance of CT in education has been widely documented, with numerous studies emphasizing its contributions to enhancing problem-solving, logical reasoning, and analytical skills across disciplines (Angeli, 2022; Das & Mitra, 2024; Oliveira et al., 2022). Although initially rooted in computer science, CT has demonstrated significant relevance in mathematics, science, and engineering, where it equips learners with systematic approaches to complex problem-solving and fosters innovative thinking (Angeli, 2022; Das & Mitra, 2024; Putra et al., 2025). Its interdisciplinary nature establishes CT as a critical 21st-century skill, enabling students to transfer cognitive strategies across domains (Angeli, 2022; Bers, 2021; Das & Mitra, 2024).

Research on CT integration in pre-service teacher education highlights the urgent need for comprehensive training programs that link theory with practice. Hybrid instructional models—combining plugged (digital) and unplugged (non-digital) activities—have shown particular promise in enabling pre-service teachers to contextualize CT concepts within classroom practice(Iwata et al., 2022; Voon et al., 2023). Studies further indicate that experiential learning frameworks, which incorporate hands-on activities and reflective practice, significantly enhance pre-service teachers' CT competencies and their ability to design CT-infused lessons(Iwata et al., 2022; Rodrigues et al., 2025; Voon et al., 2023).

However, challenges persist, especially the lack of prior computing knowledge among many pre-service teachers, which often hinders their capacity to fully grasp and apply CT concepts (Angeli & Jaipal-Jamani, 2018; Chan, 2020; Voon et al., 2023). To address this, scaffolded approaches leveraging tangible objects and educational robotics have been proposed, gradually introducing CT concepts while building confidence and pedagogical competence (Angeli & Jaipal-Jamani, 2018; Chan, 2020; Rodrigues et al., 2025). These methods have proven effective in equipping pre-service teachers with the skills to design and implement CT-based instruction. The role of teacher educators is equally pivotal in the successful adoption of CT within pre-service teacher education. Effective modeling of CT practices requires teacher educators to possess both subject expertise and pedagogical proficiency (Rajapakse Mohottige et al., 2024). Professional development initiatives—such as structured training programs, expert coaching, and peer exchanges—are widely recognized as critical pathways for advancing teacher educators' CT capacity (Ghani et al., 2022; Rajapakse Mohottige et al., 2024). Such initiatives create a supportive environment in which pre-service teachers can acquire, practice, and refine CT-related skills, strengthening their readiness to integrate CT into future classrooms.

In summary, while significant advances have been made in embedding CT into pre-service teacher education, gaps remain that warrant sustained research and intervention. Comprehensive training programs that combine theoretical knowledge with practical applications, supported by skilled teacher educators, are essential to ensure pre-service teachers are adequately prepared to teach CT effectively.

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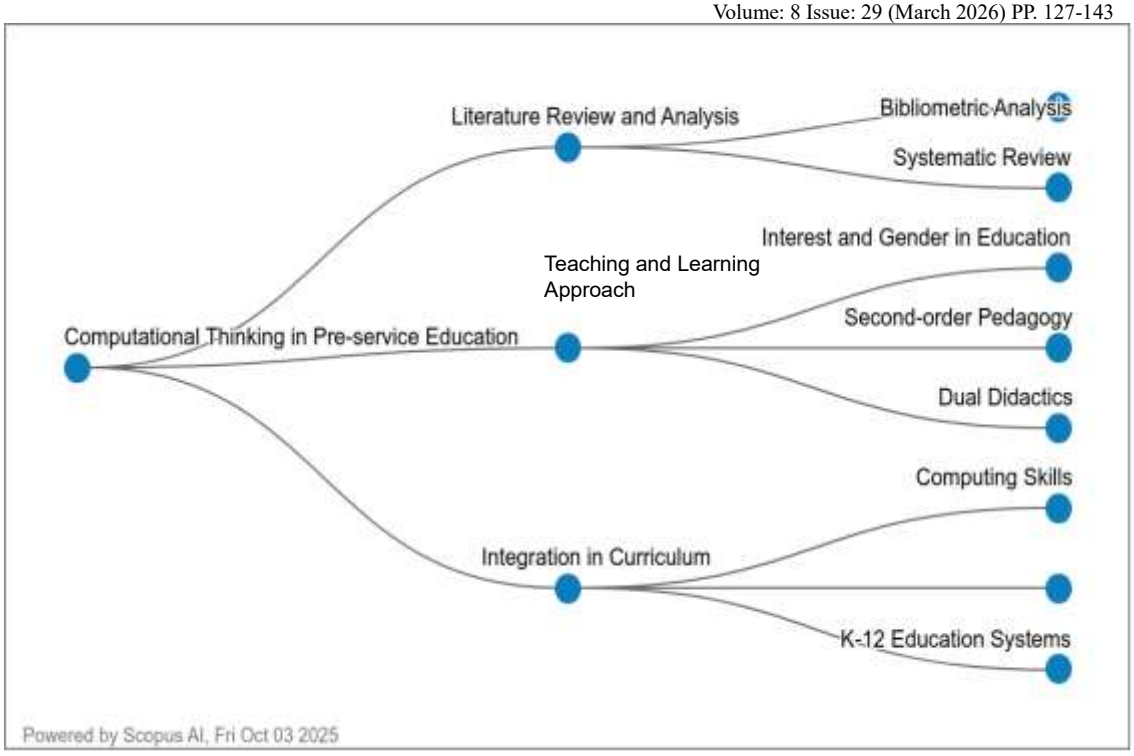

