

A Bibliometric Journey through Computational Thinking in Primary Education: Past, Present, and Future

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ABSTRACT

This study aims to map the knowledge structure and research trends in computational thinking within primary education, emphasizing its growing importance in equipping students with critical 21st-century skills. Utilizing a bibliometric analysis approach, the study systematically examines a comprehensive dataset from the Web of Science, employing co-citation, bibliographic coupling, co-occurrence analyses, and strategic diagramming to identify key themes and influential works. The findings reveal a strong emphasis on foundational concepts such as computational thinking, programming, and primary education, while also highlighting emerging areas like digital competence and teacher professional development. However, the study acknowledges limitations, including the reliance on a single database and the focus on quantitative metrics, which may overlook qualitative nuances. These findings underscore the need for further research into diverse educational contexts and the long-term impacts of computational thinking education. The study's originality lies in its comprehensive approach, offering valuable insights into the current state and future directions of computational thinking research, and highlighting its crucial role in preparing students for a technologically advanced world.

Keywords: Computational Thinking, Primary Education, Bibliometric Analysis, Educational Technology, strategic diagram, Emerging Trends

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INTRODUCTION

Computational thinking is a critical skill in today's technology-driven world, involving a structured and logical approach to problem-solving.^[1] It extends beyond computer science to fields like mathematics, science, and the arts, helping individuals systematically break down complex problems.^[1, 2] Key aspects include algorithms, abstraction, and automation.^[1] Teaching this skill to young students is essential for developing their abilities to recognize patterns and solve problems, both academically and in everyday life.^[1] It is a vital 21st-century skill for problem-solving across various domains.^[3,4] Educational strategies, such as integrating computational thinking into webpage design,^[2] Scratch programming,^[5] and STEM games,^[6] aim to enhance these skills, crucial for thriving in a technology-focused world.

Primary students, known for their curiosity and rapid learning abilities, are ideal candidates for computational thinking education.

They benefit greatly from interactive learning methods, such as hands-on activities, which allow them to explore, experiment, and discover solutions.^[7] Educational tools like games, puzzles, and interactive activities are particularly effective in teaching computational concepts.^[8] Introducing programming logic and computational thinking at this early stage prepares students for higher education and develops essential problem-solving skills.^[9] Moreover, robotics-based storytelling activities further enhance these skills.^[10]

Incorporating computational thinking in primary education is crucial for establishing a foundational understanding of key digital-era concepts. It enhances critical thinking and problem-solving skills, essential for academic success and career readiness.^[11,12] Early introduction helps bridge the digital divide, ensuring all students acquire vital 21st-century skills.^[13] Moreover, embedding computational thinking in the curriculum nurtures technologically literate and innovative individuals. Research suggests that structured programs and models can significantly enhance these abilities.^[14]

Empirical research on computational thinking in primary education has significantly expanded, highlighting its growing importance. Studies have explored integrating computational



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thinking into subjects like math and science, utilizing tools such as Scratch and robotics,^[15] and implementing project-based learning^[16] to enhance problem-solving skills.^[17] Additionally, game-based learning and unplugged activities have proven effective in engaging young learners and developing computational skills without advanced technology.^[18] These approaches emphasize critical thinking and 21st-century skills, preparing students for the digital era.

Significant gaps in the empirical literature on computational thinking in primary education include the lack of longitudinal studies, limited exploration of diverse cultural and socio-economic contexts, and insufficient evaluation of teacher training programs. These gaps result in a fragmented understanding of the field. A bibliometric analysis can address these deficiencies by systematically mapping the research landscape, identifying trends, key contributions, and underexplored areas.^[19] This method is crucial for consolidating existing knowledge and guiding future empirical research, ensuring a comprehensive understanding of computational thinking in primary education.

Previous bibliometric analyses in the field of computational thinking have primarily focused on identifying trends, key topics, and thematic areas within academic literature. For instance, Chen *et al.*^[20] analyzed research trends from 2012 to 2021, examining 249 documents from the Web of Science. Their study highlighted the significant growth of computational thinking as a topic, especially within K-12 education, and noted the involvement of various disciplinary domains. Piazza and Mengual-Andrés^[21] provided a global overview of scientific productivity on computational thinking, focusing on the role of coding in educational contexts. Their analysis of 672 documents from Scopus, covering the years 2006 to 2020, revealed an increasing number of publications, particularly in STEM fields. Similarly, Dúo-Terrón^[22] focused on the use of Scratch in educational contexts, analyzing 1023 documents from Web of Science from 2003 to 2022. This study underscored Scratch's critical role in developing computational thinking skills at the elementary level.

Despite these comprehensive analyses, there are significant gaps in the bibliometric research landscape. Notably, previous studies did not focus on primary education context. In addition, they often do not provide a holistic view that comprehensively covers past, present, and potential future research directions in computational thinking, particularly within the context of primary education. Many existing analyses are limited in scope, focusing predominantly on specific aspects, such as the use of particular tools like Scratch or the broader integration of computational thinking in education. There is a lack of studies that synthesize the evolution of the field, assess current research frontiers, and identify emerging trends that could inform future investigations.

The absence of such comprehensive bibliometric analyses creates a gap in understanding the full trajectory of research developments in this domain. A thorough examination that includes an analysis of past influential publications, current knowledge structures, and future research potential is essential.^[23] This approach would provide a nuanced understanding of the progression and shifts within the field, offering valuable insights for researchers and educators aiming to advance the integration of computational thinking in primary education. Thus, there is a critical need for a bibliometric study that not only maps the existing literature but also anticipates future research directions, ensuring a robust and dynamic understanding of the field's evolution.

The aim of this bibliometric analysis is to provide a comprehensive overview of the field of computational thinking within the context of primary education. The study seeks to map out the knowledge structure, tracing the development of key themes and identifying influential publications that have shaped the discourse. By analyzing past and present research, the study aims to uncover patterns and trends that have emerged over time. Additionally, it intends to identify potential areas for future investigation, thereby guiding researchers towards promising directions that can further enrich the academic landscape in this field.

To achieve this aim, the study is guided by the following research questions:

What is the current knowledge structure in the context of computational thinking in primary education?

Which directions for future research can be offered to researchers to further explore and expand the field of computational thinking in primary education?

This bibliometric analysis makes a significant contribution to the field by offering a novel synthesis of existing literature on computational thinking in primary education, applying advanced bibliometric techniques in an educational context. Unlike previous studies, this analysis not only maps key themes and influential publications but also introduces a comprehensive and strategic framework for understanding the evolution of computational thinking in primary education. The study extends beyond traditional bibliometric methods by integrating innovative diagram-based foresight, providing a dynamic visualization of emerging trends and research trajectories. Additionally, this work broadens the scope of the dataset by including a diverse range of interdisciplinary perspectives, thus offering fresh insights into the integration of computational thinking across various educational strategies and subjects. By addressing gaps in the literature, the study opens up new avenues for research, particularly in underexplored areas, and offers actionable guidance for future studies. Finally, the analysis highlights the critical importance of educational equity, offering a unique exploration of how computational thinking is taught in diverse contexts, with a strong emphasis on inclusive practices

that ensure equitable access to essential 21st-century skills. This research not only supports the global educational goals but also provides a comprehensive, forward-looking perspective on how computational thinking can be more effectively incorporated into curricula worldwide.

