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Review Article

Building digital thinkers: A bibliometric analysis of computational thinking in children's education for a sustainable future

Rita Wong Mee Mee [1]
0000-0002-8294-7569

Fatin Syamilah Che Yob [2*]
0000-0002-2519-277X

Lim Seong Pek [2]
0000-0002-0322-7572

Muhammad Fairuz Abd Rauf [3]
0009-0002-7776-7376

Yang Mingmei [4]
0009-0007-9952-1373

Ali Derahvasht [5]
0000-0001-6158-0852

[1] Center for Language, National Defence University of Malaysia, Kuala Lumpur, MALAYSIA
[2] Faculty of Education and Liberal Arts, INTI International University Malaysia, Nilai, MALAYSIA
[3] Faculty of Science and Defence Technology, National Defence University of Malaysia, Kuala Lumpur, MALAYSIA
[4] School of Teacher Education, Pingdingsan University, Pingdinshan, Henan, CHINA
[5] Department of Global University Rankings, Iran University of Medical Sciences, Tehran, IRAN
[*] Corresponding author: fatinsyamilah.cheyob@newinti.edu.my

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ABSTRACT

Computational thinking (CT) has emerged as a foundational skill for young learners, preparing them to navigate and contribute to an increasingly digital world. This bibliometric analysis utilizes 374 articles from the Web of Science database to explore the research landscape surrounding CT in children's learning, focusing on its applications in language acquisition and cognitive development. Using co-citation and keyword co-occurrence analyses, the study identifies key thematic clusters, including CT's integration into curricula, its role in enhancing critical thinking, and its social-emotional benefits. Findings suggest that CT holds significant potential in advancing equitable and inclusive education, aligning with Sustainable Development Goal (SDG) 4 by promoting accessible, high-quality learning experiences. Furthermore, CT's interactive and problem-solving methodologies, such as coding exercises and robotics, actively engage children and encourage collaborative learning, directly supporting SDG 10 by reducing educational inequalities across diverse learning environments. This analysis not only highlights CT's transformative impact on traditional educational practices but also reveals critical research gaps, particularly in the areas of inclusivity and accessibility. Future research is encouraged to investigate these areas further, advancing sustainable educational strategies that equip children with essential skills for a rapidly evolving technological landscape, thus fostering resilience, adaptability, and creativity among young learners.

Keywords: computational thinking, children's education, digital literacy, cognitive development, creativity

INTRODUCTION

At a time when digital literacy is just as important as traditional skills, computational thinking (CT) has become the cornerstone of preparing young people for an increasingly technology-driven world. CT is more than just coding; it is a problem-solving framework that teaches children how to deal with complex problems systematically and analytically (Angeli & Giannakos, 2020). The essence of computational thinking encompasses four basic skills: decomposition (breaking down a significant problem into manageable parts), pattern recognition (detecting trends in data or sequences), abstraction (focusing on relevant information while ignoring distractions), and algorithmic reasoning (developing step-by-step solutions). These skills are highly valued in many subjects, especially language learning, as they can help children cope with complex language structures, decipher meanings, and face learning challenges in a structured mindset (Papadakis, 2021).

The importance of teaching children computational thinking cannot be overstated. With the rapid development of digital technologies and artificial intelligence, children who develop CT skills early on are better equipped to adapt to the diverse evolution of their careers and technological environments. CT develops flexibility, adaptability, and creativity skills that enable children to solve real-world problems effectively (Parsazadeh et al., 2020). In addition to these practical benefits, CT encourages young learners to delve deeper into topics, fostering critical thinking and allowing children to apply logic and reasoning, which facilitates language learning by helping them understand complex grammar, distinguish unfamiliar vocabulary, and grasp the nuances of language structure (Wang et al., 2021). For example, in a language class, pattern recognition in computational thinking can help children recognize repetitive sentence structures, while algorithmic reasoning can assist them in forming sentences with logical consistency. These CT skills have the potential to make language learning more engaging and accessible for children who have difficulty using traditional methods (Rehmat et al., 2020).

Despite the potential benefits of language learning, traditional language teaching often faces problems such as limited participation, leading to students losing interest due to repetitive or overly abstract exercises. Additionally, children may struggle with vocabulary or grammar restrictions, reading and writing difficulties, or the intimidating nature of language barriers that can disrupt learning altogether (Cano et al., 2020). Differences in students' language skills and motivation further complicate the learning environment, often leading to gaps in comprehension. In this context, computational thinking is a promising solution to address ongoing language learning challenges. Integrating CT strategies into language classrooms can make learning more dynamic, personalized, and effective. For example, algorithmic thinking can guide children to process sentence structures systematically, while abstraction can help them focus on the main elements of the text, making comprehension easier. Moreover, CT strategies encourage active, hands-on learning and engage students through exploration and discovery rather than memorization, fostering a deeper and more practical engagement (Rottenhofer et al., 2021).

Therefore, by exploring the possibilities of computational thinking in language teaching, this bibliographic analysis sheds light on how CT addresses language learning challenges. Through an evidence-based review, this study explores how CT can provide children with a structured, engaging, and empowering approach to language learning, preparing them for future technological and language needs. Through the following research questions, this study provides a methodical overview of the subject, assisting academics and educators in understanding how computational thinking is changing in educational settings:

1. What are the most influential articles and authors on computational thinking in language teaching based on citation patterns?
2. What are the most frequently used keywords on computational thinking in language teaching research to indicate the field's focus?

METHODOLOGY

Purpose of Conducting Bibliometric Analysis

This bibliometric analysis aims to systematically review the literature on computational thinking in children, particularly within the context of language learning. Bibliometric analysis provides a quantitative approach to assess research trends, authorship, and publication patterns, offering a structured overview of the current knowledge landscape in this field (Maharani et al., 2023). By examining core concepts, influential authors, and publication networks, this study seeks to identify knowledge structures, research frontiers, and emerging issues at the intersection of computational thinking and language teaching. It will also help uncover potential gaps in existing research to guide future studies on developing CT-related language learning interventions for children (Tekdal, 2021).

Conducting bibliometric analyses enables researchers to measure scientific impact and track developments across specific subtopics within a broad research area. Understanding the bibliographic landscape is crucial because of the increasing overlap between computational thinking and educational practices, especially in language learning. This approach can highlight impactful articles, frequently cited authors, and key recurring keywords, helping educators and researchers gain insights into the role of computational thinking in language instruction (Rafiq et al., 2023). Additionally, bibliometric methodologies reveal broad patterns of co-citation and collaborative networks, reflecting foundational research areas and partnerships that shape this interdisciplinary field (Zárate-Pérez et al., 2023).

The two main bibliographic techniques (Wider et al., 2024)—co-citation and co-occurrence analysis—are used to assess the knowledge, structure, and thematic content of research in this field.

Co-citation analysis

Co-citation analysis involves identifying pairs of frequently cited articles, revealing how different studies interrelate, and highlighting significant theories, influential authors, and foundational publications within computational thinking in language learning. This technique clarifies the relationship between computational thinking research and associated fields, such as cognitive science and educational technology, helping map the field's conceptual foundations. Recent bibliometric studies have confirmed that co-citation analysis effectively uncovers influential research groups and underlying theoretical frameworks, as demonstrated in computational thinking and related educational fields (Kleminski et al., 2020; Zhaisanova & Mansurova, 2023).