Figure 1: Concept Map

The concept paper on Computational Thinking in Pre-service Education highlights three main research strands: literature review and analysis, teaching and learning approaches, and curriculum integration. Literature review efforts, such as bibliometric analysis and systematic reviews, provide a broad understanding of the field's development, while studies on teaching and learning focus on factors like interest and gender in education, second-order pedagogy, and dual didactics. It emphasizes how pre-service teachers' engagement and pedagogical strategies shape their CT growth. Meanwhile, curriculum integration addresses the practical embedding of CT into broader education systems, linking it to essential computing skills and K-12 education frameworks. Collectively, the paper underscores the multidimensional nature of CT in teacher education, stressing the importance of both evidence-based synthesis and pedagogical innovation. It concludes that preparing pre-service teachers with strong CT skills requires robust theoretical grounding and practical integration into curriculum design and systemic educational reforms.

Research Objective

The main objective of this study is to conduct a bibliometric analysis of research on CT in pre-service teacher education, covering published articles from 2015 to 2025. Specifically, the study aims to identify the most cited and influential articles, determine the leading countries based on publication output, analyze popular keywords to reveal thematic focuses, and explore co-authorship networks to understand patterns of international collaboration. Overall, this research seeks to provide a clear and insightful view of the current landscape of CT research in teacher education, offering valuable guidance for future studies and the development of effective training programs for future educators.

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Research Question

RQ1: What are the research trends over the years in studies on computational thinking in pre-service teacher education?
RQ2: What are the top 10 most-cited articles in this research area?
RQ3: Which countries rank in the top 10 based on the number of publications?
RQ4: What are the most frequently used keywords in the literature?
RQ5: What does the co-authorship network look like in terms of collaboration between countries?

Methodology

Bibliometrics is a robust methodological approach that systematically collects, organizes, and analyzes bibliographic data from scientific literature (Alves et al., 2021; Assyakur & Rosa, 2022; Verbeek et al., 2002). While it encompasses basic statistical measures—such as the identification of publication years, publishing journals, and leading authors (Wu & Wu, 2017)—it also extends to advanced techniques like document co-citation analysis, which uncover intellectual linkages and research trends within a field. A rigorous literature review, however, requires more than surface-level analysis. It is an iterative process comprising comprehensive literature searches, careful selection of keywords, as well as in-depth analytical evaluation. This process establishes the construction of a reliable and comprehensive bibliography that yields trustworthy insights (Fahimnia et al., 2015).

In line with the Bibliometric analysis protocol, the present study emphasized high-impact publications, as these works provide critical perspectives on the theoretical foundations shaping the discipline. To secure data accuracy, Scopus was employed as the primary database (Al-Khoury et al., 2022; di Stefano et al., 2010; Khiste & Paithankar, 2017). Moreover, to maintain scholarly rigor, only peer-reviewed journal articles were incorporated, while lecture notes and books were intentionally excluded [19]. Note that publications indexed in Elsevier's Scopus between 2020 and December 2023 were systematically retrieved for detailed analysis.

