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Uncovering Research Patterns in Computational Thinking in Teacher Education: A Bibliometric Mapping Study

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Computational Thinking (CT) has become an increasingly important area in teacher education due to the growing emphasis on digital competence and problem-solving skills in contemporary education. This study presents a bibliometric mapping review of research on the integration of CT in teacher education. Using 130 Scopus-indexed journal articles retrieved on 28 January 2026, the study systematically analyses publication trends, influential authors, institutions, countries, and emerging thematic structures within the field. Bibliometric data were analysed using Bibliometrix in R, VOSviewer, OpenRefine, and Microsoft Excel. The findings indicate a steady increase in research output, particularly after 2020, reflecting the expanding institutionalisation of CT within teacher preparation programmes. Thematic analysis revealed that pre-service teacher education, professional development, pedagogical integration, and educational robotics constitute the dominant research areas, while machine learning, equity, and culturally responsive teaching represent emerging directions. The findings further demonstrate that CT research in teacher education is becoming increasingly international and collaborative. By positioning teacher education as the primary analytical focus, this study extends existing bibliometric research and contributes a structured overview that may support future research, curriculum development, and policy planning related to CT integration in teacher education.

Keywords: bibliometric analysis, computational thinking, pre-service teachers, teacher education

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INTRODUCTION

The Fourth Industrial Revolution has significantly reshaped educational priorities by emphasising competencies related to problem-solving, abstraction, and digital reasoning (Wing, 2006; OECD, 2019). Within this transformation, Computational Thinking (CT) has emerged as a central construct in contemporary educational discourse. CT is increasingly recognised as an essential competence for preparing teachers to function effectively in digitally mediated and data-driven learning environments (Rodrigues et al., 2025; Voogt et al., 2015). As a result, scholarly interest in integrating CT into teacher education has expanded rapidly over the past decade (Yadav et al., 2016). Existing studies have explored how teachers conceptualise, develop, and enact CT within instructional practice (Mouza et al., 2017), reflecting broader concerns regarding teacher readiness for digital transformation across education systems (OECD, 2019). Importantly, CT is no longer viewed solely as a technical or programming-related skill but is increasingly positioned as a broader pedagogical and professional competence within teacher education. Recent evidence further indicates that CT competencies, including decomposition, abstraction, and algorithmic thinking, are progressively integrated across interdisciplinary instructional contexts (Vazquez-Uscanga et al., 2025).

The growing body of literature on CT in teacher education reflects diverse conceptual, pedagogical, and technological perspectives. Researchers have examined CT through curriculum design, teacher professional knowledge, instructional strategies, and professional development models (Mouza et al., 2017; Sentance & Csizmadia, 2017). Although this diversity has enriched the field, it has also contributed to a fragmented research landscape. Studies are dispersed across education, educational technology, computer science education, and STEM-related journals (Voogt et al., 2015), with many investigations focusing on context-specific implementations. Consequently, cumulative knowledge building and cross-study integration remain limited. At a broader level, the intellectual structure of CT research within teacher education remains insufficiently synthesised, leaving relationships among dominant themes, influential contributors, and evolving research trajectories inadequately understood.

Recent studies further reinforce the pedagogical relevance of CT across educational contexts. Vazquez-Uscanga et al. (2025) demonstrated how CT competencies can be integrated across curricula through interdisciplinary and unplugged learning approaches, while Aroonsiwagool et al. (2025) identified persistent gaps in instructors' CT competencies and digital readiness. Similarly, Rodrigues et al. (2025) emphasised the importance of sustained and practice-oriented teacher preparation experiences, including lesson planning, microteaching, and reflective pedagogical engagement, in strengthening pre-service teachers' CT competencies. Collectively, these studies highlight increasing recognition of CT as a foundational educational competence while simultaneously revealing uneven and fragmented implementation within teacher education.

Research output on CT in teacher education accelerated further during and after the COVID-19 pandemic (Trust & Whalen, 2020). The global shift toward digitally mediated teaching intensified scholarly attention toward teacher competencies and

digital pedagogy, resulting in a substantial increase in related publications. This rapid expansion raises important questions regarding dominant themes, influential contributors, and evolving citation patterns shaping the field. Bibliometric analysis provides a systematic and reproducible approach for mapping the intellectual structure and thematic development of a research domain (Aria & Cuccurullo, 2017; Donthu et al., 2021). However, existing bibliometric studies on CT have predominantly focused on student-centred or general educational contexts, with teacher education remaining comparatively underexamined as a distinct analytical domain. Therefore, this study employs a bibliometric mapping review approach to examine the intellectual structure, research trends, and thematic evolution of CT research in teacher education.

LITERATURE REVIEW

This review critically examines how scholars conceptualise Computational Thinking (CT) within teacher education and demonstrates how existing research exposes structural fragmentation that calls for systematic mapping.