This article is structured to provide a thorough exploration of computational thinking in primary education, beginning with the Introduction, which establishes the importance of the topic and outlines the research questions. The Theoretical Background section then reviews key concepts and existing literature, setting the foundation for the study. The Method section describes the research design and methodology, detailing how data was collected, filtered, and analyzed using bibliometric techniques. The Findings section presents the results of these analyses, highlighting key themes and influential works within the field. In the Discussion, these findings are contextualized within the broader literature, exploring their implications for theory, practice, and future research. The article concludes with a Conclusion that summarizes the study's contributions, acknowledges its limitations, and suggests avenues for future research, thereby providing a comprehensive overview and critical insights into the role of computational thinking in primary education.

METHODOLOGY

Research Design

This study uses bibliometric analysis to explore “Computational Thinking in Primary Education”. This approach systematically maps and quantifies research trends, major contributions, and collaboration patterns in academic literature.^[24,25] It provides a comprehensive overview of the field's development, highlighting key areas for future research.^[26]

Procedure

Figure 1 illustrates the systematic data processing workflow employed in analyzing literature related to computational thinking in primary education. The workflow comprises five main stages:

Data Retrieval and preprocessing

A comprehensive strategy for keyword determination and data retrieval involved using broad terms like “computational thinking” and “review” in the Web of Science database, capturing a wide range of relevant literature.^[27] Many bibliometric studies note the extensive citation records and indexing capabilities of WoS, which allow researchers to track historical trends and evolution in their fields effectively.^[28,29] This is in contrast to Scopus, which, although large, may not encompass the same depth of high-impact journals and may favor specific fields more than others.^[30] The top 10 most-cited articles were reviewed to refine and specify keywords, ensuring pertinent literature retrieval.

The following keywords and terminologies were established to encompass the breadth of the research area:

Computational Thinking

Keywords associated with this concept include “computational reasoning” and “algorithmic thinking”. These terms were selected to ensure that the search captured the various facets and synonyms of computational thinking in academic discourse.

Primary Education

To cover the different terminologies used in various contexts and regions, a range of equivalent terms was incorporated. These include “elementary education”, “primary school”, “elementary school”, “K-12 education”, “basic education”, and “basic school”. By including these variations, the search strategy aimed to encompass studies from diverse educational systems and terminology preferences.

Initial Search

The initial search for this bibliometric analysis was conducted using the Web of Science database. This particular database was chosen due to its comprehensive coverage of high-quality, peer-reviewed literature across a broad range of academic disciplines. This database is known for rigorous indexing and includes influential journals, making it ideal for obtaining reliable data for academic studies.^[31] The decision to use Web of Science was based on its extensive multidisciplinary content and detailed citation metrics, crucial for bibliometric analysis.^[32,33]

The search was performed on July 10, 2024. The search was conducted using the **Topic** search field, which was selected because it allows for the inclusion of keywords from the title, abstract, and author keywords of the publications. This search field was preferred over others, such as “Title” or “Abstract” alone, as it provides a broader and more comprehensive retrieval of relevant articles by capturing various aspects of the publication content.

The specific search string used was:

```
TS=(("computational think*" OR "computational reason*" OR "algorithmic think*") AND ("primary education" OR "elementary education" OR "primary school" OR "elementary school" OR "K-12 education" OR "basic education" OR "basic school"))
```

This search string was designed to encompass a wide range of relevant literature by including multiple synonyms and variations of key terms related to computational thinking and primary education. The use of truncation symbols (*) ensures the inclusion of different word forms and derivatives, further broadening the search scope.

At this stage, the search yielded a total of 825 metadata records. These records represent a diverse array of research publications that cover various aspects of computational thinking within the

context of primary education. This dataset forms the basis for the subsequent stages of data filtering and analysis in the study.

Data filtering

In this phase of the study, data filtering was performed to refine the initial dataset and ensure the inclusion of the most relevant publications. The inclusion criteria were set to be comprehensive, allowing the inclusion of all records retrieved from the initial search. At this stage, no exclusion criteria were applied, with the intent to maintain a broad and inclusive dataset.

To ensure the reliability of the filtered data, a rigorous process was employed. This involved a thorough review of the titles and abstracts of the retrieved records against the established inclusion criteria. The review process was conducted by multiple researchers independently to enhance objectivity. To quantify the consistency of the selection process, inter-rater reliability was calculated. This statistical measure helped to assess the degree of agreement among the researchers.

In cases where discrepancies arose between reviewers' decisions, a consensus-building process was initiated. This involved discussions to clarify and resolve differing interpretations, ensuring a unified understanding and agreement on the inclusion

of specific records. This consensus approach was critical to maintain the integrity and reliability of the data selection process.

As a result of this meticulous filtering process, all 825 metadata records from the initial search were retained for further analysis. This decision was made based on the lack of exclusion criteria at this stage, allowing for a comprehensive review and analysis in subsequent steps.

Data Extraction

In the data extraction phase, the primary objective was to gather all necessary information from the selected articles for further analysis. The data extraction involved two primary formats: Excel and plain text. The extracted data was saved in files with the extensions .xls for Excel and .txt for plain text.

The extraction process was carried out as follows

1. Raw Data Storage: Initially, all relevant articles were collected and saved in a marked list within the Web of Science database. This marked list served as a repository for all articles deemed relevant based on the inclusion criteria.
2. Excel File Extraction: The marked list was then exported into an Excel file format (.xls). This Excel file was used