Data Search Strategy

To obtain a comprehensive dataset for bibliometric analysis, the study employed the Scopus advanced search function, which is widely recognized for its broad coverage and reliable indexing of peer-reviewed academic publications. The search was strategically designed to capture relevant literature on CT within the context of pre-service teacher education. Specifically, the search string applied was: TITLE-ABS-KEY (("Computational thinking" OR "CT") AND ("pre-service teacher" OR "future teacher" OR "prospective teacher" OR "teacher education" OR "teacher preparation")) AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (LANGUAGE , "English")) as in Table 1, with the database accessed in October 2025. This Boolean-based search strategy was carefully constructed to ensure inclusivity while maintaining relevance, enabling the retrieval of publications where CT was explicitly discussed in relation to pre-service teachers. Following retrieval, a set of screening criteria was applied (see Table 2). Only articles published in English were included, while non-English publications were omitted to maintain linguistic consistency and accessibility. Similarly, the timeframe was restricted to 2015–2025, reflecting the period in which CT gained significant global attention in teacher education research, while studies published prior to 2015 were excluded. These deliberate inclusion and exclusion parameters ensured both the quality

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and relevance of the dataset. After applying the criteria, the final dataset comprised 439 publications, which provided a sufficiently large and diverse corpus to map the research landscape. Consequently, this dataset was used for bibliometric analysis and visualization, offering insights into the intellectual structures, thematic trends, and emerging directions of CT incorporation regarding pre-service teacher education.

Table 1: The Search String

Scopus	TITLE-ABS-KEY ((“Computational thinking” OR “CT”) AND (“pre-service teacher” OR “future teacher” OR “prospective teacher” OR “teacher education” OR “teacher preparation”)) AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (LANGUAGE , “English”)) Access date October 2025

Table 2: The Selection Criterion is Searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Time line	2015-2025	< 2015

Data Analysis

The bibliometric datasets procured from Scopus were systematically assessed utilizing VOSviewer version 1.6.20. Note that by applying VOS mapping techniques and clustering, the software facilitated the generation of network visualizations that highlighted the structural relationships among authors, journals, keywords, and citations. Unlike conventional Multidimensional Scaling (MDS), which relies primarily on similarity indices such as cosine or Jaccard coefficients, VOSviewer situates items within a low-dimensional space where distance directly reflects relatedness (van Eck & Waltman, 2010) (Appio et al., 2014).

A central feature of this approach is the use of the Association Strength (AS_{ij}) method to normalize co-occurrence frequencies. This measure expressed as:

$$AS_{ij} = \frac{C_{ij}}{w_i w_j},$$

represents the ratio between the observed co-occurrences of items i and j, as well as the expected co-occurrences under the assumption of statistical independence (Van Eck & Waltman, 2007). By adopting this normalization, VOSviewer ensures that the spatial distribution of items accurately mirrors their conceptual and bibliometric significance.

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Through this analytical process, the resulting maps revealed clusters of interconnected items that signified thematic linkages and intellectual structures within the research domain. These visualizations provided insights into dominant authorship patterns, influential publication outlets, highly cited works, and recurring keywords, enabling a detailed comprehension of the evolution and current state of research in CT within pre-service teacher education (van Eck & Waltman, 2010; Appio et al., 2014; Van Eck & Waltman, 2007).

Findings and Discussion

What Are the Research Trends Over the Years in Studies on Computational Thinking in Pre-Service Teacher Education?

