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Research Trend of Computational Thinking in Phiysics Learning: a Bibliometric Analysis from 2015 to 2024

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Abstract: Research Trend of Computational Thinking in Phiysics Learning: a Bibliometric Analysis from 2015 to 2024. This study performs bibliometric analysis to examine research development on CT in physics education for the years spanning 2015-2024. **Objective**: The study seeks to outline the research and intellectual history of Computation Thinking (CT) integration within a specific framework by examining its spatial development in terms of the primary contributors CT's development through analyzing cumulative research, leading journals, contributing countries, dominant scholars, thematic networks and the changes of key topics over time. **Methods**: From the Scopus database, 345 peer-reviewed journal articles were selected. To visualize research networks, VOSviewer was used, while Bibliometrix in R Studio was used to analyze publication trends, author contributions, journal impact, citations, and assess the citation patterns of work over time. **Findings:** From the Scopus database, a total of 345 peer-reviewed journals were selected. The quantitative data analysis involving visualization of research networks was done using VOSviewer, while Bibliometrix (R Studio) was used for evaluation of publication and author contributions in relation to impact, citation, and trends. Findings indicate significant growth in research focused on Computational Thinking (CT) in Physics Education, with an overarching 33.86% annual increase, peaking in 2023. The research covers 156 journals, with the most prolific being Education and Information Technologies. The evaluation emphasized the exceptional worldwide collaboration with 1,216 authors from countries like the United States, Indonesia, and China. Intent phrase clusters included "computational thinking", "augmented reality", and "STEM education" indicating an emphasis on the integration of CT with advanced technologies. The evolution of themes indicates movement from STEM simulations to more expansive virtual reality and critical thinking. **Conclusions:** The advancements in physics education and students' problem-solving skills, as well as teaching innovations through International collaborations, have begun using Computational Thinking CT).

Keywords: computational thinking, physics education, bibliometric analysis, vosviewer, bibliometrix.

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INTRODUCTION

In the context of 21st-century education, Computational Thinking (CT) has become an essential competency for preparing learners to thrive in a technology-driven world. CT is generally understood as a problem-solving process that involves abstraction, decomposition, algorithmic thinking, and logical reasoning (Wing, 2006, 2008). Originally conceptualized within the field of computer science, Computational Thinking (CT) has since been recognized as a fundamental skill across multiple disciplines, owing to its alignment with essential educational goals such as critical thinking, creativity, and innovation. This socially constructed recognition emphasizes the importance of developing learners' adaptive competencies to face multi-dimensional, multifaceted challenges within real-world contexts of a digitally integrated globalized society (Cao, 2023; Christensen, 2023). Accordingly, different countries across the globe have integrated Computational Thinking (CT) into the curriculum not only as an instructional skill, but also as an educational paradigm useful for preparing learners for success in technology-driven contexts (Vinnervik & Bungum, 2022).

An growing amount of research literature has examined the infusion of Computational Thinking (CT) into STEM (Science, Technology, Engineering, and Mathematics) through active and technology-enhanced learning such as simulations. In particular, project-based learning, visual programming, robotics, and specialized simulation tools have shown considerable promise in developing students' CT skills, problem solving abilities, and engagement (Berk & Gülcü, 2024; Maharani et al., 2019; Yang et al., 2024). Especially in science and mathematics education, the integration of CT has been shown to improve computational fluency and increase the depth of conceptual understanding (Angraini et al., 2024; Tongal et al., 2024). Nonetheless, the proper execution of Computational Thinking CT relies heavily on teachers being sufficiently trained, since educators' own competencies in CT qualitatively affects the learning outcomes of students (Liu et al., 2023; Park & Kwon, 2023). Regardless of this advancement, the domain of physics which focuses on reasoning and problem-solving is still lacking the research and development in integrating Computational Thinking (CT) into its curriculum.