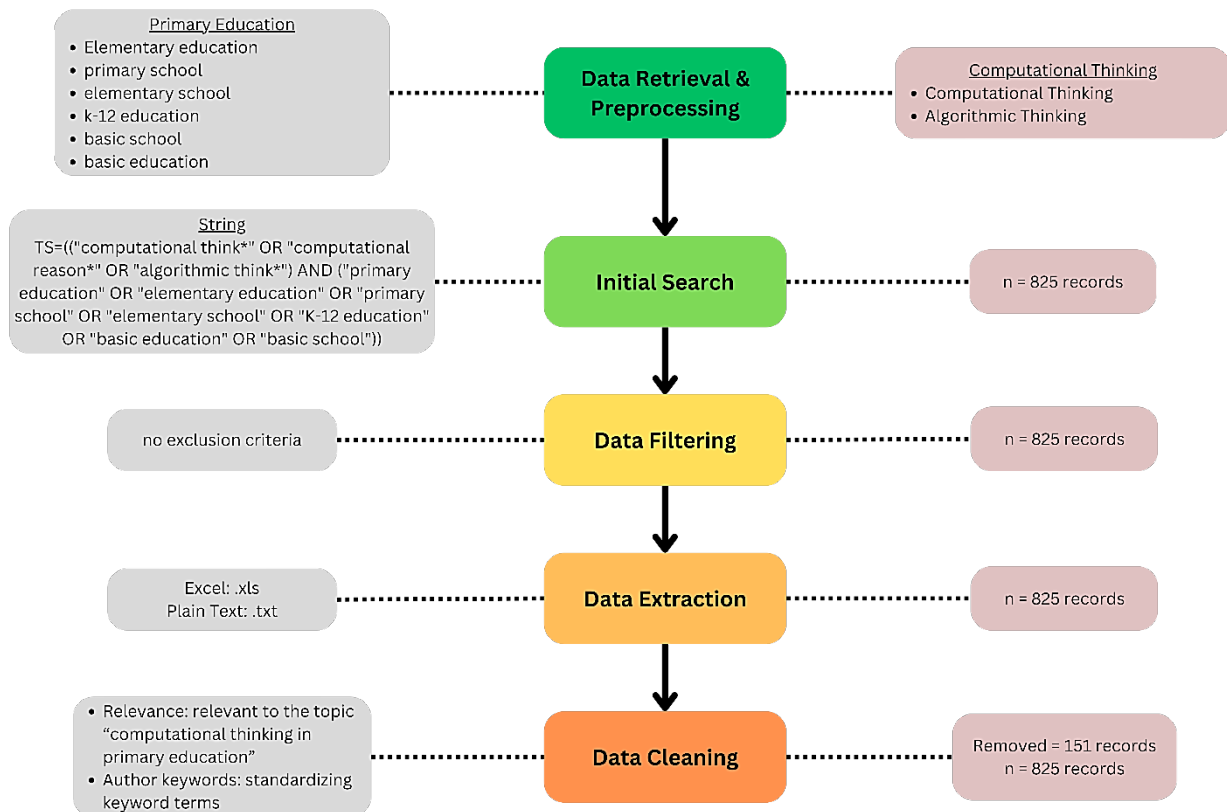


Figure 1: Data Processing Flow.

to perform a detailed relevance check, where the titles and abstracts of the articles were reviewed to ensure they met the study's focus on computational thinking in primary education.

3. **Relevance Checking:** Within the Excel file, a thorough examination was conducted to verify the relevance of each article. This involved cross-checking the titles and abstracts against the predefined criteria to confirm their pertinence to the study's objectives.
4. **Cleaning and Plain Text Extraction:** Following the relevance check, the marked list was cleaned to remove any irrelevant entries. The cleaned list was then extracted into a plain text file format (.txt). This format was specifically chosen for its compatibility with the VosViewer software, which is used for bibliometric analysis and visualization.

A total of 825 records were extracted during this process. These records were subsequently prepared for analysis in VosViewer, where they would undergo further examination to map out the intellectual structure and key themes in the field of computational thinking within primary education.

Data Cleaning

Data cleaning is a crucial step in the bibliometric analysis process to ensure the accuracy and relevance of the dataset. The purpose of data cleaning is to remove irrelevant records and standardize the terminology used in the dataset, particularly concerning author keywords. This process enhances the quality and reliability of the data, ensuring that subsequent analyses are based on precise and consistent information.

The cleaning process focused on two main aspects

1. **Relevance:** Out of the initial 825 records, 674 were identified as relevant based on the criteria established during the relevance checking phase. These records needed to be verified to ensure they directly pertain to the topic of computational thinking in primary education.
2. **Author Keywords:** There was a need to harmonize the author keywords to maintain consistency in the terminology used. This involved standardizing variations in keywords and ensuring that synonyms were appropriately aligned.

The cleaning of relevance was performed manually. This meticulous process involved all authors of the study, who collectively reviewed each record to confirm its relevance to the research focus. The manual review was necessary to accurately

assess the context and content of each article, ensuring that only those closely aligned with the study's objectives were retained.

The cleaning process was facilitated using Excel files. These files contained the detailed metadata of each record, including titles, abstracts, and author keywords. Excel's functionalities allowed for efficient sorting, filtering, and manual editing, which were essential for conducting a thorough and precise cleaning process. The outcome of this data cleaning step was a refined dataset consisting of 674 relevant records with standardized keywords, ensuring a high-quality foundation for the subsequent stages of analysis using bibliometric tools such as VosViewer.

Data Analysis

For this study, science mapping techniques were employed to address the research questions, including co-citation analysis, bibliographic coupling, co-occurrence analysis, and the development of a strategic diagram. These methods were selected due to their effectiveness in elucidating the relationships between scientific documents, identifying influential works, and mapping the intellectual structure of the research field.

Co-citation analysis was used to identify the frequency with which two documents are cited together, revealing the structure of the research field and the relationships between key papers.^[34] Bibliographic coupling, on the other hand, examines how often two works cite the same third work, which helps uncover thematic connections within the literature.^[35] Co-occurrence analysis focused on examining the frequency of keywords appearing together, thus identifying main topics and trends within the domain.^[36] Lastly, the strategic diagram was employed to visualize the relevance and maturity of different research themes, aiding in the identification of emerging areas and suggesting potential future research directions.^[37]

The data analysis procedure began with importing metadata in .txt format into the VosViewer software for both co-citation and bibliographic coupling analyses. VosViewer generated visualizations of the networks formed by co-cited documents and bibliographic couplings, mapping out the academic field's structure and highlighting clusters of related research. For the co-occurrence analysis, the same metadata, along with a thesaurus file for standardizing terminology and synonyms, was utilized in VosViewer. The resulting co-occurrence map was downloaded as a .txt file, providing insights into the most frequently co-occurring keywords, which reflected the key themes in the field. The data from the co-occurrence analysis was then processed in Microsoft Excel to create a strategic diagram. This diagram categorized keywords based on their centrality and density, identifying emerging topics and suggesting future research directions.

The tools used for these analyses were VosViewer and Microsoft Excel. VosViewer was chosen for its specialized capabilities in creating maps based on network data and visualizing bibliometric

networks, making it particularly suitable for managing large datasets and conducting co-citation, bibliographic coupling, and co-occurrence analyses. Microsoft Excel was utilized for further data processing and for creating the strategic diagrams, leveraging its versatility and capacity to handle complex datasets for detailed examination and categorization of keywords. These tools were selected for their reliability and efficacy in handling bibliometric data, ensuring comprehensive and insightful analyses to address the study's research questions.

RESULTS

Bibliographic Coupling for determining the current knowledge structure within the field of computational thinking in primary education

Bibliographic coupling analyzes the total linkage strength (TLS) between linked documents, which reflects the relationship of the citing document. Of the 674 documents, 53 met a threshold of 38 citations. The threshold was set after several experiments with the dataset to obtain the most robust and appropriate clusters in the network visualization. In this analysis, the threshold was determined by experimenting with several cutoff values between 36 and 40. The threshold value should be chosen so that it does not undermine the credibility of the network map. For example, a higher cutoff value would lead to over-filtering, increasing the likelihood of missing important clusters and topics, while a lower cutoff value would lead to under-filtering, resulting in redundant clusters and repetition (Geng *et al.*, 2020). The publications with the highest total link strength (TLS) are Angeli and Valanides^[38] (185 TLS), Brackmann *et al.*^[39] (155 TLS), and Kong *et al.*^[40] (155 TLS). Table 1 shows the top ten documents in the bibliographic coupling analysis.