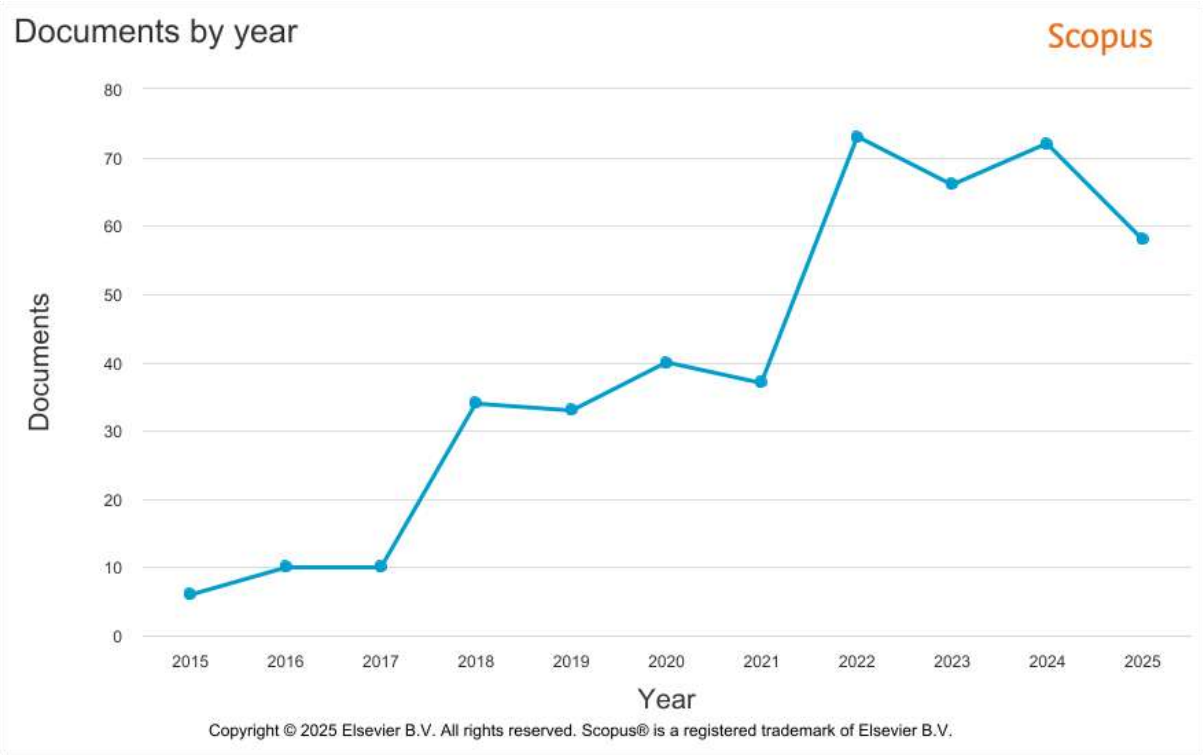

Figure 2: Number of Documents based on Year of Publication

The bibliometric data reveals a clear upward trend in publications on *computational thinking in pre-service teacher education* from 2015 to 2025, with the corpus expanding from only **6 studies in 2015** to a peak of **73 publications in 2022**. This steady growth reflects the increasing recognition of CT as a core 21st-century competency and its integration into global education policy frameworks, such as those advocated by the OECD and UNESCO. The initial years (2015–2017) recorded relatively few studies, likely due to the concept of CT still being newly introduced to teacher education discourse. However, beginning in 2018, a more consistent rise in output is observed, driven by expanding research interest, the proliferation of conferences and special issues on CT, and the growing demand for embedding CT skills into school curricula. The sharp increase between 2020 and 2022 corresponds with heightened digital transformation during the COVID-19 pandemic, where remote teaching accelerated the adoption of digital pedagogies, thereby prompting a surge of research into CT integration within teacher education.

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After 2022, the number of publications remains high but fluctuates slightly, with **66 in 2023, 72 in 2024, and 58 in 2025 (as of October)**. This slight decline after the peak may be attributed to the post-pandemic stabilization of digital education initiatives and a shift toward consolidating rather than expanding CT research. Many scholars are now focusing on refining pedagogical frameworks, integrating CT into national curricula, and evaluating long-term impacts, which may reduce the volume of exploratory studies but increase the depth and rigor of research. The sustained high output, however, underscores the continued global importance of CT in teacher preparation programs, suggesting that the field has transitioned from an emerging topic into a well-established area of educational research.

What Are the Top 10 Most-Cited Articles In This Research Area?

Table 3: Most Cited Author

Authors	Title	Year	Source title	Cited by
Angeli Valanides et al (2016)	A K-6 computational thinking curriculum framework: Implications for teacher knowledge	2016	Educational Technology and Society	345
Sentance & Csizmadia (2017)	Computing in the curriculum: Challenges and strategies from a teacher's perspective	2017	Education and Information Technologies	235
Yadav et al.(2017)	Computational thinking for teacher education	2017	Communications of the ACM	205
Mouza et al. (2017)	Resetting educational technology coursework for pre-service teachers: A computational thinking approach to the development of technological pedagogical content knowledge (TPACK)	2017	Australasian Journal of Educational Technology	120
Ketelhut et al. (2020)	Teacher Change Following a Professional Development Experience in Integrating Computational Thinking into Elementary Science	2020	Journal of Science Education and Technology	118
Li et al. (2020)	On Computational Thinking and STEM Education	2020	Journal for STEM Education Research	107
Rinke et al. (2016)	Characterizing STEM Teacher Education: Affordances and Constraints of Explicit STEM Preparation for Elementary Teachers	2016	School Science and Mathematics	106