The main concern this research tackles is the patchy and shallow incorporation of CT (Computational Thinking) within the context of physics education. There has been wide implementation of CT into domains like computer science and engineering, but its incorporation in teaching physics, especially in higher-level capstone courses and multidisciplinary topics, is rather limited. The answer proposed is to incorporate various CT instruments like algorithms, simulations, and programming environments into the teaching of physics to foster deeper understanding, better problem-solving skills, and greater participation among students.

Research on the implementation of CT in physics instruction shows good promise. For instance, block-based programming environments like Scratch have been successfully used to help students simulate and comprehend the physics of projectile motion and harmonic oscillation (Hu et al., 2022; Hutchins et al., 2020). Dinata (2022) reported that Pupils partaking in CT-based assignments demonstrated better understanding of core physics concepts like force and motion through methods that involve orderly reasoning, as by thinking logically. These tools help students understand the subject better by interacting with its abstract nature in a visual and physical way, thereby facilitating hands-on learning pertaining to physics.

In addition, incorporating new technology like augmented reality (AR) together with virtual laboratories has further CT-enhanced instruction possibilities, providing opportunities for ever more interactivity and engagement Dong et al. (2023) highlighted that blending AR with CT frameworks enhances comprehension of intricate fields like quantum mechanics and vector fields. Simulations and real-time manipulatives allow students to model systems dynamically, adding a dimension to learning that experiential goes beyond traditional instructional approaches (Bahrami et al., 2022; Sultan et al., 2023; Park & Shin, 2022}). These findings indicate that CT tools serve beyond knowledge gain in teaching physics and transform instruction to support deeper engagement and exploration in more inquiry-based environments.

Despite these advancements, the current literature reveals notable gaps. For instance, the integration of Computational Thinking (CT) into physics education research is centered around the introductory topics of mechanics and kinematics, and is often constrained to a narrow range of instruments like Scratch or PhET (Dinata, 2022; Hutchins et al., 2020). The use of CT in the context of the integration of technology in physics education still lacks substantial attention in more advanced areas, including, but not limited to, electromagnetism, thermodynamics, and quantum mechanics (Huang et al., 2023; Orban & Teeling-Smith, 2020). In addition, the cross-disciplinary uses integrating Computational Thinking (CT) and Engineering or Data Science within the Physics Education realm are still developing.

Moreover, the cross–field interfaces that connect CT with engineering or data science in relation to physics education are still underdeveloped (Atun & Usta, 2019; Güngör & Akkaº Baysal, 2024; Uzumcu & Bay, 2021) demonstrate positive correlations between CT and higher-order thinking skills, but few explore the persistence of these effects over time or their relevance in real-world problem-solving contexts. Furthermore, many studies are confined to small participant samples or localized settings, limiting the generalizability of their findings (Aziz et al., 2023; Mohd Abeden & Siew, 2022). These gaps underscore the lack of an in-depth study pertaining to the Global Integration of CT, within the context of Physics education over the past ten years, as well as an analysis of the emerging patterns, primary contributors, and themes.

This current work seeks to conduct an extensive bibliometric analysis on the integration of Computational Thinking within the context of physics education for the years 2015 to 2024. The focus captured within this decade is critical considering the global advancement of computational thinking in education after Wing's (2008) redefined perspective, alongside other curriculum standardization efforts and the adoption of instructive tools reliant on coding and digital technologies (Wing, 2008). Starting in 2015, CT or Computational Thinking shifted from being a theoretical idea into an actual element of educational policy and practice in STEM education. Hence, the years 2015 and 2024 are of particular importance for understanding the development and implementation of CT in teaching physics. This research proposes a new CT paradigm for physics by seeking synergies within this advanced physics field, which marks its originality. Based on this description, the study seeks to answer the following questions:

1. What are the annual publication trends of CT research in physics education from 2015 to 2024?
2. Which journals, authors, and countries have been the most productive in this research area?
3. How are collaboration networks among researchers structured in this domain?
4. What are the key research themes, and how have they evolved over the past decade in the context of CT integration in physics education?