Co-occurrence analysis

Co-occurrence analysis identifies frequently co-appearing keywords or terms within articles, mapping keyword frequency and associations. This approach reveals key research topics, trends, and emerging themes within computational thinking and language learning, enabling insight into prominent terminology and thematic areas within the field. For example, terms such as "computational thinking," "language literacy," and "problem-solving skills" often cluster together, indicating shared research focuses. This method provides valuable insights into evolving topics and interdisciplinary expansions of computational thinking, supporting educators and researchers in addressing the prevailing concepts and challenges in this domain (Bhuyan et al., 2021; Jacobs et al., 2022).

Data Collection and Database Selection

Bibliographic analysis focuses on research published in influential journals indexed in databases such as the Web of Science (WoS), widely known for their extensive scientific indexing and citation tracking. The WoS is perfect for co-citation and bibliometric network analysis since it contains high-impact journals with strict peer-review guidelines, guaranteeing trustworthy and high-quality research sources with robust citation monitoring. The keywords of the research included terms such as "computational thinking," "language learning," "children," "literacy," and "education," which are necessary for the collection of relevant literature in the field of CT and language education through both open-access and closed-access journals to ensure comprehensive coverage. The data search was conducted on 3rd November 2024, as shown in **Table 1**, and was limited to studies published between 2015 and 2024 to focus on the most recent developments and trends of the last decade.

Table 1. Inclusion criteria for bibliometric analysis

WoS database	Inclusion	Exclusion
Time period	2015 to 2024	2023 and prior
Search field	TS	Not TS
Search keywords	"computational thinking" and "children"	Others
Citation topics meso	All	-
Document type	Article or review article	Besides article or review article
Language	English	Besides English

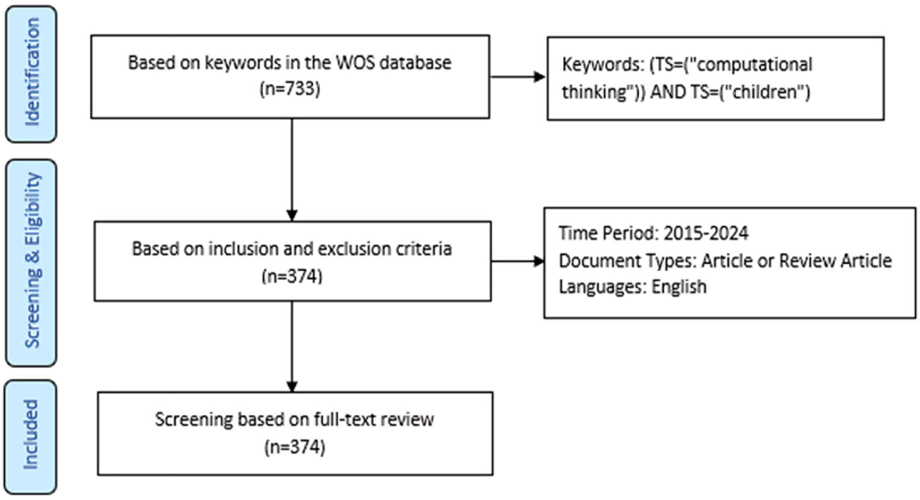

Figure 1. PRISMA flow chart (Source: Authors)

The guiding research question was used to categorize the results in order to increase clarity. Publication trends, co-citation analysis of fundamental works, keyword co-occurrence analysis emphasizing important research issues, and institutional and regional contributions to CT research are the four areas in which the findings are presented.

RESULTS

Publication Trends

The data in **Figure 1** indicates that computational thinking in children's education has steadily grown over the past decade. Beginning with 733 initial papers, a more focused selection based on specific inclusion and exclusion criteria narrowed the count to 374 articles, all concentrating on CT applications and implications for children. This refined dataset reflects targeted research within this interdisciplinary field, combining elements of computer science, pedagogy, psychology, and curriculum studies.

The annual distribution of publications, as shown in the citation report, suggests an upward trend. In the early years, fewer publications were found, indicative of the nascent stage of CT in educational research. However, the recent surge aligns with the growing recognition of CT as a crucial skill for 21st-century learners. This increase may also correspond with evolving educational policies globally that emphasize integrating CT into primary and secondary curricula. The consistent rise in publications showcases the increasing emphasis researchers and educators place CT as a foundation for children's cognitive development and problem-solving skills.

Citation Analysis

The citation report in **Figure 2** reveals a significant impact on the academic community. The dataset has a total of 5,666 citations, with 4,292 citations when excluding self-citations, resulting in an impressive average citation rate of 15.15 per item. This high average demonstrates the relevance and interest in research on CT in children, underscoring its influence across multiple disciplines.

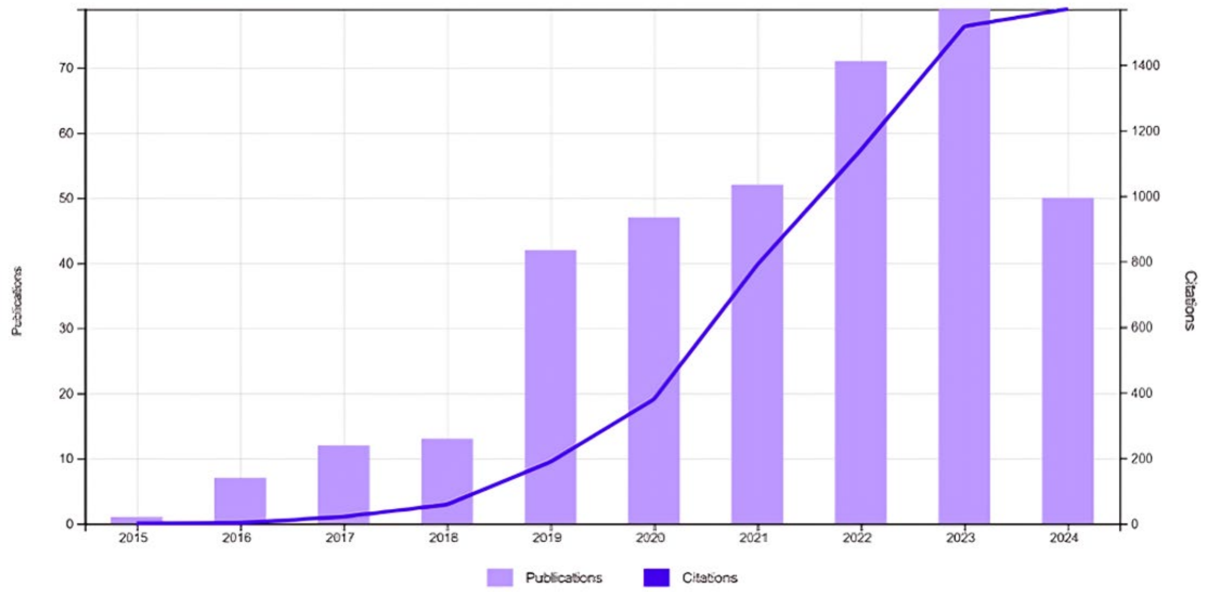

Figure 2. Quantity of publications and citations between 2015 and 2024 (Source: Generated by authors through Web of Science database)

The h-index of 40 further underscores the impact of this research field. An h-index of 40 indicates that at least 40 publications have received 40 or more citations each, a testament to the scholarly resonance and robustness of research on CT in children's learning. This metric reflects these studies' enduring interest and value, as many articles have become foundational or frequently referenced within educational technology, developmental psychology, and computer science communities. The exclusion of self-citations in reporting these metrics also highlights that this research receives genuine engagement from independent scholars, enhancing its academic credibility.