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Leonard et al. (2018)	Preparing Teachers to Engage Rural Students in Computational Thinking Through Robotics, Game Design, and Culturally Responsive Teaching	2018	Journal of Teacher Education	100
Morton (2018)	Reconceptualizing and describing teachers' knowledge of language for content and language integrated learning (CLIL)	2018	International Journal of Bilingual Education and Bilingualism	80
Prayogi et al. (2018)	Critical inquiry-based learning: A model of learning to promote critical thinking among prospective teachers of physics	2018	Journal of Turkish Science Education	74

The citation data reveal that the most influential articles on CT in pre-service teacher education are concentrated in **high-impact education and STEM-focused journals**, with citation counts ranging from **74 to 118**. Notably, *Teacher Change Following a Professional Development Program* (2020) in the *Journal of Science Education and Technology* received the highest citations (118), highlighting the scholarly community's emphasis on teacher professional development as a key driver of CT integration. Similarly, *On Computational Thinking and STEM Education* (2020), with 107 citations, underscores the strong link between CT and broader STEM education initiatives, reflecting global recognition of CT as a foundational skill across disciplines. Articles published in established outlets such as the *Journal of Teacher Education* (100 citations) further emphasized the relevance of CT in shaping teacher preparation, suggesting that highly cited works tend to focus on both theoretical frameworks and practical strategies for embedding CT within teacher training.

The clustering of influential articles between **2018 and 2020** suggests a critical period when CT gained momentum in teacher education research. This spike aligns with global educational reforms emphasizing 21st-century competencies and the integration of digital literacy into national curricula. The high citation counts can also be attributed to the **timeliness and applicability of the research**, particularly studies offering models, frameworks, or empirical evidence that educators and policymakers could adopt. Furthermore, the presence of diverse publication venues, ranging from bilingual education to science education journals, reflects the interdisciplinary nature of CT research and its adaptability across educational contexts. Collectively, these citation trends demonstrate that impactful studies are those that bridge **policy, practice, and pedagogy**, offering scalable approaches for equipping pre-service teachers with CT competencies.

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Which Countries Rank in The Top 10 Based on The Number Of Publications?