METHOD

Research Design

Bibliometric analysis involves the use of quantitative techniques to examine scholarly publications, allowing for the identification of patterns, thematic trends, and the structural dynamics within a particular field of research (Donthu et al., 2021). In the realm of physics education and Computational Thinking (CT), bibliometric methods offer a robust and systematic framework for charting the progression of research, recognizing key contributors, and outlining the intellectual landscape of the field As emphasized by Lim & Kumar (2024), this method minimizes subjectivity by offering an empirical, data-driven alternative to traditional literature reviews.

This study utilized a structured bibliometric approach to examine the trajectory of Computational Thinking (CT) research in physics education from 2015 to 2024. Through keyword co-occurrence analysis, the research explored the frequency, distribution, and relationships of key concepts, uncovering thematic trends and emerging research directions (Mukherjee et al., 2022). The key bibliometric indicators in this study included annual publication output, citation metrics, influential authors and journals, institutional affiliations, and thematic trends derived from term mapping. This research does not include thematic content analysis and is solely based on quantitative bibliometric methods.

The dataset was compiled from the Scopus database, chosen for its broad coverage of peer-reviewed journals and its compatibility with bibliometric tools. A Boolean search strategy was designed to identify publications related to both Computational Thinking (CT) and physics education, with filters applied to narrow the results to English-language journal articles published within the specified timeframe. All retrieved records were assessed for relevance based on their titles, abstracts, and keywords. The final dataset served as the empirical basis for the quantitative and visual analyses presented in this study. In light of the increasingly fragmented nature of CT research in physics education, the use of bibliometric methods facilitated a comprehensive and objective synthesis of the literature.

Search Strategy

On June 13, 2024, data was extracted exclusively from Scopus due to its extensive collection of peer-reviewed literature, as well as its compatibility with bibliometric software VOSviewer and Bibliometrix. A tailored search strategy employing Boolean operators was crafted to create a high level query to retrieve relevant results.

("computational thinking") AND ("physics education") AND (education OR teaching OR learning OR learn OR study OR didactic OR didactical) AND PUBYEAR > 2014 AND PUBYEAR < 2025 AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English").

Figure 1 presents the PRISMA flow chart, which illustrates each step of the document selection process, from the initial retrieval (n=345) to the final inclusion (n=124). The flow diagram follows the PRISMA format, detailing the sequential screening process implemented in this study. After removing duplicate records and conducting an initial screening based on titles and abstracts to assess topical relevance, 288 articles were retained. These records were then subjected to full-text evaluation, leading to the inclusion of 124 articles that met the predefined eligibility criteria and were deemed appropriate for bibliometric analysis.

Inclusion and Exclusion Criteria

The criteria for selection for this study were: (1) peer-reviewed documents that are part of the Scopus database; (2) texts published from 2015 to 2024 in English; (3) research focused on the integrating and teaching the impact of CT on CT in physics education. (4) Articles concentrating on instructional process, CT-based teaching, and curriculum construction relating to CT. The Stated exclusion criteria were: (1) all other abstractions like Conference papers, review articles, editorials, and non-journal textbooks were not considered; (2) CT's use in physics education and physics education research were too loosely connected; and (3) articles that did not provide adequate accessibility to the text or adequate methodology