Conceptualising Computational Thinking in Teacher Education

Wing (2006) initially conceptualised Computational Thinking (CT) as a cognitive framework grounded in abstraction, decomposition, algorithmic reasoning, and data-driven logic. From this perspective, CT represents a transferable mode of thinking rather than merely a set of technical skills. Within teacher education, CT is increasingly positioned as part of professional knowledge that supports instructional problem-solving across disciplines (Voogt et al., 2015). However, the conceptual status of CT remains contested. Some scholars interpret CT as a domain-general cognitive competence, whereas others embed it within subject-specific pedagogies or technological applications. More recent studies further conceptualise CT as a multidisciplinary educational competence associated with problem-solving, creativity, and data-oriented reasoning across diverse instructional settings (Vazquez-Uscanga et al., 2025; Aroonsiwagool et al., 2025).

This ambiguity becomes more evident when CT is reframed as a pedagogical approach. Researchers frequently operationalise CT through programming, educational robotics, unplugged activities, and inquiry-oriented learning environments (Kong et al., 2020). In such contexts, CT shifts from a cognitive framework toward a collection of instructional strategies. Although these approaches encourage experiential learning and active engagement, they may also reduce CT to a predominantly tool-oriented practice rather than a deeper epistemic transformation. Recent empirical studies similarly indicate that CT integration often emphasises technological implementation and classroom activities while paying comparatively limited attention to broader issues related to teacher cognition and professional epistemology (Vazquez-Uscanga et al., 2025). Consequently, the distinction between CT as a cognitive process and CT as an instructional activity remains insufficiently clarified within teacher education research.

A further dimension emerges when policymakers position CT as a policy-driven competency. International agendas increasingly frame CT as part of digital competence and future-ready skills (OECD, 2019; UNESCO, 2023). In this discourse, CT becomes a measurable professional requirement aligned with national education reforms.

However, research rarely examines how such policy framing reshapes teacher preparation structures or institutional priorities. As a result, conceptual overlap persists, while theoretical clarification within teacher education remains comparatively limited.

Pedagogical Emphases and Research Fragmentation

A dominant strand of literature emphasises design-based and experiential pedagogies in CT-focused teacher education (Mouza et al., 2017; Sentance & Csizmadia, 2017). Within this orientation, scholars position teachers as active designers of CT-infused lessons rather than passive recipients of theoretical knowledge. Empirical studies frequently report improvements in teacher confidence and pedagogical content knowledge following participation in programming tasks, robotics-based activities, or collaborative lesson design (Bers et al., 2014; Mouza et al., 2017; Yadav et al., 2014). More recent studies also report positive outcomes associated with interdisciplinary CT integration, particularly through inquiry-based learning, unplugged activities, and collaborative instructional design approaches (Vazquez-Uscanga et al., 2025). Although these findings suggest promising instructional outcomes, researchers predominantly rely on short-term interventions. They frequently report increases in confidence and perceived competence but rarely provide longitudinal evidence of sustained pedagogical transformation. Consequently, researchers insufficiently examine the durability of CT integration beyond structured training contexts.

In addition, the research landscape remains dispersed across disciplinary and educational contexts, including science education, computer science education, early childhood education, and broader STEM domains. This dispersion contributes to conceptual and methodological heterogeneity, with studies employing varied designs ranging from small-scale qualitative case studies to design-based experiments. Although such diversity reflects interdisciplinary engagement, it also obscures cumulative knowledge building. Crossfield synthesis remains limited, and there is comparatively little meta-level analysis examining publication trajectories, influential contributors, institutional collaboration, and evolving thematic concentrations. Consequently, the rapid expansion of CT-related scholarship has not yet produced a systematic mapping of its intellectual structure. Without a teacher-education-specific bibliometric overview, scholars cannot fully trace the field's development, identify concentrations of influence, or determine which conceptual gaps remain unresolved. A systematic bibliometric review is therefore necessary to clarify structural patterns, consolidate fragmented evidence, and establish a coherent foundation for advancing research on CT in teacher education.

Comparison of Previous Bibliometric Studies on Computational Thinking and the Positioning of the Present Study

Several bibliometric studies have examined Computational Thinking (CT) from broad and domain-specific perspectives; however, important conceptual and methodological gaps remain. As summarised in Table 1, previous studies have primarily focused on publication trends, thematic categorisation, citation structures, and topic modelling across general CT research domains. For instance, Ozyurt and Ozyurt (2023) analysed 1,083 Scopus-indexed publications to identify thematic structures and publication growth patterns within the broader CT landscape. Although comprehensive in scope,

teacher education was treated only as a peripheral category within wider STEM and educational technology contexts.

Similarly, Chen et al. (2024) employed bibliometric and content analysis to examine research trends related to CT enhancement studies; however, teacher education was not positioned as a distinct analytical focus. More specialised bibliometric studies have also emerged within discipline-specific contexts. For example, Irawan et al. (2024) investigated CT research in mathematics education, whereas Abdul Hamed et al. (2025) focused on CT definitions, components, and assessment tools. Although these studies contribute valuable disciplinary and conceptual insights, they provide limited explanation of how CT research has evolved specifically within teacher education as a professional preparation domain.

Overall, existing bibliometric studies demonstrate either macro-level breadth or discipline-specific depth, yet limited attention has been given to the intellectual structure and thematic evolution of CT research within teacher education. Existing studies also predominantly emphasise technological implementation, publication metrics, and thematic categorisation, while providing comparatively limited discussion on teacher professional formation, curriculum integration, and pedagogical development.