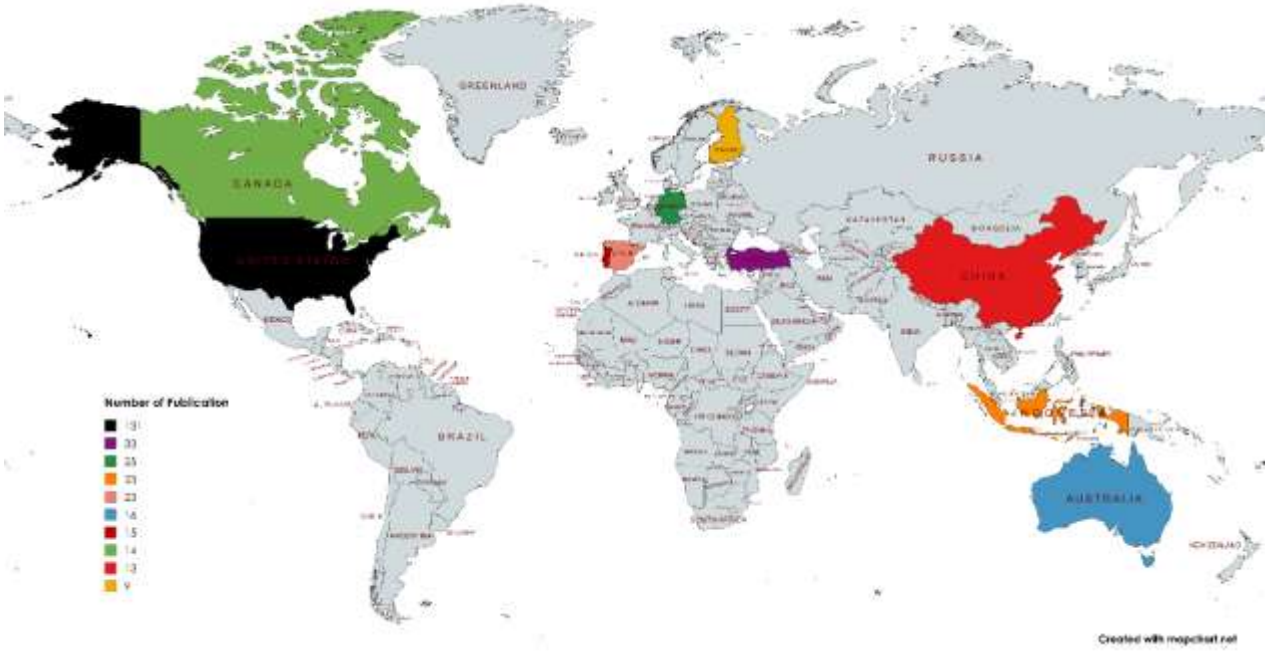

Figure 3: Number of Documents Based on Country

The country-wise distribution of publications indicates that the **United States (131 documents)** dominates research on CT in pre-service teacher education, accounting for nearly one-third of the total output. This leadership is unsurprising given the strong policy and funding support for CT integration within the US education system, most notably following Wing's seminal work on CT and subsequent federal and state-level initiatives. Countries such as **Turkey (33), Germany (25), Indonesia (23), and Spain (23)** also demonstrate significant research activity, reflecting regional policy priorities and the inclusion of CT in teacher education reforms. Notably, **Indonesia's strong contribution** signals the growing emphasis on CT in Southeast Asia, where national curricula increasingly mandate digital and computational skills as part of broader STEM education goals. Similarly, European nations like Germany, Spain, and Portugal show steady engagement, likely influenced by EU-funded research frameworks that encourage cross-country collaboration in digital education and teacher training.

The presence of **Australia (16), Portugal (15), Canada (14), China (13), and Finland (9)** highlights the global diffusion of CT research, with contributions from both developed and emerging educational systems. For example, **Finland's reputation for innovation in teacher education** aligns with its emphasis on integrating digital literacy and CT into teacher preparation. Meanwhile, China's growing output reflects national strategies to embed CT and AI education within its educational modernization agenda. The diversity of contributing countries demonstrates that CT in pre-service teacher education has become a **global research priority**. However, regional variations suggest differing motivations: in Western contexts, emphasis is often on educational innovation and digital pedagogy, whereas in developing contexts, research is driven by the urgency of preparing teachers to meet rapidly evolving national curriculum reforms. The disparities in output also highlight opportunities for more

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international collaboration to ensure that best practices and frameworks for CT integration are shared across diverse educational systems.

What Are the Most Frequently Used Keywords in The Literature?