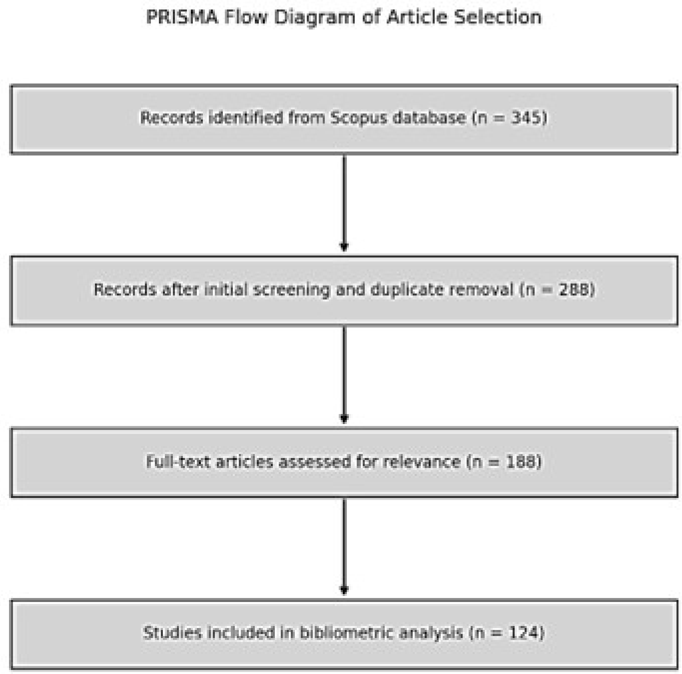

Figure 1. PRISMA flow chart

were excluded. Every article was reviewed manually to confirm its relevance concerning the Integration of CT in Physics Education using its title, abstract, and keywords. While cleaning the data, duplicate entries were found and removed. Affiliations and authors were uniformed for consistency, such as "MIT" blended with "Massachusetts Institute of Technology." Further standardization was completed to resolve spelling discrepancies and consolidate variations of names linked to institutions. To accomplish the study's goals, the articles were checked once more to make sure their titles, abstracts, and keywords were relevant.

Data Analysis

This study employed a bibliometric analysis framework adapted from (Dong et al., 2023), encompassing four phases: defining objectives and scope, selecting bibliometric techniques, collecting and cleaning data, and visualizing and interpreting results. Only Scopus was used as a source of data as it provides a comprehensive collection of peer-reviewed publications, is well indexed, and has tools for citation and co-occurrence analysis. Data obtained for the study's purpose could be enhanced by employing multiple databases, however, Scopus offers sufficient trust and is suitable for bibliometric studies.

The metadata such as titles, abstracts, keywords, authors, their affiliations, sources, and citation counts were fetched in RIS and BibTeX formats. 345 articles were generated as the output results. In the data scrubbing phase, all copies of the same record were removed. To streamline the author name matching logic and improve author and institution level analytic accuracy, variations of institution names were standardized pseudonymized aswell as author names were standardized.

The following two bibliometric tools were used: VOSviewer (version 1.6.20) and Bibliometrix (R package version 4.2.3). With Bibliometrix, the analysis of annual publication trends, author productivity, source impact and citation counts as well as the thematic evolution across time was performed. VOSviewer was used for the construction and visualization of bibliographic coupling and co-authorship and keyword co-occurrence maps. The settings made in VOSviewer included full counting and a minimum of 5 occurrences for the keywords, 3 documents for the authors and sources, overall 3 documents and 3 authors, together with a default clustering resolution of 1.0 which was set as a default for the rest of the parameters.

Findings were explained keeping in mind the computational thinking and physics education literature alongside the research questions. The visualizations created include yearly publication growth, author-country collaboration networks, and research clusters evolution thematic maps. These insights were used for the four research questions that framed the study. Publication data for four years through twenty-two was analyzed for RQ1. RQ2 was solved through the observation of highly productive authors, journals, and highly productive countries. RQ3 was addressed through visualization of co-authorship networks and RQ4 through thematic and keyword mapping and timeline analysis. Theme focus included integration of computational thinking (CT) within mechanics, technology integration for teaching CT such as simulations and augmented reality (AR), and competency in CT for educators in teacher education. These themes form a coherent structure for presenting the results and discussion that follows.

RESULT AND DISCUSSION

RQ 1. What are the annual publication trends of CT research in physics education from 2015 to 2024?