Performance Analysis

The VOSviewer, a tool for analyzing WoS data on CT in children's learning, offers a detailed account of the development of the field, its most significant contributors, and the regions with the highest concentration of study worldwide. A more detailed look into each data category reveals nuanced insights into the driving forces behind this growing domain.

Highest-cited documents: Foundational works in the field

The documents with the highest citations reflect pivotal contributions that shape the understanding and implementation of CT in early education. For instance, Angeli and Valanides (2020), with 199 citations, examined the effects of educational robotics in developing CT skills, particularly exploring the impact of gender and tailored support through scaffolding. This work is foundational because it emphasizes adapting CT education to meet diverse learning needs. It makes a case for gender-sensitive approaches that foster inclusivity in technology education from a young age. Similarly, Leonard et al. (2016) and Bers (2019) contribute substantially by integrating robotics and game design into CT education. These works highlight how interactive, play-based methodologies can boost children's engagement, confidence, and skill acquisition in computational thinking, bridging the gap between abstract concepts and tangible experiences. Each top-cited article is highly referenced for its findings and the innovative educational strategies it proposes, which resonate with educators, policymakers, and researchers. The frequent citation of these documents suggests they are seen as essential resources, setting benchmarks for curriculum development, instructional design, and inclusive practices in CT.

Influential journals: Interdisciplinary publication venues

Prominent journals, such as Computers & Education and Education and Information Technologies, reflect the interdisciplinary appeal of CT in children's learning. With a substantial citation count of 645, Computers &

Education is a leading journal showcasing studies interweaving educational theory, cognitive development, and digital literacy. This journal's high citation count signals its status as a repository of high-quality, impactful research that bridges technology and pedagogy, appealing to educators, psychologists, and computer scientists alike. The appearance of journals like Early Childhood Research Quarterly indicates that the topic also engages early childhood specialists keen on understanding how foundational CT skills can be nurtured during critical developmental stages. This range of publication venues illustrates the broad academic interest in CT, emphasizing how the topic transcends disciplinary boundaries to create a shared platform for advancing digital literacy in young learners.

Top authors: Thought leaders in CT education

The authors with the most contributions reveal who the thought leaders in CT research are and where their work focuses. Yang Weipeng, the top author with 14 documents and 150 citations, has likely established a research portfolio that addresses various dimensions of CT in education, positioning him as a prolific contributor whose work influences ongoing dialogues and directions within the field. Marina Umaschi Bers, another leading figure, is notable for her work on using coding as a pedagogical tool. Her research often emphasizes coding as a playful, language-like activity, providing children a platform to express creativity while building computational skills. Bers' focus on early childhood education, coupled with her high citation count, underscores her research's value in establishing coding as an integral part of early education frameworks. These authors and others on the list contribute to building the theoretical and practical foundations of CT in education, informing curriculum design, teaching methodologies, and policy recommendations.

Leading institutions: Research hubs driving CT in education

The presence of renowned universities, such as the Education University of Hong Kong and Tufts University, signifies strong institutional backing for CT research in children's learning. The Education University of Hong Kong leads with 16 documents and a notable link strength, suggesting its role as a central hub for collaborative research. Tufts University's significant citation count of 571 highlights a targeted focus on early childhood CT, likely linked to Marina Umaschi Bers and her extensive research in this area. Institutions like Stanford University and Beijing Normal University also appear on the list, indicating that leading universities globally are invested in CT education research. These institutions often have robust research funding and interdisciplinary teams, which support sustained research efforts and produce findings that contribute to global understanding and best practices in CT education.

Geographical distribution: Regional focus and research collaborations

The geographic data reveals that the United States is at the forefront of CT research in children's learning, with 100 documents and 1,913 citations. This strong showing likely reflects substantial investment in STEM education and digital literacy initiatives. The high output from the U.S. may also result from policy initiatives aimed at integrating CT into school curricula, which creates demand for research that can guide effective implementation. China's presence, with 65 documents, highlights the country's increasing focus on technology education and reflects its emphasis on preparing students for a digital economy. Despite fewer documents, Spain's high citation count suggests that Spanish research is highly impactful, potentially focusing on specialized areas or adopting innovative methods that attract international attention. These geographic trends underline the global significance of CT, with each region contributing unique perspectives and approaches shaped by local educational policies and societal needs.

Co-Citation Analysis of Computational Thinking

The co-citation analysis of CT in children's learning reveals key scholarly works, their influence, and underlying thematic clusters. By examining the top ten articles with the highest co-citation counts, we can understand which publications serve as foundational references across studies in this field. Additionally, the cluster analysis suggests distinct thematic groups, each representing unique research focuses and methodological approaches. The following is a detailed analysis of each cluster, with suggested labels based on the thematic focus of representative works.

Table 2. Co-citations (top 10 articles)

Rank	Authors	Title	Citations	Total link strength
1	Wing (2006)	Computational thinking	229	1,771
2	Grover and Pea (2013)	Computational thinking in K-12: A review of the state of the field	127	1,110
3	Bers et al. (2014)	Computational thinking and tinkering: Exploration of an early childhood robotics curriculum	115	1,044
4	Lye and Koh (2014)	Review on teaching and learning of computational thinking through programming: What is next for K-12?	86	846
5	Wing (2008)	Computational thinking and thinking about computing	84	748
6	Shute et al. (2017)	Demystifying computational thinking	81	851
7	Barr and Stephenson (2011)	Bringing computational thinking to K-12: What is involved, and what is the role of the computer science education community?	75	692
8	Resnick et al. (2009)	Scratch: Programming for all	71	544
9	Román-González et al. (2017)	Which cognitive abilities underlie computational thinking? Criterion validity of the Computational Thinking Test	70	708
10	Papert (1980)	Mindstorms: Children, computers, and powerful ideas	69	433

Top co-cited articles

The top ten articles in **Table 2** showcase foundational theories and practices within CT education. Jeanette Wing's seminal papers from 2006 and 2008 are at the forefront, collectively accumulating high co-citation counts and establishing core computational thinking concepts (Wing, 2006, 2008). Wing's work is frequently referenced for framing CT as a fundamental skill set applicable across disciplines, reinforcing its importance in early education. Other highly co-cited works, such as Grover and Pea (2013), Bers et al. (2014), and Lye and Koh (2014), provide comprehensive reviews and empirical studies on CT in K-12 education. These articles delve into practical applications, challenges, and opportunities for integrating CT into curricula. Resnick et al. (2009) on Scratch programming is another cornerstone, representing the application of visual programming environments to foster creativity and problem-solving skills in young learners. Papert's (1980) Mindstorms remains influential as early work advocating for constructivist learning through technology.