Figure 2 shows the network visualization of the bibliographic coupling, which produced four clusters that are visibly independent of each other based on emerging and future trends of Computational Thinking in Primary Education. The labeling of the clusters is based on an inductive interpretation by evaluating representative articles in the clusters and a synthesis based on common themes and research streams.

Cluster 1 (red)

With 16 publications, cluster 1 labeled “**Computational Thinking and Programming in Primary Education**”. This cluster focuses on the implementation and impact of teaching computational thinking (CT) through programming in primary schools. The articles in this cluster explore various teaching approaches, tools such as Scratch, and methodologies to enhance CT skills among students. For instance, Rich *et al.*^[48] presents learning trajectories based on an in-depth review of over 100 scholarly articles in computer science education, identifying learning goals and the influence of context and language on the creation of these trajectories. Pérez-Marín *et al.*^[49] proposes

and validates a methodology based on metaphors and the use of Scratch (MECOPROG) to teach basic programming concepts to children, demonstrating significant improvements in CT skills. Falloon^[50] analyzes data from 5-6-year-old students using Scratch Jr. to learn basic shapes, showing that basic coding in the primary curriculum effectively enhances students' general and higher-order thinking skills.

Cluster 2 (green)

With 13 publications, cluster 2 labeled as “**Teacher Professional Development and Computational Thinking**”. This cluster explores various professional development programs for teachers aimed at enhancing their ability to teach computational thinking. The articles in this cluster cover training, curriculum design, and the evaluation of program effectiveness. For example, Menekse^[51] reviews studies on computer science teacher professional development in the United States, exploring the structure, goals, and effectiveness of these training programs. Zhong *et al.*^[52] investigates the impact of social factors such as gender and partnership on pair programming in primary schools, highlighting the importance of partnerships in enhancing the effectiveness of pair programming. Kong *et al.*^[40] evaluates the impact of students' interest, collaboration attitude, and programming empowerment in CT education, showing a positive relationship between interest and the effectiveness of CT learning.

Cluster 3 (blue)

With 11 publications, this cluster is labeled “**Computational Thinking through Unplugged Activities**”. This cluster includes research that employs unplugged activities (without digital devices) to teach computational thinking. The articles highlight the effectiveness of these activities in developing CT skills, especially in schools with limited technological resources. For instance, Brackmann *et al.*^[39] demonstrates that unplugged activities significantly enhance CT skills among primary school students, particularly in resource-constrained schools. Arfé *et al.*^[53] shows that coding practice not only improves coding problem-solving abilities but also executive functions such as planning and inhibition in children. Relkin *et al.*^[54] develops a CT assessment instrument suitable for young children, demonstrating its validity and reliability in measuring CT skills without requiring prior programming knowledge.

Cluster 4 (yellow)

With 9 publications, cluster 4 labeled “**Integrating Computational Thinking with Other Subjects**”. This cluster focuses on integrating computational thinking with other subjects such as science, mathematics, and literacy. The articles explore how CT can be incorporated into existing curricula to enhance students' understanding of various academic concepts. For example, Wei *et al.*^[55] evaluates the effectiveness of partial pair programming

Table 1: Top 10 documents in bibliographic coupling analysis.

Sl. No.	Author	Article Title	Source Title	Citation	TLS	Scope
1	Grover and Pea ^[41]	Computational Thinking in K-12: A Review of the State of the Field	Educational Researcher	1066	131	Review of computational thinking in K-12 education.
2	Bers <i>et al.</i> ^[42]	Computational thinking and tinkering: Exploration of an early childhood robotics curriculum	Computers and Education	448	67	Early childhood robotics curriculum and computational thinking.
3	Sáez-López <i>et al.</i> ^[43]	Visual programming languages integrated across the curriculum in elementary school: A two year case study using Scratch in five schools	Computers and Education	271	138	Scratch programming in elementary school curriculum.
4	Chen <i>et al.</i> (2017) ^[44]	Assessing elementary students' computational thinking in everyday reasoning and robotics programming	Computers and Education	221	147	Assessing CT through robotics and everyday reasoning in fifth grade.
5	Kalelioğlu ^[45]	A new way of teaching programming skills to K-12 students: Code.org	Computers in Human Behavior	201	68	Teaching programming skills using code.org in primary education.
6	Angeli and Valanides ^[38]	Developing young children's computational thinking with educational robotics: An interaction effect between gender and scaffolding strategy	Computers in Human Behavior	177	185	Impact of educational robotics on young children's CT, focusing on gender and scaffolding.
7	Israel <i>et al.</i> ^[46]	Supporting all learners in school-wide computational thinking: A cross-case qualitative analysis	Computers and Education	152	119	School-wide CT integration in high-need schools.
8	Kong <i>et al.</i> ^[40]	A study of primary school students' interest, collaboration attitude, and programming empowerment in computational thinking education	Computers and Education	145	155	Interest, collaboration attitude, and empowerment in CT education.
9	Bers <i>et al.</i> ^[47]	Coding as a playground: Promoting positive learning experiences in childhood classrooms	Computers and Education	134	89	Introducing coding and CT in early childhood education with robotics.
10	Brackmann <i>et al.</i> ^[39]	Development of Computational Thinking Skills through Unplugged Activities in Primary School	Proceedings of the 12 th Workshop in Primary and Secondary Computing Education (WIPSCE 2017)	114	155	Unplugged activities for developing CT skills in primary school.

Source(s): Authors' own creation/own work

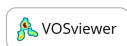
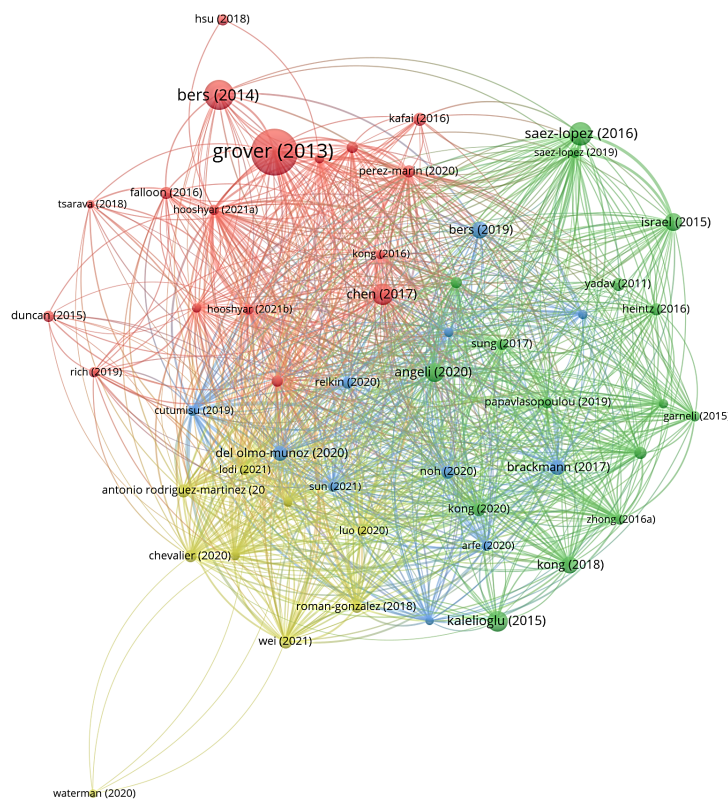


Figure 2: Bibliographic Coupling Visualization Network (Dynamic Figure: <https://unusa.id/ct-bc>).

in improving CT skills and self-efficacy among primary school students, showing significant improvements in participants. Lodi and Martini^[56] reviews the historical and epistemological approaches to CT from the perspectives of Papert and Wing, highlighting the relevance of both in current K-12 computer science education. Tsarava *et al.*^[57] provides a cognitive definition of CT and shows positive associations between CT and complex numerical abilities, verbal reasoning abilities, and non-verbal visuospatial abilities in primary school students.