As a result of the bibliometric analysis with information obtained from the Scopus database, a total of 345 journal articles concentrating on Computational Thinking (CT) within the boundaries of physics education were found. This assessment was accompanied by a formal evaluation which was carried out using the Bibliometrix R package, which allowed to evaluate CT publications in regards to their citations, authors, journals, keywords, co-authorships, an all other relevant parameters. All these parameters taken together portray the picture of the research within the given field indicating its progress, influence, and cooperation in research.

Table 1. Main information of data collected

Description	Result
Timespan	2015-2024
Sources	156
Documents	345
Annual Growth Rate	33.86 %
Document Average Age	1.97
Average Citations Per Document	9.463
Author's Keywords	1048
Authors	1216
Authors Of Single-Authored Documents	24
International Co-Authorships	23.1 %
Co-Authors Per Document	3.85
Corresponding Author's Countries	55

From 2015 to 2024, publications on Computational Thinking (CT) in physics education exhibited a notable annual growth rate of 33.86%, reflecting increasing academic and institutional involvement. This growth had aligned with even wider educational patterns, where CT has emerged as a focal point within the competences of science and technology education (Gazali et al., 2023). The spread of 345 articles over 156 journals highlights the increasing cross-disciplinary attention this particular subject has received, showing that the discussions regarding CT in the discipline of physics have moved beyond specialized academic journals to a more general pedagogical dialogue.

Average citation count of 9.46 per article sustains a noteworthy amount of scholarly attention and propels the field as important for ph academic contributions (Murnaka et al., 2021). This trend aligns with previous findings by Watrianthos et al., (2022), who stated that such themes are emerging in the area of education and technology, adding that their importance is evident in citation metrics. This area of literature had contributions from 1,216 unique authors across 55 countries, showcasing effective international collaboration (Aktaº, 2022). This number reveals extraordinary international collaboration considering that there are 1,216 unique authors from 55 countries. The remarkable global participation is likely due to the increasing policy harmonization across different countries advocating for Computation Thinking (CT) in STEM education. In addition, the fact of multi-national co-authorship is indicative of the emerging international research communities which foster innovation and resource sharing along with differing cultural perspectives (Lei et al., 2020)

The dataset highlights the variety and richness of CT research in physics education with a total of 1,048 unique keywords. Included were rudimentary programming to more recent areas of augmented reality (AR), virtual reality (VR), pedagogical content knowledge for pre-service teachers, and model-based teaching (Kondrashev et al., 2024). Thematic mapping revealed a shift from early investigations of CT integration to more advanced, context-specific studies. As Wang et al., (2023) note, Identifying and predicting future research directions can be done efficiently using keyword co-occurrence analysis. In the same manner, the co-authorship networks created through VOSviewer reflected that a certain cluster of researchers collaborated with one another. Within these clusters, academic centers emerge which cultivate the enhancement and propagation of CT-related techniques in physics education. The formation of these networks suggests the existence of common research interests, bundled funding, or some collaborative proximity to undertake educational reform CT (Computational Thinking) integration. In short, the findings illustrated the essence that CT within the realm of physics education is a newly emerged, rapidly evolving domain. This is made possible due to collaboration from different countries, diversification of themes, and institutional recognition of the educational value of CT. Out of all the other branches of educational research, physics education stands out because it is closely intertwined with computational modeling, data mining, and interdisciplinary research. This uniqueness opens up the application of bibliometric analysis not just as a retrospective tool, but as a forward-looking instrument, marking the intersection of history and strategy for guiding future work within the discipline.