Accordingly, the present study addresses several important gaps in the literature by:

- positioning teacher education as the primary analytical domain rather than a peripheral subset of general CT research;
- examining the intellectual structure, thematic evolution, and research patterns of CT research within teacher education;
- integrating bibliometric mapping with critical interpretation of pedagogical and professional dimensions of CT integration; and
- providing a focused synthesis that supports future research, curriculum development, and policy planning related to CT-oriented teacher education.

Table 1
Summary of previous bibliometric studies on computational thinking in education

Authors	Focus of Study	Data Source & Coverage	Methodology Focus	Main Contribution	Limitation
Ozyurt & Ozyurt (2023)	General CT research trends	Scopus (1,083 articles)	Topic modelling and bibliometric mapping	Identified publication growth, thematic structures, and topic acceleration	Teacher education remained a peripheral rather than primary analytical focus.
Chen et al. (2024)	Research trends in CT enhancement studies	Scopus	Bibliometric and content analysis	Analysed publication trends, keyword co-occurrence, and thematic clusters.	Did not isolate teacher education as a specific focus of analysis
Irawan et al. (2024)	CT in mathematics education	Scopus (276 articles)	Bibliometric analysis	Mapped citation networks and thematic evolution in mathematics learning	Discipline-specific and not broadly generalisable to teacher education.
Abdul Hamed et al. (2025)	CT definitions, components, and assessment tools	Scopus	Bibliometric mapping	Analysed conceptual structures and assessment trends	Limited focus on curriculum integration and teacher competencies

Research Questions

To systematically map the intellectual landscape, scholarly influence, and thematic development of research on the integration of Computational Thinking in teacher education, this study employs a bibliometric and systematic review approach. Specifically, the review aims to examine influential sources and contributors, as well as the dominant and emerging research themes that have shaped this field over time. Accordingly, the study proposes the following research questions.

RQ1: Who are the key contributors, including leading authors, institutions, and countries, driving the development of Computational Thinking scholarship in the context of teacher education?

RQ2: What dominant and emerging research themes characterize the integration of Computational Thinking in teacher education, and how do these themes reflect pedagogical approaches, competency development, and assessment practices?

METHOD

This study employed a bibliometric review approach to examine the scholarly landscape of research on the integration of Computational Thinking (CT) in teacher education. Data were retrieved from the Scopus database on 28 January 2026. The dataset extracted for this study included information on publication types, source titles, publication years, subject areas, authorship patterns, institutional and country contributions, citation performance, and author keywords relevant to CT and teacher education.

Search Strategy

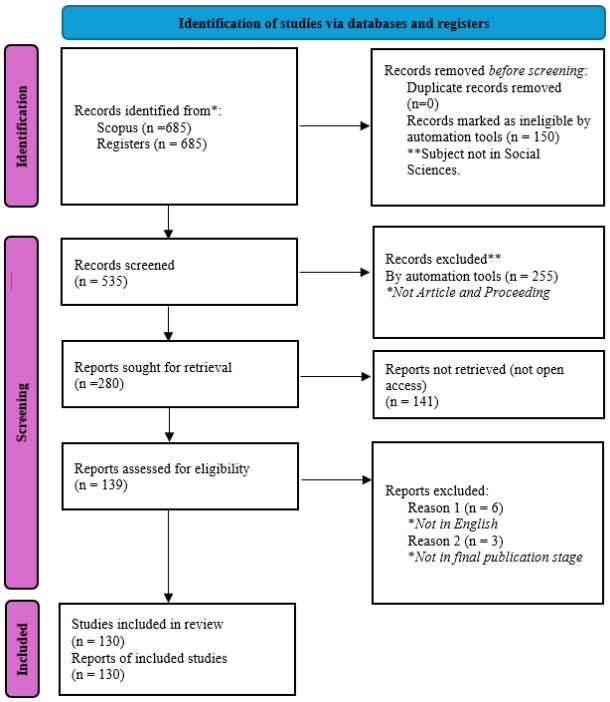
This review adopted the modified PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to identify, screen, and select relevant studies systematically. The researchers conducted a comprehensive literature search in the Scopus database to identify peer-reviewed studies on the integration of Computational Thinking (CT) into teacher education. Scopus was selected as the primary database because of its extensive coverage of peer-reviewed literature across education, social sciences, and technology-related disciplines, making it particularly suitable for bibliometric analysis in interdisciplinary research domains. Previous bibliometric studies have also recognised Scopus as a reliable source due to its broad indexing coverage, citation consistency, and compatibility with bibliometric software such as VOSviewer and Bibliometrix (Aria & Cuccurullo, 2017; Donthu et al., 2021). Furthermore, Scopus provides comprehensive metadata and citation information that support large-scale science mapping and thematic visualisation analyses.The search query ("computational thinking" AND ("teacher education" OR "teacher training" OR "pre-service teacher*" OR "preservice teacher*" OR "in-service teacher*" OR "teacher preparation" OR "teacher professional development")) was applied, followed by subject-specific filters to refine the results.

The scope of the review was defined based on search field, source type, document type, and subject area to exclude irrelevant records. The initial search yielded 685 records.

Before screening, 150 records were automatically removed using Scopus filtering tools due to duplication and misalignment with the Social Sciences subject area. The remaining 535 records were screened based on title and abstract relevance, resulting in the exclusion of 255 records identified as conference proceedings or non-article documents.