Based on the aforesaid discussion, Table 2 summarizes the bibliographic coupling analysis on computational thinking in primary education context.

Directions for future research of computational thinking in primary education

Co-occurrence Analysis

This work produced a thorough data map by means of co-occurrence analysis, therefore showing the relationships between keywords in the field of computational thinking in elementary education. Examining Total Link Strength (TLS) and Occurrence (OCC) of the keywords helps one to get important understanding of the relevance and relationships of many

ideas. TLS gauges the strength of the links between keywords; occurrence shows the frequency of a keyword in the dataset.

A criteria was established whereby only terms with minimum seven occurrences were considered to guarantee the strength of the analysis. This criterion was developed to concentrate on the most pertinent and important keywords, therefore lowering noise from less often appearing terms that might not be very important for the field's development. By use of this criteria, the dataset was distilled to a reasonable and significant collection of keywords.

Out of 889 keywords first found, the threshold filtering produced 57 keywords satisfying the minimal occurrence criterion. After that, these keywords were mapped on a data map to show the keyword network inside the research area graphically. Using a strategic diagram, this data map was further examined to divide terms into four quadrants.

Strategic Diagram and Emerging Topics

Strategic diagram analysis can identify research topics based on the centrality and density of keywords.^[58] This study focuses on analyzing author keywords. Cobo *et al.*^[59] visualized the centrality and density in a two-dimensional strategic diagram with four quadrants. Research topics in Quadrant 1 (Q1) represent the

specialty's motor themes with strong centrality and high density. Quadrant 2 (Q2) represents specialized and peripheral topics with well-developed internal links and irrelevant external links. Research topics in Quadrant 3 (Q3) represent emerging or declining themes with low density and low centrality. Research topics in Quadrant 4 (Q4) represent general and basic topics in the research field.

Four metrics are used to represent the centrality and density to determine the types of quadrants in the strategic diagram, such as Total Link Strength (TLS), Occurrence (OCC), average publication year, the logarithmic value of TLS (Log TLS), and logarithmic value of OCC (Log OCC). Based on the density and centrality calculation, the values of average publication year, log TLS and log OCC were 2020.118, 1.462, and 1.044, respectively. Figure 3 shows the strategic diagram with the X-axis as the centrality measure, represented by the values of Log TLS, and the Y-axis as the density measures, denoted by the Log OCC value (Raw data is in Appendix 1).

In Quadrant 1, known as Motor Themes, the themes are both highly central and dense, indicating they are well-developed and integral to the field. These core areas include “computational thinking”, which serves as the primary focus for integrating computational skills into education, and “primary education”, which underscores the educational level being studied. Other significant themes in this quadrant include “programming”, “K-12”, “teaching strategy”, “computer science”, “assessment”, “coding”, “educational robotics”, “Scratch”, “STEM”, “problem solving”, “robotics”, “education”, “computing”, “mathematics education”, “game-based learning”,

“21st century skills”, “gender gap”, “mathematics”, and “unplugged activities”. These keywords collectively represent the foundational elements and practical applications of computational thinking, indicating their widespread relevance and established presence in the literature.

In Quadrant 2, Niche Themes are highly developed but less central, indicating specialized areas that are significant but not as broadly influential. These include “algorithmic thinking”, which focuses on designing and understanding algorithms, “gamification”, which incorporates game design elements into educational contexts, and “STEAM”, which integrates arts into the traditional STEM disciplines. These themes, while important, cater to specific niches within the broader context of computational thinking in education.

Quadrant 3 contains Emerging or Declining Themes, which are characterized by lower development and centrality. These themes are either in the early stages of exploration or losing relevance. Included in this quadrant are “curriculum”, which involves the integration of computational thinking into educational curricula, “cognitive skills”, and “digital competence”, which highlight the mental and digital proficiencies necessary for computational thinking. Other themes such as “professional learning”, “artificial intelligence”, “ICT”, “constructionism”, “educational technology”, “systematic literature review”, “teacher training”, “informatics education”, “teacher education”, “teacher professional development”, “computer programming”, “computer-aided instruction”, “creativity”, “self-efficacy”, “visual programming”, “abstraction”, “digital learning”, “pedagogical

Table 2: Bibliographic coupling analysis on computational thinking in primary education context.

Cluster	Cluster Label	Number of Publication	Representative Article
1 (red)	Computational Thinking and Programming in Primary Education	16	Rich, et al., ^[48] Pérez-Marín, et al., ^[49] Falloon ^[50]
2 (green)	Teacher Professional Development and Computational Thinking	13	Menekse, ^[51] Zhong, et al., ^[52] Kong, et al. ^[40]
3 (blue)	Computational Thinking Through Unplugged Activities	11	Menekse, ^[51] Zhong, et al., ^[52] Kong, et al. ^[40]
4 (yellow)	Integrating Computational Thinking with Other Subjects	9	Wei, et al., ^[55] Lodi and Martini, ^[56] Tsarava, et al. ^[57]

Source(s): Authors' own creation/own work

issues”, “technology-aided learning”, “augmented reality”, “Bebras”, “block-based programming”, “digital storytelling”, “integration”, “learning”, “secondary education”, “teaching”, “technology”, “project-based learning”, and “robotics education” reflect a wide array of concepts ranging from theoretical frameworks to practical implementations and technological advancements in education.

We focused on Quadrant 3 in the strategic diagram to determine emerging and declining research topics. Emerging topics are when the average number of publications on a particular topic is greater than or equal to the average of the overall average number of publications. Table 3 shows the emerging and declining research topics from the 33 keywords in Quadrant 3. The results show that there were 18 (55%) emerging research topics of computational thinking in primary education context, and 15 (45%) declining research topics.

Future research

Digital Competence and Learning Technologies

This theme encompasses keywords such as digital competence, digital learning, technology-aided learning, block-based programming, and robotics education. Digital competence refers to the ability to effectively use digital technologies, which is integral to digital learning and technology-aided learning. Block-based programming and robotics education exemplify the practical application of technology in teaching computational

thinking to students. This theme is crucial as it highlights the importance of equipping students with the necessary digital skills and leveraging technological tools to enhance the learning experience.