As illustrated by Figure 2, the number of publications related to Computational Thinking (CT) in the context of physics education has steadily increased since 2018, especially in 2023, which recorded the highest growth with 102 published papers. As illustrated by the growing number documents published, as of June 13 2024, the number published stands at 72. In all likelihood, this trend will not cease anytime soon indeed. The Bibliometric Analysis CT in Physics Education Framework showed that the number of published papers increases at an annual rate of 33.86%. It indicates that more and more academics and institutions are focusing on CT in Physics Education (Gazali et al., 2023). This development correlates with other educational

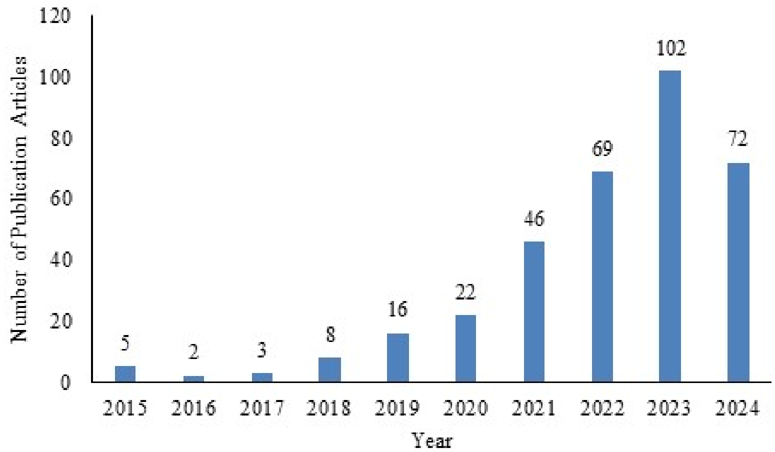

Figure 2. Progression of the number of publications articles by years on CT in physics from 2015 to 2024

fields where CT (computational thinking) is viewed as a critical component within STEM fields (Phuong et al., 2023). The focus on CT's ability to improve learners' reasoning skills, problem-solving abilities, and understanding of complex scientific concepts (Nouri et al., 2020; Wing, 2006) has further amplified scholarly interest in this area.

This change in publication trends may be attributed to a number of reasons, explained as follows. For one, the worldwide CT education reform accompanied by an educational technology zeal considers CT to be one of the central pedagogical methodologies to resolve problematic areas in science education. The use of digital instruments such as simulations, block-based programming, and augmented reality in the teaching of physics has fostered an environment conducive to research and invention (Kondrashev et al., 2024). Its principles might explain why this discipline has a sharper research trajectory as compared to other domains. Physics derives deeply from the analytical and system-based CT principles, which CT, in turn, relies on (Aktaº, 2022; Watrianthos et al., 2022). Additionally, the increasing rate of international collaborations and the institutional investments on CT-based curricula have most likely contributed greatly towards the increase in scholarly output. In the future, expansion in this area seems highly likely due to the growing recognition of the role of computational thinking (CT) in developing responsive, multidisciplinary, and tech-centric physics education (Lei et al., 2020; Wang et al., 2023).

RQ 2. Which journals, authors, and countries have been the most productive in this research area?

Based on the data in Table 2, Education and Information Technologies emerges as the most productive journal, contributing 14 publications, which represent 4.13% of the total articles. It is followed by Physical Review Physics Education Research with 12 publications (3.54%), and Education Sciences with 11 publications (3.24%).

In terms of citation impact, Computers and Education leads with a total of 161 citations, followed by Journal of Science Education and Technology with 102 citations, and Education Sciences with 85 citations. The other journals in the top 10 have citation counts ranging from 11 to 82. Having a look at their publication and citation numbers, it would be safe to say that the Education and Information Technologies, Journal of Science Education and Technology, as well as Physical Review Physics Education Research are the most significant journals toward the

Table 2. Most productive journals

Journal	TP	TP (%)	TC	Publisher
Education and Information Technologies	14	4.13	60	Springer
Physical Review Physics Education Research	12	3.54	82	American Physical Society
Education Sciences	11	3.24	85	Multidisciplinary Digital Publishing Institute (MDPI)
Journal of Science Education and Technology	11	3.24	102	Springer Science and Business Media B.V.
Computers and Education	9	2.65	161	Elsevier LTD
International Journal of Interactive Mobile Technologies	9	2.65	46	International Association of Online Engineering
Sustainability (Switzerland)	9	2.65	63	Multidisciplinary Digital Publishing Institute (MDPI)
Jurnal Pendidikan Ipa Indonesia	8	2.36	20	Universitas Negeri Semarang
Journal of Turkish Science Education	6	1.77	26	Ekip Buro Makineleri A.
Physics Education	6	1.77	11	Institute of Physics

development of research on computational thinking (CT) in physics education. These results are illustrative of the scholarly attention towards computational thinking (CT), while demonstrating that the field has captured the attention of several international journals, which improves its prospects for disseminating research (Dong et al., 2023; Gao et al., 2022; Phuong et al., 2023).