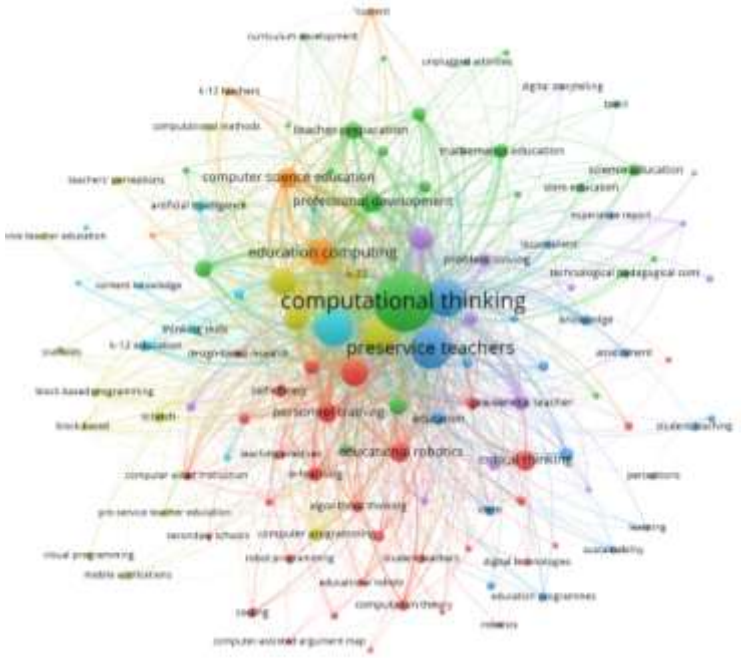

Figure 4: Network Visualization Map of Author Keywords' Co-Occurrence

The co-occurrence analysis of author keywords using VOSviewer is a bibliometric technique that examines how frequently keywords appear together in the same body of literature, with the assumption that co-occurring terms represent related concepts or themes. In the network visualization, keywords are represented as nodes, the size of each node reflects its frequency of occurrence, and the connecting lines (or edges) indicate the strength of their relationships. This allows researchers to detect conceptual structures, thematic linkages, and emerging research trends within a field. In the case of CT in pre-service teacher education, the map shows that terms such as *computational thinking* (285 occurrences, 1410 link strength), *pre-service teachers* (139, 664), and *teacher education* (123, 619) dominate the field, highlighting their centrality in shaping discourse.

The settings applied to generate this map were based on the **full counting method**, ensuring that each co-occurrence was given equal weight, regardless of how many times it appeared in a single publication. A **minimum occurrence threshold of five** was established, filtering the original 971 keywords down to 106 relevant ones, and a **minimum cluster size of five** was set to ensure meaningful thematic grouping. These parameters produced **nine distinct clusters**, each representing different strands of scholarship such as curriculum design, digital pedagogy, professional development, robotics, STEM integration, and higher-order skills like critical thinking and problem solving. Note that the results contribute to the body of knowledge by mapping the intellectual landscape of CT research in teacher education, demonstrating both established anchors and emerging frontiers. The strong associations with *professional development, educational robotics, algorithmic thinking,* and *digital competence* reflect how the field has matured from defining the CT conceptually to embedding it in practical teacher training and curriculum innovations. This evidences a global shift toward equipping future

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teachers with both the theoretical grounding and practical tools necessary to integrate CT into diverse educational contexts.

What Does the Co-Authorship Network Look Like in Terms of Collaboration Between Countries?