Subsequently, 280 reports were sought for retrieval, of which 141 were unavailable due to limited availability. The remaining 139 full-text articles were assessed for eligibility. Nine records were excluded at this stage, including six non-English publications and three articles not in their final publication form. Following the eligibility assessment, 130 studies met the inclusion criteria and were retained as the final dataset for bibliometric analysis and systematic synthesis of research trends, contributors, and thematic developments in Computational Thinking within teacher education.

Figure 1
Flow diagram of the search strategy



Data Cleaning

Data cleaning and harmonisation are essential for ensuring accuracy, consistency, and analytical reliability in bibliometric research. In this study, the bibliographic dataset was refined and standardised using OpenRefine and the bibliometrix package in R, which are well-suited for managing large-scale bibliographic data on Computational Thinking

in teacher education. These tools enabled systematic correction of inconsistencies in author names, institutional affiliations, keywords, and other bibliographic attributes, thereby improving data precision and overall analytical reliability.

The cleaning process began with downloading bibliographic records in CSV format, followed by a structured review of selected fields. Key columns, including author names, affiliations, and author keywords, were standardised to resolve spelling variations, abbreviations, and inconsistent naming conventions. Keyword harmonisation involved merging synonymous and semantically related terms, such as variations in pre-service teachers, teacher education, and teacher professional development, to ensure coherent thematic representation and accurate mapping of research themes.

Following data harmonisation, the bibliometrix package in R was used to generate core bibliometric indicators, including Number of Publications (NP), Number of Contributing Authors (NCA), Number of Cited Publications (NCP), Total Citations (TC), Citations per Publication (C/P), and Citations per Cited Publication (C/CP). The harmonised dataset established a robust foundation for subsequent analyses, enabling systematic examination of research trends, influential contributors, and thematic structures within Computational Thinking in teacher education.

Data Analysis

Data analysis was conducted to address the research questions and provide a comprehensive mapping of the scholarly landscape of Computational Thinking (CT) in teacher education. The analytical framework examined publication distribution and development across multiple bibliometric dimensions, including document types, source categories, subject areas, publication languages, and citation metrics. Descriptive and performance-based analyses were conducted to identify annual publication trends, leading authors, prominent institutions, key contributing countries, and influential source titles, thereby revealing major contributors and structural patterns within the field.

To evaluate academic impact and scholarly significance, several bibliometric indicators were employed, including total publications, number of cited publications, total citations, citations per publication, citations per cited publication, h-index, g-index, and citation counts within the h-core. These indicators provided a quantitative basis for assessing research productivity, visibility, and influence across authors, institutions, and national contexts.

In addition to performance analysis, science mapping techniques were applied to uncover conceptual structures and thematic relationships within the field. These techniques included co-word analysis, keyword co-occurrence networks, thematic mapping, and factorial analysis based on authors' keywords. For keyword co-occurrence analysis, VOSviewer was applied using the full counting method and association strength normalization. A minimum threshold of 10 keyword occurrences was established to ensure analytical relevance and reduce fragmentation within the visualisation network. The resulting visualisations enabled the identification of dominant themes, emerging research clusters, and intellectual linkages among subfields

related to CT integration in teacher education. Collectively, these analyses supported a systematic and multidimensional understanding of research trends, thematic evolution, and knowledge structures within this evolving domain.

Tools

This study employed multiple analytical tools to support a rigorous bibliometric analysis of Computational Thinking research in teacher education. Microsoft Excel was used for initial data screening, cleaning, and organisation of bibliographic records. The bibliometrix package in R facilitated data cleaning, harmonisation, and standardisation, particularly for authors' affiliations, institutional names, and country information. OpenRefine was applied to harmonise authors' keywords by resolving inconsistencies, spelling variations, and synonymous terms. VOSviewer was subsequently used to generate visualisations, including collaboration networks, citation structures, and keyword co-occurrence maps. Mendeley supported reference management and citation handling throughout the review process, ensuring systematic and transparent analysis.

FINDINGS

This section presents the principal findings of the bibliometric analysis, highlighting patterns of scholarly productivity, institutional contributions, geographical distribution, and emerging thematic directions within the field. The results are organised to reflect both structural influence and intellectual development, beginning with leading contributors and progressing toward evolving research themes.

Leading authors

Table 2 indicates a relatively concentrated authorship structure, with a small group of recurring contributors. J. O. Costa (University of Trás-os-Montes e Alto Douro) and Fernando Martins (Instituto Politécnico de Coimbra) are the most prolific authors, each with 4 publications, 3 cited works, and 6 total citations (C/P = 1.50; C/CP = 2.00; h = 2; m = 0.667). Their profiles reflect consistent productivity, moderate citation impact, and highlight Portugal's prominent role in CT research within teacher education.

Among authors with three publications, Brito-Costa (Instituto Politécnico de Coimbra) records six total citations (C/P = 2.00; h = 2), indicating balanced productivity and influence. From an international perspective, Tsai (National Chiayi University, Taiwan) demonstrates stronger citation efficiency, with eight citations across three publications (C/CP = 4.00). In contrast, Schröder (Denmark) reports the highest total citations among this group (TC = 10), although concentrated in two cited works (h = 1). Overall, the pattern suggests moderate citation intensity combined with strong institutional clustering, particularly within Portuguese institutions, signalling an emerging yet increasingly stable research community in CT-oriented teacher education.