Teacher Professional Development

Keywords under this theme include professional learning, teacher education, teacher professional development, and self-efficacy. This theme focuses on the improvement of teachers' competencies and confidence in teaching computational thinking. Professional learning and teacher professional development encompass the training and development needed by teachers, while self-efficacy reflects teachers' beliefs in their abilities to effectively teach this subject. Emphasizing this theme ensures that teachers are well-prepared and motivated to integrate computational thinking into their teaching practices.

Instructional Strategies and Approaches

This theme includes keywords such as teaching, project-based learning, integration, and bebras. It covers various strategies and approaches used in teaching computational thinking. Teaching refers to the general practice of instruction, project-based learning is a relevant method that involves learning through projects, and integration highlights the importance of incorporating computational thinking into existing curricula. Bebras, an international competition promoting computational thinking,

Table 3: Emerging keyword themes.

Themes	Keywords	Log TLS	Log Occ.	APY	Q	Status
Digital Competence and Learning Technologies	digital competence	1.7924	1.1461	2020.429	3	Emerging
	digital learning	1.5911	0.9542	2021.111	3	Emerging
	technology-aided learning	1.5682	0.9542	2020.667	3	Emerging
	block-based programming	1.5798	0.9031	2021.375	3	Emerging
	robotics education	1.4624	0.8451	2020.571	3	Emerging
Teacher Professional Development	professional learning	1.699	1.1461	2021.286	3	Emerging
	teacher education	1.7243	1.0414	2021.818	3	Emerging
	teacher professional development	1.6335	1.0414	2020.909	3	Emerging
	self-efficacy	1.6721	1	2021	3	Emerging
Instructional Strategies and Approaches	teaching	1.4914	0.9031	2022.125	3	Emerging
	project-based learning	1.5441	0.8451	2020.429	3	Emerging
	integration	1.5911	0.9031	2022.625	3	Emerging
	bebras	1.5563	0.9031	2021.5	3	Emerging
Educational Research and Evaluation	systematic literature review	1.6812	1.0792	2021.917	3	Emerging
	secondary education	1.7782	0.9031	2020.75	3	Emerging
Cognitive and Analytical Skills	cognitive skills	1.7243	1.2041	2021.375	3	Emerging
	abstraction	1.5798	0.9542	2021.111	3	Emerging
	artificial intelligence	1.7076	1.1139	2021.692	3	Emerging

NB: Log TLS=Log Total Link Strength; Log Occ=Log Occurrence; APY=Average Publication Year; Q=Quartile; Status=Emerging or declining

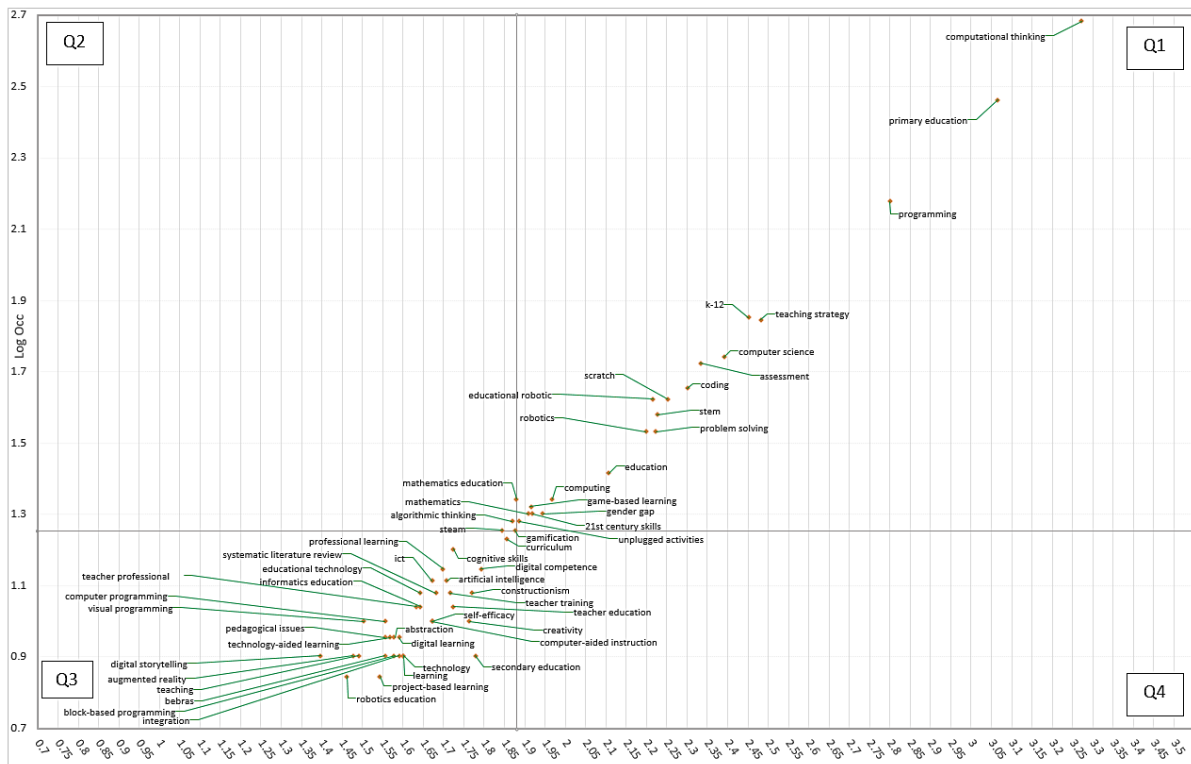


Figure 3: Strategic diagram.

illustrates how competitions can also serve as an effective instructional strategy. This theme is essential for understanding and implementing diverse teaching methodologies.

Educational Research and Evaluation

Keywords like systematic literature review and secondary education fall under this theme. It pertains to research and evaluation within the educational context. Systematic literature review is a research method used to systematically evaluate existing literature, while secondary education refers to the context of middle and high school education, which can be a subject or area of study in educational research. This theme is vital for advancing knowledge through rigorous research and evaluation methods.

Cognitive and Analytical Skills

This theme includes keywords such as cognitive skills, abstraction, and artificial intelligence. It covers the cognitive and analytical skills that support the teaching of computational thinking. Cognitive skills involve critical thinking and problem-solving abilities, abstraction is a key skill in computational thinking that involves simplifying complex problems, and artificial intelligence represents an advanced topic requiring high-level analytical skills. This theme underscores the importance of developing these foundational skills in students to prepare them for more complex computational concepts.

DISCUSSION

This bibliometric analysis provides a comprehensive overview of the knowledge structure and research trends within this field. The co-occurrence analysis further refined the focus by identifying 57 critical keywords from an initial pool of 888, using a threshold of seven occurrences to ensure relevance. This analysis highlighted core themes such as “computational thinking”, “primary education”, and “programming”, which are central to the discourse. The strategic diagram classified these keywords into quadrants, differentiating between well-established motor themes, specialized niche areas, and emerging or declining topics. Notably, emerging themes like digital competence, teacher professional development, and project-based learning were identified, suggesting new areas of focus and growth. These findings not only underscore the current state of research but also illuminate potential avenues for future exploration, making this study a valuable guide for researchers and educators aiming to advance the field of computational thinking in primary education.