Table 3. Top-10 productive authors

Author	TP	TC	Affiliation
G. -J. Hwang	4	25	Soochow University
E. Istiyono	4	1	Universitas Negeri Yogyakarta
A.-J. Magana	4	45	Pontificia Universidad Católica Del Perú
H. Putranta	4	3	Universitas Negeri Yogyakarta
T. Sapounidis	4	15	Aristotle University of Thessaloniki (AUTH)
M. -D. Caballero	3	26	Michigan State University
S. Chandrasekharan	3	8	Tata Institute of Fundamental Research
El-Hamamsy L	3	3	Ecole Polytechnique Fédérale De Lausanne
I. Irwanto	3	29	Universitas Negeri Surabaya
H. Kuswanto	3	4	Universitas Negeri Yogyakarta

As shown in table 3, 1,216 unique authors have published on the topic of computational thinking (CT) in physics education. The 10 most prolific authors are ranked by their total publications (TP) and total citations (TC). According to the number of published articles, Table 3 reveals that Hwang (Hwang et al., 2009), G. J., Istiyono, E. (Zakwandi, R. & Istiyono, E., 2023), Magana, A.-J. (Magana et al., 2011), Putranta, H., & Sapounidis, T(Rapti et al., 2025) are the most prominent authors, each having published four articles on CT in physics learning. Additionally, significant contributions have been made by Caballero, M. D., Chandrasekharan, S., El-Hamamsy, L., Irwanto, I., and Kuswanto, H., each of whom has published three articles. In terms of citations, A.-J. Magana stands out as the most cited author, with 45 citations, followed by Irwanto I., who has received 29 citations. The remaining authors have citation counts ranging from 1 to 26. This citation data highlights the influence of these scholars in advancing research on computational thinking (CT) in physics education, with Magana and Irwanto making particularly impactful contributions to the field.

Table 4. 10 most productive countries

Country	TPC (%)	TCC
USA	187 (22.86%)	1.249
Indonesia	124 (15.16%)	100
China	91 (11.12%)	228
Malaysia	40 (4.89%)	36
Turkey	30 (3.67%)	74
Spain	24 (2.93%)	34
Greece	22 (2.69%)	59
Germany	20 (2.44)	172
India	18 (2.20%)	9
Switzerland	14 (1.17%)	65

As shown in Table 4, the United States leads in the number of publications, with 187 articles, representing approximately 22.86% of the total publication count (TPC) among the top 10 countries. Indonesia follows as the second most productive country, contributing 124 articles (15.16%), with China ranking third with 91 articles (11.12%). Other notable contributors include Malaysia with 40 articles (4.89%), Turkey with 30 articles (3.67%), Spain with 24 articles (2.93%), Greece with 22 articles (2.69%), Germany with 20 articles (2.44%), India with 18 articles (2.20%), and Switzerland with 14 articles (1.17%).

RQ 3. How are collaboration networks among researchers structured in this domain?

As shown in Figure 3, the author collaboration network constructed using VOSviewer visually represents the bibliographic coupling among researchers in the field of computational thinking (CT) in physics education. Each node represents an individual author, with the size of the node corresponding to the number of publications, thereby indicating academic productivity. The proximity of the nodes reflects the degree of bibliographic coupling; authors who cite similar references are placed closer together, suggesting thematic alignment or shared academic interests (Mohamad et al., 2023). The visualization identifies seven clusters, each color-coded to represent distinct collaborative groups. These clusters highlight the underlying structures within the research landscape, where scholars who frequently co-author tend to contribute to specific subdomains of computational thinking (CT), such as simulation-based learning, computational modeling, or cognitive skill development.