Co-citation by clusters

As in **Figure 3**, the co-citation analysis provides an intricate map of how research on CT in children's learning is organized, with distinct clusters representing critical focal areas. Each cluster in **Table 3** contributes uniquely to understanding and promoting CT education and underscores different research paradigms, methodologies, and applications. Below is an expanded analysis of each cluster, detailing their foundational studies, thematic focus, and implications for the broader educational landscape.

Cluster 1 introduces CT to young learners through interactive and experiential learning methods, often utilizing tools like robotics, coding games, and other hands-on resources. This cluster is characterized by foundational works like Bers et al. (2014), which investigates an early childhood robotics curriculum. Bers et al.'s (2014) contributions, combined with other notable studies such as Angeli and Valanides (2020), reflect a commitment to adapting CT teaching methods to meet the developmental needs of young children. One of the core ideas in this cluster is the recognition that early exposure to CT through play-based and tangible activities fosters positive attitudes and engagement in learning computational skills. Studies in this cluster explore the pedagogical frameworks necessary to engage young children, examining how scaffolding (structured guidance) and differentiation (tailoring instruction to individual needs) support CT learning.

The approach is grounded in the constructivist theories popularized by Seymour Papert (1980) in Mindstorms, which posits that learning is most effective when children can manipulate physical or digital tools to construct knowledge. Additionally, this cluster frequently addresses socio-emotional aspects, including how CT activities can improve young learners' social skills, collaboration, and self-efficacy. Studies like Relkin et al. (2020) and Saxena et al. (2020) further explore how "unplugged" activities (those without computers) can develop CT skills in ways accessible to young children and adaptable to diverse learning environments. These

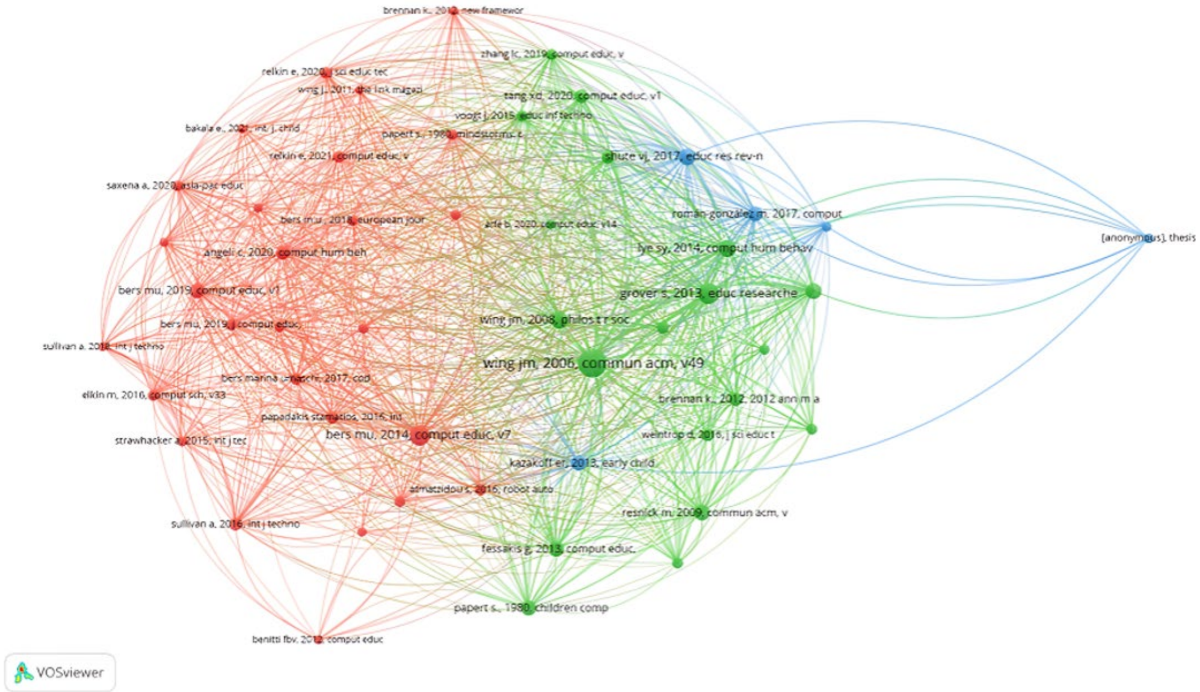

Figure 3. Co-citations analysis (VOSviewer visualization) (Source: VOSviewer visualization by authors)

Table 3. Co-citations cluster

Cluster No and color	Cluster labels	No. of articles	Representative Publications
1 (red)	Early childhood computational engagement and pedagogy	27	Angeli and Valanides (2020), Bers (2017, 2019), Bers et al. (2014), Elkin et al. (2016), Papadakis et al. (2016), Papert (1980), Relkin et al. (2020, 2021), and Saxena et al. (2020)
2 (green)	Foundations and frameworks of CT in K-12 education	19	Barr and Stephenson (2011), Fessakis et al. (2013), Grover and Pea (2013), Lye and Koh (2014), Papert (1990), Resnick et al. (2009), Tang et al. (2020), Voogt et al. (2015), and Wing (2006, 2008)
3 (blue)	Cognitive and assessment dimensions of CT	5	Flórez et al. (2017), Kazakoff et al. (2013), Román-González et al. (2017), and Shute et al. (2017)

findings underscore the potential for CT activities beyond cognitive development, influencing broader social and emotional skills foundational in early education.

Cluster 2 is a theoretical backbone for CT education, establishing definitions, frameworks, and methodologies for integrating CT across K-12 education. Jeanette Wing's influential papers from 2006 and 2008 form the core of this cluster, as they introduced CT as a universal skill, advocating that it should be taught as early as possible in formal education. Wing's work sets the stage for a systems-level approach to CT, positioning it as an essential skill akin to literacy or numeracy. Following Wing's foundational perspective, Grover and Pea (2013) provide a comprehensive review of CT in K-12 education, detailing existing methodologies and proposing paths forward for embedding CT into curricula. The papers in this cluster also address the importance of the computer science education community in supporting CT's expansion in schools.

Barr and Stephenson (2011) highlight the need for collaboration among educators, policymakers, and computer science professionals to promote CT at all levels of education. This cluster emphasizes the creation of structured curricula, teacher training, and assessment standards that align with CT's theoretical frameworks. For example, Lye and Koh (2014) explore how programming can serve as a vehicle for teaching CT skills, advocating for structured, step-by-step classroom approaches. Resnick et al. (2009) on Scratch programming contributes to this cluster by providing practical insights into how visual programming tools can democratize access to CT education and make abstract concepts more accessible to younger learners.

Table 4. The 15 most frequent keywords in the co-occurrence analysis

Rank	Keyword	Occurrences	Total link strength
1	Computational thinking	293	1,045
2	Robotics	91	440
3	Education	71	279
4	Children	65	278
5	Coding	49	209
6	Skills	47	246
7	K-12	46	220
8	Programming	45	197
9	Design	36	170
10	Early childhood education	34	140
11	Technology	33	160
12	Students	32	141
13	Curriculum	32	166
14	Science	30	164
15	Mathematics	29	149

Cluster 3 represents a specialized focus on the cognitive processes underlying CT skills and the development of reliable assessment tools to measure these skills. Studies like Román-González et al. (2017) and Shute et al. (2017) delve into understanding the mental processes involved in CT, such as problem-solving, logical reasoning, and pattern recognition. These studies are significant as they seek to define what it means to be "competent" in CT, moving beyond programming ability to identify broader cognitive traits. Román-González et al. (2017) specifically focus on the criterion validity of a Computational Thinking Test (CTT), which assesses various cognitive abilities tied to CT. This study contributes to establishing standardized measures of CT skills, enabling educators and researchers to track students' progress in developing CT competencies objectively.