This concentration of recurring contributors may facilitate greater theoretical continuity and methodological consistency within CT-oriented teacher education research. At the same time, it also highlights the importance of expanding international scholarly participation to encourage broader contextual and pedagogical perspectives.

Table 2
The top 5 most productive authors who published more than three (3) documents

Full Name	Current Affiliation	Country	TP	NCP	TC	C/P	C/CP	*h*	*g*	*m*
Costa, C.	University of Trás-os-Montes and Alto Douro	Portugal	4	3	6	1.50	2.00	2	2	0.667
Martins, Fernando M.L.	Instituto Politécnico de Coimbra	Portugal	4	3	6	1.50	2.00	2	2	0.667
Brito-Costa, Sonia M.	Instituto Politécnico de Coimbra	Portugal	3	3	6	2.00	2.00	2	2	0.667
Tsai, Fuhsing	National Chiayi University	Taiwan	3	2	8	2.67	4.00	2	2	0.500
Schrøder, Vibeke	Københavns Professionshøjskole	Denmark	3	2	10	3.33	5.00	1	3	0.167

Note: TP=total number of publications; NCP =number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; g=g-index, m=m-index.

Leading institutions

Table 3 presents institutions with at least nine publications, revealing a relatively concentrated yet internationally distributed pattern of research productivity. The University of Maryland (United States) leads with 12 publications and 130 total citations (C/P = 10.83; h = 8), indicating both strong productivity and substantial scholarly influence within the field. Universitas Sebelas Maret (Indonesia) and the University of Trás-os-Montes and Alto Douro (Portugal) each contributed 10 publications; however, their citation profiles differ considerably. Universitas Sebelas Maret recorded 60 citations (C/P = 6.00; C/CP = 20.00), whereas the Portuguese institution accumulated 12 citations (C/P = 1.20), suggesting variation in international visibility and citation impact despite comparable publication output.

Universiti Putra Malaysia demonstrates particularly strong citation performance, with 111 citations across nine publications (C/P = 12.33; h = 5), indicating increasing visibility of Southeast Asian scholarship within CT-oriented teacher education research. In contrast, Instituto Politécnico de Coimbra reflects moderate citation influence despite stable publication productivity. Collectively, these findings indicate that institutional contributions to CT research in teacher education are increasingly distributed across North America, Europe, and Asia rather than concentrated within a single geographical region. This pattern reflects the growing internationalisation of the field and suggests the emergence of globally connected yet regionally grounded research networks.

These findings suggest that institutional leadership plays an increasingly important role in shaping the global direction of CT-oriented teacher education research. Strong citation performance among several Asian institutions further indicates the growing diversification of scholarly influence beyond traditionally dominant Western research centres.

Table 3
Most productive institutions with a minimum of nine (9) publications

Institution Name	Country	TP	NCA	NCP	TC	C/P	C/CP	*h*	*g*	*m*
University of Maryland	United States	12	NR	12	130	10.83	10.83	8	11	1.00
Universitas Sebelas Maret	Indonesia	10	NR	3	60	6.00	20.00	3	7	0.600
University of Trás-os-Montes and Alto Douro	Portugal	10	NR	6	12	1.20	2.00	2	3	0.667
Universiti Putra Malaysia	Malaysia	9	NR	9	111	12.33	12.33	5	9	1.250
Instituto Politécnico de Coimbra	Portugal	9	NR	9	18	2.00	2.00	3	4	1.000

Note: TP=total number of publications; NCA=number of contributing authors; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; g=g-index; m=m-index

Leading countries

Figure 2 and Table 4 illustrate the global distribution of Computational Thinking research in teacher education, revealing a geographically concentrated yet progressively diversified research landscape. The United States leads with 28 publications (21.54%), positioning it as the dominant contributor within the field. This prominence reflects sustained institutional engagement in teacher preparation, digital pedagogy, and computational literacy research. European countries collectively demonstrate substantial participation, particularly Turkey (13 publications; 10.00%), Portugal (12 publications; 9.23%), and Spain (12 publications; 9.23%). Rather than a single dominant European centre, the findings indicate a distributed regional research presence across multiple national contexts.

Figure 2 further demonstrates that research activity extends beyond North America and Europe. Indonesia emerges as the leading Asian contributor with 10 publications (7.69%), reflecting increasing scholarly engagement with CT integration in emerging education systems. Australia, Brazil, Canada, and Finland also contribute to the expanding international footprint of the field. The visual distribution presented in Figure 2 suggests that CT research in teacher education is becoming progressively internationalised, with scholarly activity distributed across multiple continents rather than confined to a limited group of technologically dominant nations.