The analysis of scholarly journals from 2019 to 2024 on computational thinking in primary education reveals consistent themes and emerging areas. Foundational elements like “computational thinking”, “primary education”, and “programming” remain central, while new focuses include digital competence and teacher professional development.^[60,61] Earlier studies, such as Wing,^[62] emphasized computational thinking as fundamental, akin to literacy, but recent research delves into specific pedagogical strategies and their effectiveness.^[63] The

literature also highlights challenges in integrating computational thinking, such as infrastructure limitations and curriculum constraints.^[64,65]

Critical analysis of previous research highlights both strengths and limitations in the study of computational thinking. While studies like those by Grover and Pea^[41] provide robust theoretical frameworks, they often lack empirical data on implementation effectiveness in diverse classroom settings.^[66] This study addresses these gaps by focusing on practical applications and challenges, such as “project-based learning” and “teacher professional development”, thereby bridging theory with classroom realities. The integration of findings reveals a need to consider contextual differences in educational systems and cultural contexts. Theories such as constructionism and cognitive load theory underscore the importance of a nuanced approach to computational thinking education. This discussion suggests a shift towards a holistic, context-sensitive approach in primary education, informed by empirical data and theoretical insights.^[67,68]

Future Research

The emergence of these five thematic areas in computational thinking research within primary education contexts is not coincidental but reflects broader educational trends, technological advancements, and societal needs. Understanding why these themes are emerging provides valuable insights for researchers and practitioners in the field.

Digital Competence and Learning Technologies has emerged as a significant research area due to the rapid digitalization of society and education systems worldwide. Previous research by Bers *et al.*^[47] highlighted the importance of early exposure to digital technologies, but recent studies have expanded this focus to include comprehensive digital competence development. The COVID-19 pandemic accelerated this trend. The emergence of block-based programming and robotics education as research topics aligns with Falloon^[50] findings on the effectiveness of visual programming tools for young learners, but extends the application to more diverse educational contexts.

Teacher Professional Development has gained prominence as researchers recognize that effective implementation of computational thinking curricula heavily depends on teacher preparedness. This theme's emergence addresses gaps identified by Israel *et al.*^[46] who found that many teachers lack confidence and competence in teaching computational thinking concepts. The focus on self-efficacy particularly responds to Angeli and Valanides's^[38] research highlighting the critical role of teacher confidence in successful computational thinking integration. As Kong *et al.*^[40] noted, teacher professional development needs have evolved from basic awareness to sophisticated pedagogical approaches, explaining why this theme continues to gain traction in recent literature.

Instructional Strategies and Approaches has emerged as researchers move beyond theoretical frameworks to practical implementation methods. The growing interest in project-based learning specifically builds upon Brackmann *et al.*'s^[39] work on unplugged activities, extending to more comprehensive instructional designs. The emergence of integration as a key topic reflects Lye and Koh's^[69] call for embedding computational thinking across the curriculum rather than treating it as a standalone subject. The Bebras competition's appearance in the literature indicates a shift toward gamified assessment approaches, as suggested by Kalelioğlu's^[45] research on motivational factors in computational thinking education. Finally, Farooqui *et al.*^[70] emphasised the importance of collaborative learning environments in developing computational thinking skills, paying attention to the role of social interaction and technology.

Educational Research and Evaluation has emerged as the field matures and requires more rigorous assessment of existing practices. The prevalence of systematic literature reviews responds to Grover and Pea's^[41] call for consolidating the fragmented research landscape. The focus on secondary education alongside primary education indicates researchers' growing interest in educational continuity, addressing concerns raised by Earl *et al.*^[31] about transition challenges between educational levels. This theme reflects the field's movement toward evidence-based practices and comprehensive evaluation frameworks.

Cognitive and Analytical Skills has emerged as researchers delve deeper into the cognitive foundations of computational thinking. The focus on abstraction specifically builds upon Lodi and Martini's^[56] theoretical work connecting computational thinking to cognitive development theories. The emergence of artificial intelligence as a research topic represents a significant evolution from Chen *et al.*'s^[44] earlier work on basic computational reasoning, reflecting the increasing sophistication of computational thinking applications. This theme indicates a shift from viewing computational thinking as primarily programming-related to understanding it as a fundamental cognitive approach applicable across domains.

These emerging themes collectively demonstrate the field's evolution from defining computational thinking to implementing it effectively across diverse educational contexts, with increasing attention to teacher preparation, cognitive foundations, and technological integration. The timing of their emergence (2020-2022) coincides with both technological advancements and educational responses to global challenges, particularly the pandemic-induced shift to digital learning environments.

Implications

The findings from this bibliometric analysis have several important implications, particularly in the theoretical, practical, and social domains. Theoretically, the study enhances the existing body of knowledge by identifying both established and

emerging themes in computational thinking within primary education. It supports the notion that computational thinking is not only a critical skill but also a versatile one that intersects with various educational subjects and pedagogical approaches.^[71] The identification of emerging areas, such as digital competence and teacher professional development, suggests a need for theoretical frameworks that better integrate these elements into the broader discourse on computational thinking. This expansion of theoretical boundaries provides a richer, more nuanced understanding of how computational thinking can be effectively taught and learned across different contexts.

Practically, the study offers valuable insights for educators, curriculum developers, and policymakers. The emphasis on practical applications, such as project-based learning and the role of educational robotics, underscores the necessity for hands-on, experiential learning methods.^[72,73] These findings advocate for a shift in teaching strategies, encouraging the adoption of more interactive and student-centered approaches. Moreover, the recognition of the importance of teacher professional development highlights the need for comprehensive training programs that equip educators with the skills and confidence to integrate computational thinking into their curricula. This practical implication is crucial for ensuring that educators are not only aware of computational thinking concepts but are also proficient in delivering them effectively.

Socially, the study's findings emphasize the potential for computational thinking to address broader educational and societal goals. By identifying themes like the gender gap and 21st-century skills, the analysis highlights the role of computational thinking in promoting inclusivity and preparing students for future challenges in a digital world.^[71,73] The social implication here is the call for educational equity, ensuring that all students, regardless of background, have access to quality computational thinking education. This emphasis on inclusivity and equal access aligns with global educational goals and reflects a broader commitment to social justice in education. Overall, this study not only contributes to academic scholarship but also offers practical and social pathways for enhancing computational thinking education in primary schools.

Limitations and Recommendations

This bibliometric analysis, while comprehensive, has several limitations that should be acknowledged. First, the study relies solely on data from the Web of Science database, which, although extensive, may not capture all relevant publications, particularly those in non-English languages or lesser-known journals. This limitation potentially excludes significant research contributions from regions or contexts where computational thinking in primary education might be discussed differently. Second, the analysis is constrained by the use of predetermined keywords and the specific thresholds set for inclusion in the

co-occurrence and co-citation analyses. These methodological choices, while necessary for manageability, may have led to the exclusion of relevant studies that use alternative terminologies or those that did not meet the threshold criteria. Additionally, the strategic diagrams and keyword clustering presented in this study could be influenced by the keyword selection strategy itself, especially when relying solely on Web of Science. The reliance on a specific set of keywords may not fully capture the diversity of terminology used across different databases or research fields, potentially distorting the clustering and visualizations of related research topics. Finally, the study's focus on bibliometric metrics such as Total Link Strength (TLS) and occurrence rates provides a quantitative overview but lacks qualitative depth, potentially overlooking nuanced insights into the application and impact of computational thinking education.