On the other hand, Shute et al. (2017) break down CT into manageable components, offering a "demystified" framework that helps educators understand and teach CT in practical terms. A vital aspect of this cluster is its emphasis on empirically validated assessment tools. Reliable and valid assessments are critical for determining the effectiveness of CT curricula, identifying students' strengths and areas for improvement, and guiding instructional adjustments. This cluster's research also underscores the cognitive foundations of CT, suggesting that specific mental abilities can predict a student's proficiency in CT, which has implications for targeted interventions and differentiated instruction in CT education.

Co-Occurrence Analysis of Keywords in Computational Thinking

The co-occurrence analysis of keywords in computational thinking research for children's learning offers a thematic breakdown of prominent concepts and areas of focus in the field. We understand the primary topics and methodologies driving CT education research by examining the top fifteen keywords. Furthermore, the co-word clusters provide a structured view of interrelated themes, each representing a different angle within CT education.

Top keywords

The most frequently occurring keyword in **Table 4**, "computational thinking," appears 293 times, indicating its centrality to the field. Other high-frequency terms included "robotics" (91 occurrences), "education" (71 occurrences), and "children" (65 occurrences). These terms suggest a strong focus on CT as a skill and its practical application in educational settings, primarily through robotics, commonly used as an entry point for young learners. Terms like "coding," "skills," and "K-12" highlight the breadth of CT's relevance, spanning various skill areas and educational stages. Collectively, these keywords point to a field grounded in early engagement, hands-on activities, and a focus on building essential skills.

Co-occurrence analysis by clusters

The co-occurrence analysis of keywords in CT research, as in **Figure 4**, reflects a diverse and interdisciplinary field. Each cluster reveals a unique dimension of CT education, highlighting its multifaceted

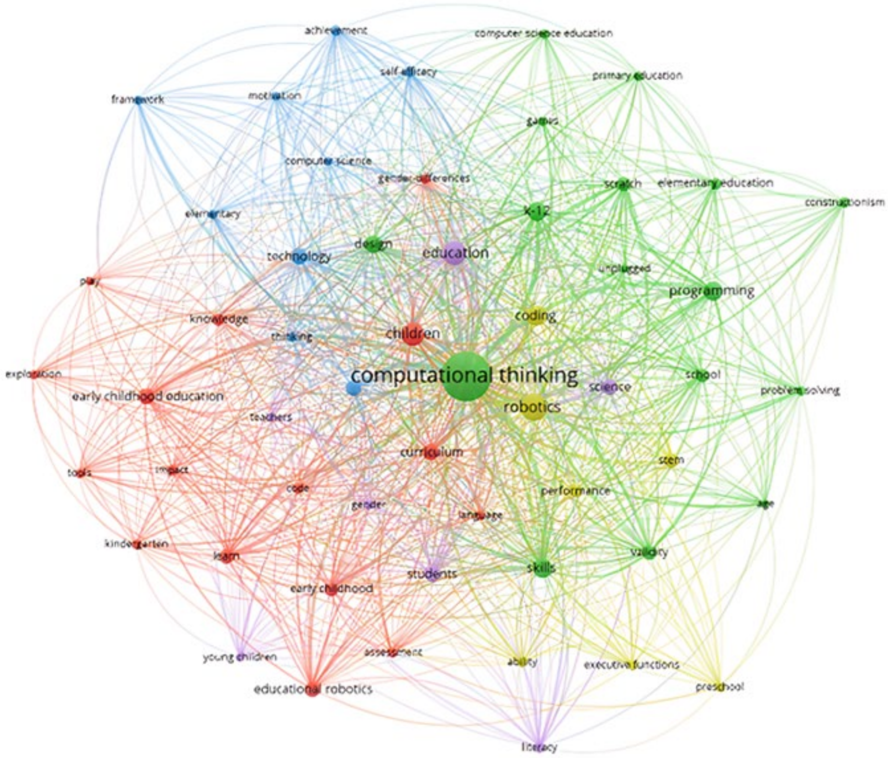

Figure 4. Co-occurrence analysis (VOSviewer visualization) (Source: VOSviewer visualization by authors)

Table 5. Co-occurrence analysis on computational thinking in children's learning

Cluster No and Color	Cluster label	Number of keywords	Representative keywords
1 (red)	Early childhood education and curriculum development	16	"children", "curriculum", "early childhood education", "educational robotics", "learn", "language", "knowledge", "impact", "exploration", "assessment"
2 (green)	CT skills and programming in K-12 education	16	"computational thinking", "programming", "k-12", "skills", "validity", "design", "school", "scratch", "problem-solving", "elementary education"
3 (blue)	Technology, motivation, and achievement in CT learning	9	"technology", "mathematics", "thinking", "self-efficacy", "motivation", "elementary", "achievement"
4 (yellow)	Robotics and STEM integration in CT education	7	"robotics", "coding", "performance", "stem", "ability"
5 (purple)	CT in education and gender dynamics	7	"education", "students", "science", "gender", "young children"

nature as it applies to early childhood engagement, K-12 skill development, motivation through technology, STEM integration, and gender inclusivity.

The clusters in **Table 5** collectively illustrate that CT education imparts technical skills and fosters an inclusive, motivating, and interdisciplinary learning environment.

Cluster 1 includes keywords such as "children," "curriculum," "early childhood education," and "educational robotics." This cluster focuses on integrating CT concepts into early childhood settings and adapting the curriculum to be developmentally appropriate for young learners. Studies within this cluster often emphasize the need to design CT activities that are age-appropriate, engaging, and foster foundational skills in young children. In particular, keywords like "assessment" and "exploration" emphasize evaluating the effectiveness of CT curricula and activities tailored for early learners. "Educational robotics" also appears in this cluster, which aligns with findings that young children benefit from tangible, interactive tools in learning CT concepts. This cluster's thematic focus reflects the growing consensus that introducing CT early through structured curricula can set a strong foundation for future learning, supporting cognitive and socio-emotional development in young children.

Cluster 2 is characterized by keywords such as “computational thinking,” “programming,” “K-12,” “skills,” and “design.” This cluster represents research on teaching CT as an essential skill within the K-12 education system. Keywords like “validity,” “school,” and “problem-solving” highlight this cluster’s interest in validating CT as a critical skill that can be systematically developed through structured educational practices. “Scratch,” a popular visual programming tool, suggests that this cluster includes research on tools and platforms designed to make CT accessible for students at various grade levels. The term “problem-solving” underscores the cognitive and practical applications of CT, as it is often used to teach students analytical and logical thinking. Overall, this cluster emphasizes the practical and pedagogical frameworks for incorporating CT into formal K-12 curricula, supporting the view that CT is a skill every student should acquire.