Figure 2
Visualisation of the global distribution of integration of Computational Thinking in Teacher Education research

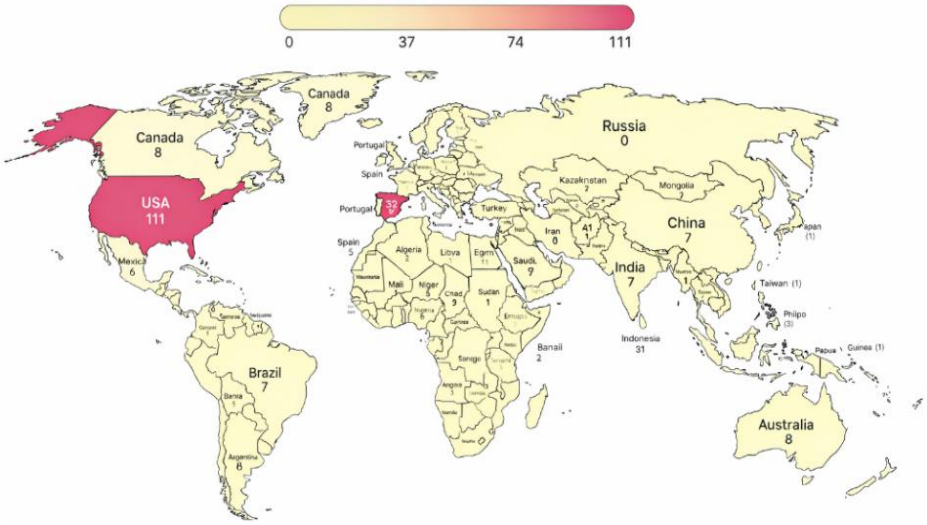


Table 4
Countries that contributed four (4) or more publications

Country	Continent	TP	%
United States	North America	28	21.54%
Turkey	Europe	13	10.00%
Portugal	Europe	12	9.23%
Spain	Europe	12	9.23%
Indonesia	Asia	10	7.69%
Norway	Europe	7	5.38%
Australia	Oceania	5	3.85%
Brazil	South America	4	3.08%
Canada	North America	4	3.08%
Finland	Europe	4	3.08%

Note: TP=total number of publications.

The expanding geographical distribution of research activity suggests that CT integration is becoming a globally recognised priority within teacher education. This trend may encourage greater cross-national collaboration and facilitate the development of more contextually responsive approaches to CT curriculum integration and teacher preparation.

Emerging Research Themes

The keyword co-occurrence analysis presented in Figure 3 provides a structured visualisation of the thematic composition and conceptual relationships within Computational Thinking research in teacher education. By standardising synonymous keywords and applying co-occurrence mapping, the analysis identifies groups of terms that frequently appear together, revealing dominant research concentrations alongside emerging pedagogical and methodological directions. The proximity and interconnection among clusters indicate that CT research in teacher education is strongly shaped by interactions between pedagogical practice, technological integration, professional development, and disciplinary applications.

Figure 3
Co-occurrence network of the author's keywords with at least 10 Occurrences

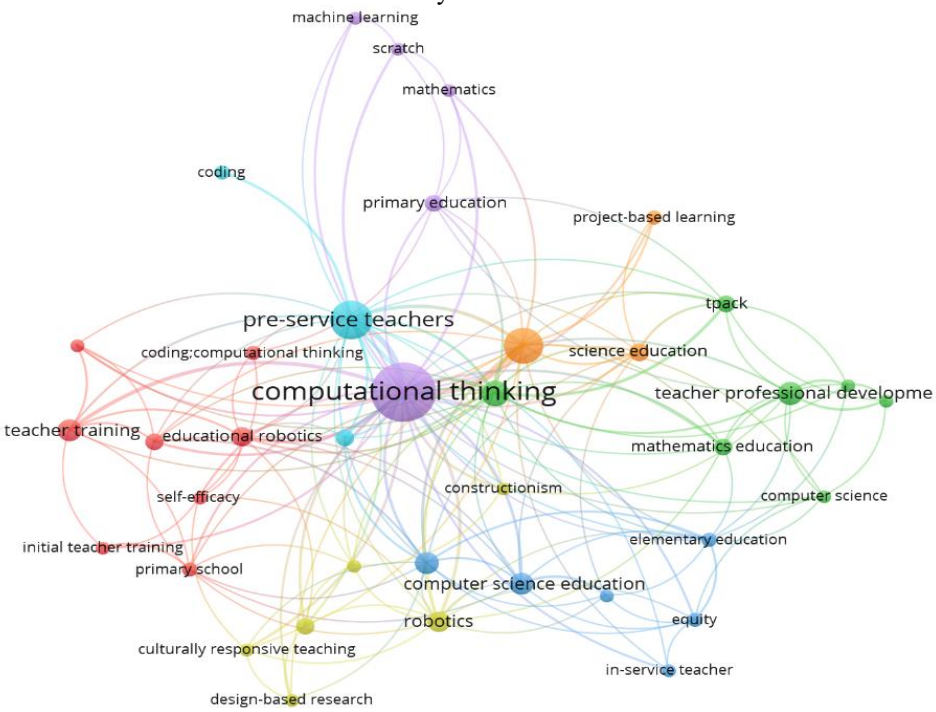


Table 5
Main keywords in the integration of computational thinking in teacher education