Based on these limitations, several recommendations for future research are proposed. To address the database limitation, future studies should incorporate a broader range of databases, including Scopus, Google Scholar, and regional databases, to ensure a more comprehensive collection of relevant literature. Additionally, including publications in multiple languages can provide a more global perspective on the integration of computational thinking in primary education. Researchers should also consider using a wider variety of keywords and lower inclusion thresholds to capture a broader scope of studies, especially emerging research that may not yet have high citation counts.

Furthermore, future research should delve deeper into the qualitative aspects of computational thinking education. This could involve case studies, ethnographic research, or interviews with educators and students to provide richer, context-specific insights. Exploring how different educational systems and cultural contexts influence the implementation and perception of computational thinking can offer valuable contributions to the field. Additionally, unanswered questions identified in this study, such as the long-term impacts of computational thinking education on students' career trajectories and the specific challenges faced by teachers in diverse educational settings, warrant further investigation. Expanding the research to explore these areas can provide a more holistic understanding of computational thinking's role and effectiveness in primary education, ultimately guiding better educational practices and policies.

CONCLUSION

This study provides a comprehensive overview of the knowledge structure and research trends in computational thinking within the context of primary education. Our findings align with previous research that emphasized the foundational importance of computational thinking concepts in early education, while extending their work by identifying emerging areas such as digital competence and teacher professional development. The

bibliometric approach employed in this study offers distinct advantages over traditional literature reviews by providing quantitative evidence of research patterns and enabling visualization of knowledge structures through strategic diagrams, similar to methodological benefits noted in previous studies.

For future research, we propose several new studies: (1) longitudinal investigations tracking the impact of computational thinking education on students' academic and career trajectories from primary school through higher education; (2) cross-cultural comparative studies examining how computational thinking is implemented across different educational systems and cultural contexts; and (3) mixed-methods research combining bibliometric analysis with qualitative approaches to provide deeper insights into classroom implementation challenges. These proposals address gaps regarding the need for more contextually-sensitive research in computational thinking education.

The theoretical and practical implications of our findings suggest a need for integrating computational thinking across various educational contexts and enhancing teacher training programs, supporting arguments for a more holistic educational approach. However, limitations include reliance on a single database and the focus on bibliometric metrics, which may overlook qualitative insights that other researchers have captured through classroom observations and interviews.

Ultimately, this study contributes to the growing body of knowledge on computational thinking in primary education by systematically mapping the field's evolution and identifying emerging research directions. Computational thinking represents not merely a technical skill but a fundamental cognitive ability essential for future generations. Our findings reinforce this perspective while providing a methodologically rigorous foundation for future research endeavors aimed at developing more inclusive and effective computational thinking education for all students in an increasingly technology-driven world.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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APPENDIXES

Appendix 1: Raw data of keywords status.

Keywords	Log TLS	Log Occ	APY	Q	Status
computational thinking	3.272074	2.683947	2020.476	1	NA
primary education	3.066326	2.462398	2020.41	1	NA
programming	2.798651	2.176091	2020.007	1	NA
k-12	2.451786	1.851258	2020	1	NA
teaching strategy	2.481443	1.845098	2019.829	1	NA
computer science	2.390935	1.740363	2020.509	1	NA
assessment	2.332438	1.724276	2020.66	1	NA
coding	2.30103	1.653213	2019.6	1	NA
educational robotic	2.217484	1.623249	2020.857	1	NA
scratch	2.25042	1.623249	2020.286	1	NA
stem	2.225309	1.579784	2020.947	1	NA
problem solving	2.222716	1.531479	2020.353	1	NA
robotics	2.198657	1.531479	2020.912	1	NA
education	2.10721	1.414973	2020.039	1	NA
computing	1.968483	1.342423	2018.909	1	NA
mathematics education	1.880814	1.342423	2021.636	1	NA
game-based learning	1.913814	1.322219	2019.714	1	NA
21 st century skills	1.919078	1.30103	2021.15	1	NA
gender gap	1.944483	1.30103	2022.05	1	NA
mathematics	1.908485	1.30103	2020.15	1	NA
unplugged activities	1.886491	1.278754	2021.158	1	NA
algorithmic thinking	1.869232	1.278754	2018.737	2	NA
gamification	1.875061	1.255273	2020.111	2	NA
steam	1.845098	1.255273	2021.444	2	NA
curriculum	1.857332	1.230449	2019.647	3	Declining
cognitive skills	1.724276	1.20412	2021.375	3	Emerging
digital competence	1.792392	1.146128	2020.429	3	Emerging
professional learning	1.69897	1.146128	2021.286	3	Emerging
artificial intelligence	1.70757	1.113943	2021.692	3	Emerging
ict	1.672098	1.113943	2018.615	3	Declining
constructionism	1.770852	1.079181	2019.25	3	Declining
educational technology	1.643453	1.079181	2019.417	3	Declining
systematic literature review	1.681241	1.079181	2021.917	3	Emerging
teacher training	1.716003	1.079181	2019.167	3	Declining
informatics education	1.643453	1.041393	2020.182	3	Declining
teacher education	1.724276	1.041393	2021.818	3	Emerging
teacher professional development	1.633468	1.041393	2020.909	3	Emerging
computer programming	1.556303	1	2020.2	3	Declining
computer-aided instruction	1.672098	1	2018.2	3	Declining

Keywords	Log TLS	Log Occ	APY	Q	Status
creativity	1.763428	1	2019.8	3	Declining
self-efficacy	1.672098	1	2021	3	Emerging
visual programming	1.50515	1	2019.6	3	Declining
abstraction	1.579784	0.954243	2021.111	3	Emerging
digital learning	1.591065	0.954243	2021.111	3	Emerging
pedagogical issues	1.556303	0.954243	2019.222	3	Declining
technology-aided learning	1.568202	0.954243	2020.667	3	Emerging
augmented reality	1.477121	0.90309	2019.875	3	Declining
bebras	1.556303	0.90309	2021.5	3	Emerging
block-based programming	1.579784	0.90309	2021.375	3	Emerging
digital storytelling	1.39794	0.90309	2019.875	3	Declining
integration	1.591065	0.90309	2022.625	3	Emerging
learning	1.60206	0.90309	2019.5	3	Declining
secondary education	1.778151	0.90309	2020.75	3	Emerging
teaching	1.491362	0.90309	2022.125	3	Emerging
technology	1.60206	0.90309	2019	3	Declining
project-based learning	1.544068	0.845098	2020.429	3	Emerging
robotics education	1.462398	0.845098	2020.571	3	Emerging
	1.879643	1.253503	2020.424		

NB: Log TLS: Log Total Link Strength; Log Occ: Log Occurrence; APY: Average Publication Year; Q: Quartile; Status: Emerging or declining