Cluster 3 includes keywords like “technology,” “mathematics,” “thinking,” “self-efficacy,” and “achievement.” This cluster focuses on the psychological and motivational factors associated with CT learning, mainly how technology can drive students’ motivation and self-efficacy in learning CT. The keywords concentrate on understanding how CT and related subjects like mathematics influence students’ overall achievement and cognitive development. “Self-efficacy” and “motivation” point to studies that examined how students’ confidence and enthusiasm for technology-based learning affect their engagement and performance in CT activities. By connecting CT with subjects like mathematics, this cluster explores interdisciplinary learning models where CT principles enhance broader educational goals. This cluster’s thematic focus aligns with research examining technology’s role as a motivating tool that enhances students’ confidence and achievement across various STEM domains.

Cluster 4 is identified by terms like “robotics,” “coding,” “performance,” “STEM,” and “ability.” This cluster highlights the integration of CT within the broader STEM framework, with a particular focus on robotics and coding as essential components of CT education. The keywords here emphasize the role of robotics in fostering CT skills, particularly in engaging students through hands-on learning. The appearance of “performance” and “ability” suggests that this cluster also includes research on assessing students’ competencies and skill acquisition in CT through STEM-related activities. Robotics often serves as a focal point within STEM education, making abstract CT concepts tangible and accessible to students. This cluster represents research that bridges CT with STEM subjects, leveraging robotics to build foundational programming, engineering, and critical thinking skills.

Cluster 5 contains keywords such as “education,” “students,” “science,” “gender,” and “young children.” This cluster appears to focus on the broader educational applications of CT, with a particular emphasis on understanding gender differences in CT learning and engagement. The inclusion of “gender” highlights research that explores how boys and girls may experience CT education differently, aiming to identify and address gender-based disparities in access and interest. This cluster’s focus on “young children” and “students” suggests a broader exploration of how various demographic factors, including gender, influence engagement with CT. Studies within this cluster often aim to understand how educational strategies can be tailored to create inclusive CT learning environments that encourage participation from all students, regardless of gender or background. This focus is particularly relevant in ongoing efforts to close the gender gap in STEM fields, advocating for strategies that promote equity in early CT education.

DISCUSSION

The bibliometric analysis of computational thinking in children’s learning reveals critical insights with significant theoretical and practical implications for researchers, educators, and policymakers. By understanding the trends, influential publications, thematic clusters, and co-occurrence of keywords, this analysis provides a foundation for advancing both the scholarly understanding and the practical application of CT education. The implications are organized below to address the theoretical advancements this field contributes to and the practical recommendations for implementing CT in educational settings.

Theoretical Implications

The bibliometric analysis highlights foundational works, such as those by Wing and Grover & Pea, establishing CT as a core competency in 21st-century education. Co-citation clusters indicate a growing recognition of CT as a fundamental cognitive skill, analogous to literacy or numeracy, suggesting a shift in educational theory toward viewing CT as a versatile problem-solving framework that applies across disciplines (Weintrop et al., 2021). Theoretical advancements increasingly frame CT as essential for cognitive development, linking it with critical thinking, problem-solving, and analytical abilities (Angeli & Giannakos, 2020).

CT education research spans multiple disciplines, including early childhood education, psychology, and STEM. Co-occurrence clusters highlight the integration of concepts like "self-efficacy," "motivation," and "achievement" within CT education, reflecting an interdisciplinary approach that incorporates psychological theories of learning. Current frameworks now include socio-emotional development, self-regulation, and collaborative learning, positioning CT as a cognitive and socially embedded process (Ballard & Haroldson, 2021). This multidisciplinary approach supports CT's integration across various learning contexts, recognizing the importance of mental and affective dimensions in children's learning (Agbo et al., 2021). Early engagement with CT is increasingly viewed as foundational for long-term cognitive and educational benefits. Theoretical implications suggest that early childhood provides a critical window for introducing CT concepts through playful, hands-on activities, supported by constructivist theories emphasizing exploratory learning (Saxena et al., 2020). This perspective underscores the need for age-appropriate scaffolding to foster CT skills that lay the foundation for more advanced competencies in later years (Relkin & Bers, 2020).

The strong link between CT and STEM fields, particularly through robotics and coding, positions CT as a bridge to broader STEM education. Cluster analysis reveals CT's frequent integration with subjects like mathematics and science, reinforcing theories that CT enhances understanding in these areas by promoting logical reasoning and problem-solving (García-Peñalvo et al., 2021). This suggests that CT is an interdisciplinary gateway that prepares children for diverse academic and vocational pathways beyond computer science (Baroutsis et al., 2019).

Practical Implications

Identifying key clusters around K-12 education, programming, and early childhood pedagogy underscores the importance of age-appropriate CT curricula. Educational institutions should implement differentiated curricula that address developmental stages, with a focus on exploratory learning tools like robotics and coding games for young learners. In K-12, CT should be woven into core subjects, enhancing math and science education with programming and problem-solving elements. Developing structured, flexible CT curricula across grade levels can ensure students progressively build and reinforce their CT skills (Nagumo et al., 2021; Weintrop et al., 2021).

The interdisciplinary nature of CT frameworks indicates a need for comprehensive teacher training in both the technical and pedagogical aspects of CT. Professional development programs should equip educators with a grasp of CT concepts, programming tools like Scratch, and age-specific teaching strategies. Effective training workshops should emphasize integrating CT across subjects and support educators in assessing CT competencies to adapt their methods based on student progress (Ghani et al., 2022; Herbert et al., 2022). Keywords related to diversity and inclusion emphasize the need for equitable CT education. This implies designing CT curricula and activities that address gender disparities and encourage participation from underrepresented groups in STEM. Inclusive strategies could involve collaborative projects, real-world problem-solving activities, and accessible CT tools for diverse learners, thus fostering a more diverse future in STEM fields (Tabesh, 2017; Xie et al., 2022).

The cognitive focus in recent research highlights the need for robust CT assessment tools. Schools should consider validated assessments like the Computational Thinking Test to evaluate students' competencies and personalize learning. Such tools enable educators to identify areas for student improvement and assess the effectiveness of CT programs, thereby refining curriculum and teaching approaches (Nagumo et al., 2021). Technology's role in motivating and building self-efficacy in CT is evident. Practical implications include using robotics kits, interactive games, and platforms like Scratch to make CT concepts accessible and engaging. These tools provide visual, hands-on learning experiences, which are especially beneficial for younger learners who gain motivation through immediate feedback (Ghani et al., 2022; Weintrop et al., 2021).

The foundational work of Wing and others reinforces CT as an essential educational skill, supporting the need for policy initiatives that standardize CT across schools. Policymakers should consider incorporating CT into national curricula, providing resources, teacher training, and technology access to ensure equitable CT learning opportunities. A standardized approach can bridge disparities across schools and regions, preparing a generation of computationally skilled learners (Ghani et al., 2022; Tabesh, 2017).