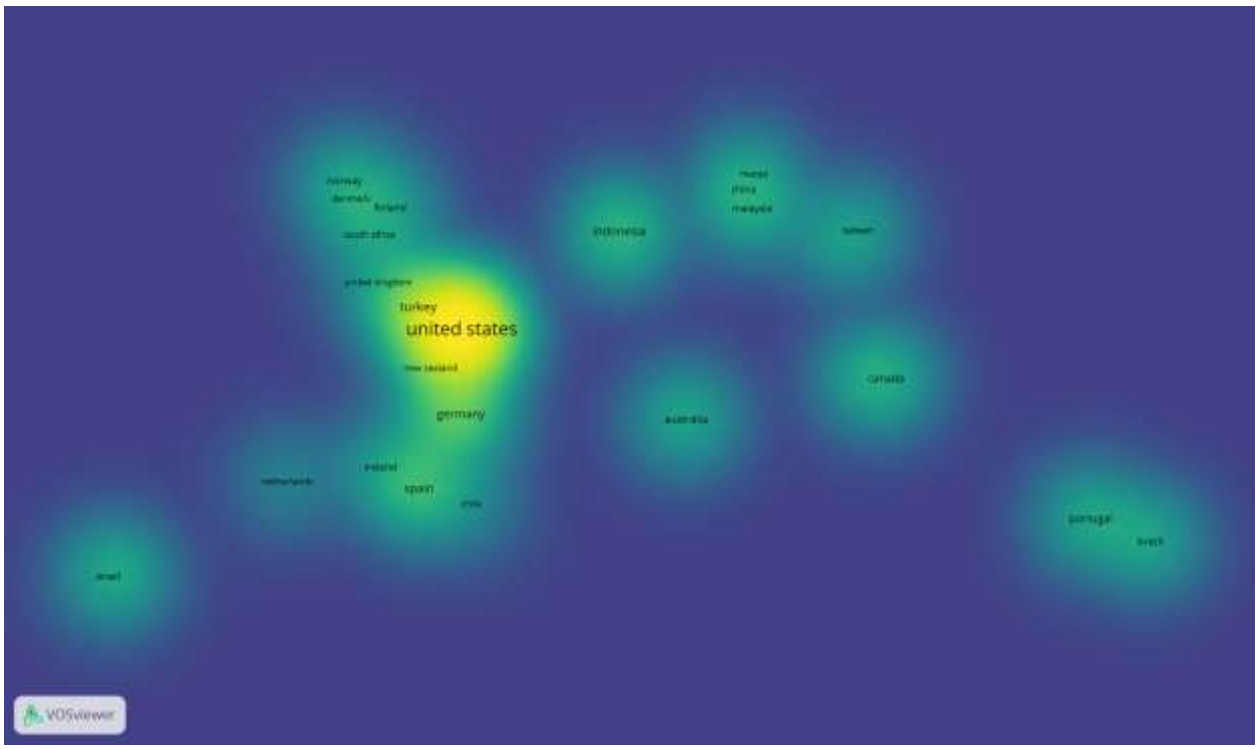

Figure 5: Density Map of Top Contributing Countries

The co-occurrence co-authorship analysis of countries using VOSviewer is a bibliometric technique that maps collaboration patterns between nations based on joint publications. In this context, each country is represented as a node, the size of the node reflects the number of documents produced, and the links indicate co-authorship ties between countries. The strength of these links, also known as total link strength, demonstrates the intensity and frequency of collaborations. Larger nodes such as the United States, Turkey, Germany, and Spain signify countries with higher research outputs, while thick connecting lines illustrate strong international partnerships. By visualizing these relationships, the analysis provides insights into how research on CT concerning pre-service teacher education is shaped by international collaboration and knowledge exchange.

Note that the settings applied used the full counting method, ensuring each co-authorship link was weighted equally. With a minimum threshold of five publications, 30 countries out of 61 met the criteria, and by setting a minimum cluster size of five, the analysis produced eight distinct clusters. These clusters highlight global collaborative networks, with the United States (132 documents, 2154 citations, link strength 25) serving as the central hub. European countries such as Germany, Portugal, and the Netherlands are strongly embedded in regional and cross-continental collaborations, while emerging contributors like Indonesia and Malaysia demonstrate increasing visibility through partnerships. This finding contributes to the body of knowledge by illustrating the globalized nature of CT research, where collaboration fosters the exchange of pedagogical models, adaptation of frameworks to local contexts, and the diffusion

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of innovation across educational systems. It also underscores the need for strengthening Global South–Global North partnerships to balance knowledge production and ensure more inclusive global development in CT within teacher education.

Conclusion

This study set out to systematically map and analyze global research trends on CT in pre-service teacher education via a bibliometric lens. Guided by five research questions, the analysis explored publication growth, citation patterns, country-level contributions, keyword co-occurrences, and international collaboration networks. The results demonstrate a consistent upward trajectory in CT-related publications from 2015 to 2025, with a pronounced surge between 2020 and 2022, coinciding with the global digital transformation in education. This sustained high output underscores the growing significance of CT in teacher preparation programs and indicates that the field has evolved from an emerging discourse into a well-established domain of educational research. The citation analysis revealed that highly influential studies are those bridging policy, pedagogy, and classroom practice, offering scalable models for embedding CT competencies in teacher training. Moreover, the United States, Turkey, and Germany emerged as leading contributors, reflecting both research maturity and institutional investment in CT education.

The co-occurrence analysis identified nine thematic clusters, showing strong associations with teacher education, professional development, STEM integration, educational robotics, algorithmic thinking, and digital competence. These patterns highlight a clear evolution from defining the CT conceptually to embedding it within practical training and curricular design. This shift evidences a broader global movement toward preparing future educators with both theoretical grounding and applicable pedagogical strategies for incorporating CT across diverse educational contexts. At the same time, disparities in publication output point to uneven global participation, emphasizing the need to strengthen collaboration between Global South and Global North institutions. Enhanced cross-regional partnerships can help democratize knowledge production and promote more inclusive development of CT education worldwide.
Overall, this bibliometric study contributes a comprehensive and evidence-based understanding of how CT in pre-service teacher education has developed over the past decade. It offers actionable insights for policymakers, curriculum designers, and educators to refine teacher preparation frameworks, emphasizing CT as a core 21st-century competency. While this analysis was limited to Scopus-indexed and English-language publications, future research should expand to include multilingual and cross-database studies to capture a more holistic global picture. The findings reaffirm the value of bibliometric methods in tracing intellectual progress, mapping collaboration networks, and guiding strategic directions for advancing CT in pre-service teacher education.

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