Cluster (Color)	Author keyword cluster
Cluster 1 (Purple)	Computational Thinking, Pre-service Teachers, Teacher Education
Cluster 2 (Red)	Teacher Training, Initial Teacher Training, Self-efficacy, Educational Robotics
Cluster 3 (Green)	Teacher Professional Development, TPACK, Mathematics Education, Science Education
Cluster 4 (Blue)	Computer Science Education, In-service Teacher, Equity, Elementary Education
Cluster 5 (Yellow)	Constructionism, Robotics, Design-based Research, Culturally Responsive Teaching
Cluster 6 (Turquoise)	Coding, Scratch, Machine Learning, Primary Education

Cluster 1 (Purple), comprising Computational Thinking, pre-service teachers, and teacher education, represents the conceptual core of the research landscape. Its central positioning within the network suggests that teacher preparation remains the dominant organising focus of CT scholarship. The strong association between CT and pre-service teacher education further indicates that existing research prioritises early professional preparation and competency development rather than solely focusing on in-service implementation contexts. This pattern reinforces the growing recognition of CT as an essential component of professional teacher preparation rather than as a peripheral technological skill.

Cluster 2 (Red), which includes teacher training, self-efficacy, and educational robotics, reflects growing interest in pedagogical readiness and affective dimensions of teacher learning. The close relationship between self-efficacy and robotics-based instruction suggests that experiential and technology-enhanced learning environments are frequently used to support CT integration. These findings indicate that successful CT implementation increasingly depends not only on technical competence but also on teachers' confidence and pedagogical readiness to integrate CT into instructional practice.

Cluster 3 (Green) connects teacher professional development, TPACK, mathematics education, and science education, indicating that CT integration increasingly occurs through interdisciplinary and technologically mediated pedagogical frameworks. The presence of TPACK within this cluster further suggests that researchers frequently conceptualise CT through the integration of technological, pedagogical, and disciplinary knowledge. This pattern highlights the continuing influence of technology integration frameworks in shaping CT-oriented teacher education research.

Cluster 4 (Blue) highlights computer science education, in-service teachers, equity, and elementary education, suggesting expanding attention toward inclusive implementation and broader educational access. However, the comparatively peripheral positioning of equity-related terms within the network indicates that inclusive and culturally responsive dimensions remain less central within the broader research landscape. This finding suggests that equity-oriented approaches to CT integration remain an emerging rather than fully established area of scholarly focus.

Cluster 5 (Yellow) combines constructionism, design-based research, and culturally responsive teaching, reflecting theoretical and methodological orientations grounded in

iterative and practice-based pedagogical inquiry. The presence of culturally responsive teaching within this cluster further indicates increasing awareness of contextual and learner-centred approaches to CT integration. These patterns suggest that researchers are progressively moving beyond purely technical implementation toward more socially and pedagogically situated perspectives of CT education.

Cluster 6 (Turquoise), consisting of coding, Scratch, machine learning, and primary education, reflects emerging instructional directions associated with tool-oriented and technology-mediated CT learning environments. The inclusion of machine learning within this cluster suggests the gradual expansion of CT research toward more advanced and data-oriented computational concepts. At the same time, the association with primary education indicates growing efforts to introduce CT competencies at earlier stages of formal education.

Collectively, the thematic network presented in Figure 3 illustrates that CT research in teacher education is evolving from isolated technology-focused interventions toward a more interconnected field that integrates pedagogical, disciplinary, and professional dimensions of teacher preparation. This shift suggests increasing recognition that sustainable CT integration requires not only technological competence but also broader engagement with curriculum design, teacher professional development, and inclusive pedagogical practices. The findings further indicate emerging opportunities for future research to explore equity-oriented approaches, longitudinal teacher development, and interdisciplinary integration within CT-focused teacher education.

DISCUSSION

The findings of this bibliometric review indicate that research on Computational Thinking (CT) in teacher education has progressed from exploratory experimentation toward structured expansion and increasing thematic consolidation. The steady rise in publication output, particularly after 2020, reflects not only growing scholarly interest but also the progressive institutionalisation of CT within teacher preparation discourse. This pattern is consistent with earlier bibliometric studies that reported rapid expansion of CT-related scholarship across educational contexts (Ozyurt & Ozyurt, 2023; Chen et al., 2024). However, unlike previous studies that positioned teacher education as a peripheral category within broader CT research, the present findings demonstrate that teacher preparation has emerged as a more distinct and increasingly central area of scholarly attention. This shift suggests that CT is no longer viewed solely as a technical or programming-oriented competence but is progressively recognised as part of professional teacher formation.

The geographical distribution of publications further reveals important implications for the global development of CT-oriented teacher education. Although the United States remains the dominant contributor, the increasing visibility of countries such as Indonesia, Portugal, Malaysia, and Turkey suggests that CT integration is expanding beyond traditionally dominant Western educational contexts. This diversification indicates that CT is becoming a globally recognised educational priority shaped by varied institutional, cultural, and policy environments. The emergence of strong contributions from Asian and European institutions also suggests growing opportunities

for cross-national collaboration and contextually responsive approaches (Vazquez-Uscanga et al., 2025) to CT curriculum integration. At the same time, uneven geographical distribution indicates that access to CT-related research and implementation capacity may remain concentrated in countries with stronger technological infrastructure and research investment. Consequently, future international collaborations and policy initiatives may play an important role in reducing disparities in CT-oriented teacher education development.