CONCLUSION

The bibliometric analysis of computational thinking in children's learning underscores the emergence of CT education as a vital field with rich theoretical foundations and significant practical applications. The analysis calls for redefining CT as a fundamental skill supporting cognitive, socio-emotional, and interdisciplinary learning, aligning with Sustainable Development Goal (SDG) 4's emphasis on inclusive, equitable, and quality education. Key recommendations for effective CT integration include age-appropriate curricula, inclusive teaching practices, robust assessment tools, and comprehensive policy support, creating a roadmap for sustainable educational development. This study highlights the need for ongoing research to explore cognitive, social, and motivational dimensions that enhance CT learning, fostering young learners' readiness for a digital and interconnected world.

CT research for children's education has reached a significant level of maturity, supported by a broad empirical base and evolving interdisciplinary frameworks, reflecting SDG 10's aim to reduce inequalities through accessible, adaptable, and inclusive learning methodologies. The increasing societal demand for digital literacy, early engagement with computational skills, and adaptable teaching approaches has driven this field forward. The expanding body of interdisciplinary studies from education, technology, and psychology showcases CT's relevance across sectors, building a comprehensive model for CT in early education. Bibliometric data from WoS database illustrates a dynamic, impactful area of research rapidly gaining traction, reflecting a shift towards preparing young learners for digital futures. As this field grows, future research will likely focus on refining CT strategies that foster children's cognitive, academic, and social development, making CT an essential element of sustainable, inclusive education.

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REFERENCES

Agbo, F., Yigzaw, S., Sanusi, I., Oyelere, S., & Mare, A. (2021). Examining theoretical and pedagogical foundations of computational thinking in the context of higher education. In *Proceedings of the 2021 IEEE Frontiers in Education Conference* (pp. 1–8). IEEE. https://doi.org/10.1109/FIE49875.2021.9637405

Angeli, C., & Giannakos, M. (2020). Computational thinking education: Issues and challenges. *Computers in Human Behavior, 105*, Article 106185. https://doi.org/10.1016/j.chb.2019.106185

Angeli, C., & Valanides, N. (2020). Developing young children's computational thinking with educational robotics: An interaction effect between gender and scaffolding strategy. *Computers in Human Behavior, 105*, Article 105954. https://doi.org/10.1016/j.chb.2019.03.018

Ballard, E., & Haroldson, R. (2021). Analysis of computational thinking in children's literature for K-6 students: Literature as a non-programming unplugged resource. *Journal of Educational Computing Research, 59*, 1487–1516. https://doi.org/10.1177/07356331211004048

Baroutsis, A., White, S. L., Ferdinands, E., Lambert, E., & Goldsmith, W. (2019). Computational thinking as a foundation for coding: Developing student engagement and learning. *Australian Primary Mathematics Classroom, 24*(2), 10–15.

Barr, V., & Stephenson, C. (2011). Bringing computational thinking to K-12: What is involved and what is the role of the computer science education community?. *ACM Inroads, 2*(1), 48–54. https://doi.org/10.1145/1929887.1929905

Bers, M. U. (2017). *Coding as a playground: Programming and computational thinking in the early childhood classroom*. Routledge. https://doi.org/10.4324/9781315398945

Bers, M. U. (2019). Coding as another language: A pedagogical approach for teaching computer science in early childhood. *Journal of Computers in Education, 6*(4), 499–528. https://doi.org/10.1007/s40692-019-00147-3

Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education, 72*, 145–157. https://doi.org/10.1016/j.compedu.2013.10.020

Bhuyan, A., Sanguri, K., & Sharma, H. (2021). Improving the keyword co-occurrence analysis: An integrated semantic similarity approach. In *Proceedings of the 2021 IEEE International Conference on Industrial Engineering and Engineering Management* (pp. 482–487). IEEE. https://doi.org/10.1109/IEEM50564.2021.9673030

Cano, S., Naranjo, J., Henao, C., Rusu, C., & Albiol-Pérez, S. (2020). Serious game as support for the development of computational thinking for children with hearing impairment. *Applied Sciences, 11*(1), Article 115. https://doi.org/10.3390/app11010115

Elkin, M., Sullivan, A., & Bers, M. U. (2016). Programming with the KIBO robotics kit in preschool classrooms. *Computers in the Schools, 33*(3), 169–186. https://doi.org/10.1080/07380569.2016.1216251

Fessakis, G., Gouli, E., & Mavroudi, E. (2013). Problem solving by 5–6 years old kindergarten children in a computer programming environment: A case study. *Computers & Education, 63*, 87–97. https://doi.org/10.1016/j.compedu.2012.11.016

Flórez, F. B., Casallas, R., Hernández, M., Reyes, A., Restrepo, S., & Danies, G. (2017). Changing a generation's way of thinking: Teaching computational thinking through programming. *Review of Educational Research, 87*(4), 834–860. https://doi.org/10.3102/0034654317710096

García-Peñalvo, F. J., Corell, A., Abella-García, V., & Grande-de-Prado, M. (2021). Recommendations for mandatory online assessment in higher education during the COVID-19 pandemic. In D. Burgos, A. Tlili, A. Tabacco (Eds.), *Radical solutions for education in a crisis context* (pp. 85–98). Springer. https://doi.org/10.1007/978-981-15-7869-4_6

Ghani, A., Griffiths, D., Salha, S., Affouneh, S., Khalili, F., Khlaif, Z., & Burgos, D. (2022). Developing teaching practice in computational thinking in Palestine. *Frontiers in Psychology, 13*. https://doi.org/10.3389/fpsyg.2022.870090

Grover, S., & Pea, R. (2013). Computational thinking in K-12: A review of the state of the field. *Educational Researcher, 42*(1), 38–43. https://doi.org/10.3102/0013189X12463051

Herbert, K., Anu, V., Sultana, K., Robila, S., Miller, J., Hagiwara, S., Goldstein, R., & Marlowe, T. (2022). Professional and capacity building in K-12 computer science education: A multi-faceted approach. In *Proceedings of the 54th ACM Technical Symposium on Computer Science Education* (pp. 1384–1384). ACM. https://doi.org/10.1145/3545947.3576329

Jacobs, D., Bobic, A., & Gütl, C. (2022). Comparison of network and readability properties with traditional bibliometric properties in the Journal of Universal Computer Science. In *Proceedings of the 2022 9th International Conference on Social Networks Analysis, Management and Security* (pp. 1–8). https://doi.org/10.1109/SNAMS58071.2022.10062567

Kazakoff, E. R., Sullivan, A., & Bers, M. U. (2013). The effect of a classroom-based intensive robotics and programming workshop on sequencing ability in early childhood. *Early Childhood Education Journal, 41*, 245–255. https://doi.org/10.1007/s10643-012-0554-5

Kleminski, R., Kazienko, P., & Kajdanowicz, T. (2020). Analysis of direct citation, co-citation and bibliographic coupling in scientific topic identification. *Journal of Information Science, 48*, 349–373. https://doi.org/10.1177/0165551520962775

Leonard, J., Buss, A., Gamboa, R., Mitchell, M., Fashola, O. S., Hubert, T., & Almughyirah, S. (2016). Using robotics and game design to enhance children's self-efficacy, STEM attitudes, and computational thinking skills. *Journal of Science Education and Technology, 25*, 860–876. https://doi.org/10.1007/s10956-016-9628-2

Lye, S. Y., & Koh, J. H. L. (2014). Review on teaching and learning of computational thinking through programming: What is next for K-12? *Computers in Human Behavior, 41*, 51–61. https://doi.org/10.1016/j.chb.2014.09.012

Maharani, S., Susanti, V., Andari, T., Krisdiana, I., & Astuti, I. (2023). Trend publication of computational thinking in mathematics education: Bibliometric review. *Jurnal Ilmiah Pendidikan Matematika, 12*(1), 22–32. https://doi.org/10.25273/jipm.v12i1.17654

Nagumo, H., Oomori, Y., & Takemura, Y. (2021). Mutual improvement between teaching materials and assessment tools for K-12 programming education. In *Proceedings of the 2021 IEEE Frontiers in Education Conference* (pp. 1–8). IEEE. https://doi.org/10.1109/FIE49875.2021.9637257

Papadakis, S. (2021). The impact of coding apps to support young children in computational thinking and computational fluency. A literature review. *Frontiers in Education, 6*. https://doi.org/10.3389/feduc.2021.657895

Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2016). Developing fundamental programming concepts and computational thinking with ScratchJr in preschool education: A case study. *International Journal of Mobile Learning and Organisation, 10*(3), 187–202. https://doi.org/10.1504/IJMLO.2016.077867

Papert, S. A. (1980). *Mindstorms: Children, computers, and powerful ideas*. Basic Books.

Papert, S. A. (1990). *Children, computers and powerful ideas*. Basic Books.

Parsazadeh, N., Cheng, P., Wu, T., & Huang, Y. (2020). Integrating computational thinking concept into digital storytelling to improve learners' motivation and performance. Journal *of Educational Computing Research, 59*, 470–495. https://doi.org/10.1177/0735633120967315

Rafiq, A., Triyono, M., Djatmiko, I., Wardani, R., & Köhler, T. (2023). Mapping the evolution of computational thinking in education: A bibliometrics analysis of Scopus database from 1987 to 2023. *Informatics in Education, 22*(4), 691–724. https://doi.org/10.15388/infedu.2023.29

Rehmat, A., Ehsan, H., & Cardella, M. (2020). Instructional strategies to promote computational thinking for young learners. *Journal of Digital Learning in Teacher Education, 36*, 46–62. https://doi.org/10.1080/21532974.2019.1693942

Relkin, E., & Bers, M. U. (2021). Factors influencing learning of computational thinking skills in young children. In *Proceedings of the 2021 AERA Annual Meeting*. https://doi.org/10.3102/1687044

Relkin, E., de Ruiter, L. E., & Bers, M. U. (2020). TechCheck: Development and validation of an unplugged assessment of computational thinking in early childhood education. *Journal of Science Education and Technology, 29*, 482–498. https://doi.org/10.1007/s10956-020-09831-x

Relkin, E., de Ruiter, L. E., & Bers, M. U. (2021). Learning to code and the acquisition of computational thinking by young children. *Computers & Education, 169*, Article 104222. https://doi.org/10.1016/j.compedu.2021.104222

Resnick, M., Maloney, J., Monroy-Hernández, A., Rusk, N., Eastmond, E., Brennan, K., Millner, A., Rosenbaum, E., Silver, J., Silverman, B., & Kafai, Y. (2009). Scratch: Programming for all. *Communications of the ACM, 52*(11), 60–67. http://doi.acm.org/10.1145/1592761.1592779

Román-González, M., Pérez-González, J. C., & Jiménez-Fernández, C. (2017). Which cognitive abilities underlie computational thinking? Criterion validity of the computational thinking test. *Computers in Human Behavior, 72*, 678–691. https://doi.org/10.1016/j.chb.2016.08.047

Rottenhofer, M., Sabitzer, B., & Rankin, T. (2021). Developing computational thinking skills through modeling in language lessons. *Open Education Studies, 3*, 17–25. https://doi.org/10.1515/edu-2020-0138

Saxena, A., Lo, C. K., Hew, K. F., & Wong, G. K. W. (2020). Designing unplugged and plugged activities to cultivate computational thinking: An exploratory study in early childhood education. *The Asia-Pacific Education Researcher, 29*(1), 55–66. https://doi.org/10.1007/s40299-019-00478-w

Shute, V. J., Sun, C., & Asbell-Clarke, J. (2017). Demystifying computational thinking. *Educational Research Review, 22*, 142–158. https://doi.org/10.1016/j.edurev.2017.09.003

Tabesh, Y. (2017). Computational thinking: A 21st century skill. *Olympiads in Informatics, 11*(2), 65–70. https://doi.org/10.15388/IOI.2017.SPECIAL.10

Tang, X., Yin, Y., Lin, Q., Hadad, R., & Zhai, X. (2020). Assessing computational thinking: A systematic review of empirical studies. *Computers & Education, 148*, Article 103798. https://doi.org/10.1016/j.compedu.2019.103798

Tekdal, M. (2021). Trends and development in research on computational thinking. *Education and Information Technologies, 26*, 6499–6529. https://doi.org/10.1007/s10639-021-10617-w

Voogt, J., Fisser, P., Good, J., Mishra, P., & Yadav, A. (2015). Computational thinking in compulsory education: Towards an agenda for research and practice. *Education and Information Technologies, 20*, 715–728. https://doi.org/10.1007/s10639-015-9412-6

Wang, X. C., Choi, Y., Benson, K., Eggleston, C., & Weber, D. (2021). Teacher's role in fostering preschoolers' computational thinking: An exploratory case study. *Early Education and Development, 32*, 26–48. https://doi.org/10.1080/10409289.2020.1759012

Weintrop, D., Rutstein, D., Bienkowski, M., & McGee, S. (2021). Assessing computational thinking: An overview of the field. *Computer Science Education, 31*, 113–116. https://doi.org/10.1080/08993408.2021.1918380

Wider, W., Jiang, L., Lin, J., Fauzi, M. A., Li, J., & Chan, C. K. (2024). Metaverse chronicles: A bibliometric analysis of its evolving landscape. *International Journal of Human-Computer Interaction, 40*(17), 4873–4886. https://doi.org/10.1080/10447318.2023.2227825

Wing, J. M. (2006). Computational thinking. *Communications of the ACM, 49*(3), 33–35. https://doi.org/10.1145/1118178.1118215

Wing, J. M. (2008). Computational thinking and thinking about computing. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 366*(1881), 3717–3725. https://doi.org/10.1098/rsta.2008.0118

Xie, Z., Radloff, J., Wong, G., & Yeter, I. (2022). The future nexus of computational thinking education: A preliminary systematic review of reviews. In *Proceedings of the 2022 IEEE International Conference on Teaching, Assessment and Learning for Engineering* (pp. 548–553). IEEE. https://doi.org/10.1109/TALE54877.2022.00096

Zárate-Pérez, E., Cornejo-Carbajal, C., Melgarejo-Alcántara, M., Ramos-Moreno, J., & Acevedo-Carrillo, M. (2023). Design thinking capabilities in the STEAM education: A bibliometric analysis. *LACCEI, 1*(8). https://doi.org/10.18687/LACCEI2023.1.1.294

Zhaisanova, D., & Mansurova, M. (2023). A bibliometric study on blockchain concept: A theme analysis and future directions for computer science training. *Scientific Journal of Astana IT University, 15*, 41–54. https://doi.org/10.37943/15owjc3702