At the same time, the distribution of journals and thematic clusters reveals a distinctive intellectual orientation within the field. The prominence of educational technology outlets and the recurrent linkage of CT with robotics, coding platforms, and design-based learning position the field within a predominantly technological–pedagogical discourse. Similar patterns have also been observed in previous reviews highlighting the dominance of technology-mediated approaches to CT integration (Irawan et al., 2024; Abdul Hamed et al., 2025). Within this orientation, CT is frequently interpreted through the lens of Technological Pedagogical Content Knowledge (TPACK), foregrounding the integration of digital tools into classroom practice (Mishra & Koehler, 2006; Mouza et al., 2017). Constructionist perspectives further reinforce hands-on and artefact-based engagement (Papert, 1980; Bers et al., 2014). Although these approaches have strengthened implementation pathways, they simultaneously reinforce the tendency to conceptualise CT primarily as an extension of technological competence rather than as a transformation of teacher epistemology and curriculum reasoning.

Despite signs of consolidation, bibliometric patterns reveal a persistent structural tension within the field. Much of the expansion appears implementation-driven, as evidenced by the dominance of tool-oriented keywords, coding platforms, robotics, and intervention-based studies. Research frequently reports improvements in teacher confidence, self-efficacy, and readiness following CT-focused programmes (Mouza et al., 2017; Yadav et al., 2016; Rodrigues et al., 2025). However, such findings are commonly derived from short-term interventions. Similar concerns regarding limited longitudinal evidence have also been identified in recent CT literature (Vazquez-Uscanga et al., 2025). As a result, sustained epistemic transformation in teacher knowledge remains insufficiently examined. Recent evidence further suggests that differences in metacognitive readiness and prior coding experience may contribute to uneven CT competency development among pre-service teachers (Chichekian et al., 2026). The field therefore appears to be advancing more rapidly at the level of instructional enactment than at the level of conceptual consolidation within teacher education structures.

This imbalance may be interpreted through the lens of pedagogical instrumentalism, whereby CT is enacted primarily as a set of instructional tools or strategies rather than internalised as a restructuring of teacher cognition and disciplinary reasoning. Operationalisation through coding platforms, robotics, and technology-based activities aligns closely with technological competence frameworks such as TPACK (Mishra & Koehler, 2006). Although this instrumental orientation has accelerated innovation and classroom adoption, it also risks narrowing CT into a methodological toolkit rather than positioning it as a deeper professional and epistemic competency. Consequently, CT

integration may become pedagogically visible yet conceptually shallow, reflecting a transitional phase between technological implementation and deeper professional internalisation.

These findings carry several important implications for theory, practice, and policy. At the theoretical level, CT requires clearer articulation as a component of professional teacher knowledge that extends beyond technological competence models toward broader engagement with teacher cognition, curriculum theory, and pedagogical reasoning. At the practice level, teacher education programmes may need to move beyond isolated workshops and short-term interventions by embedding CT longitudinally across coursework, practicum experiences, and interdisciplinary pedagogical training. The findings also highlight the importance of developing more inclusive and context-sensitive approaches to CT integration, particularly given the emerging yet still peripheral positioning of equity-related themes within the bibliometric network. From a policy perspective, the post-2020 acceleration of CT research aligns with global digital competence agendas advanced by OECD (2019) and UNESCO (2023); however, policy expansion must be accompanied by stronger conceptual clarity and sustainable institutional support. Without deeper theoretical consolidation, CT risks being operationalised primarily as a compliance-driven digital competency rather than evolving into a transformative foundation of teacher professional formation.

CONCLUSION

This bibliometric review provides a systematic mapping of research on the integration of Computational Thinking (CT) in teacher education, positioning teacher preparation as the primary analytical domain rather than a peripheral subset of broader CT scholarship. The findings indicate sustained growth, expanding international participation, and increasing thematic consolidation, suggesting that CT has become progressively institutionalised within teacher education discourse. At the same time, the field remains strongly shaped by technological–pedagogical approaches, particularly through coding platforms, robotics, and short-term professional development initiatives.

The findings further suggest that CT integration is still largely implementation-driven, with comparatively limited attention given to teacher epistemology, curriculum reasoning, and long-term professional formation. Through the lens of pedagogical instrumentalism, this review highlights the need to move beyond tool-oriented integration toward more sustained and theoretically grounded approaches within teacher education structures.

Several practical implications emerge from this review. Teacher education institutions may benefit from embedding CT across coursework, practicum experiences, and interdisciplinary pedagogical training rather than relying solely on isolated workshops or technology-focused activities. The findings also highlight the importance of contextually responsive and inclusive approaches to CT integration, particularly within diverse educational settings.

Future research should prioritise longitudinal studies examining the long-term impact of CT integration on teacher professional knowledge and classroom practice. Further research is also needed on cross-country comparisons, equity-oriented approaches, interdisciplinary curriculum integration, and the relationship between CT and emerging technologies such as artificial intelligence and machine learning in teacher education.

Overall, this review contributes not only to the systematic mapping of CT research in teacher education but also to clearer understanding of how CT is currently positioned within teacher professional formation. The findings underscore the importance of aligning technological innovation with coherent theoretical grounding, sustainable curriculum design, and meaningful teacher development.

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