For example, Cluster 1 focuses on Tsai, C.-C., and he is connected to numerous collaborators, which suggests a highly cohesive research group. The development of these clusters illustrates the thematic specialization and the institutional affiliations that aid in interdisciplinary collaboration. Along with co-citation analysis that allows predicting the future impact of a scholarly work, bibliographic coupling analysis attempts to disentangle shared intellectual heritages (Jashari et al., 2022; Zaib et al., 2022). This technique enables identification of noteworthy scholars and

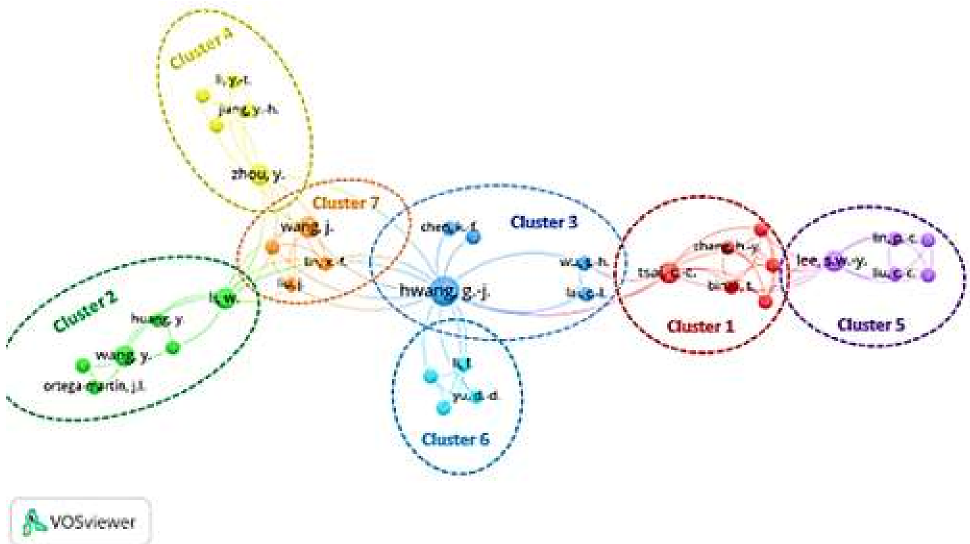

Figure 3. Collaborative network between authors on CT in physics learning

their intellectual networks, mapping out knowledge creation and dissemination processes within a discipline. This method also aids in tracing the development of research in conjunction with the emergence of new themes, informs strategic planning for future studies, and promotes collaboration between different institutions. (Maseda et al., 2022).

In Figure 4, the co-occurrence network of author keywords is shown in the overlay mode of VOSviewer which showcases a timeline of themes related to computational thinking (CT) research within the educational setting. Each keyword is represented by a geometric shape referred to as a node, with the size corresponding to the total number of occurrences. The color progression from blue (which indicates earlier years around 2021) to yellow (indicating more recent years 2023) represents the average year of the keyword's first appearance. Keywords such as computational thinking, education, science education, teaching, and educational computing form a prominent cluster, illustrating both their continued importance and centrality in the discussion. These terms demonstrate the continued embracement of CT across the educational landscape, both at the holistic level as well as in specific subjects for teaching such as in physics and STEMYe²€ (Tongal et al., 2024; Verawati et al., 2023). The high co-occurrence among these keywords reveals strong thematic linkages across interdisciplinary studies.

Surrounding the central cluster are emerging thematic areas that reflect the expanding scope of computational thinking (CT) research. A notable group of keywords, including robotics, Arduino, and educational robotics, signals an increasing focus on hands-on, technology-driven pedagogies (Angraini et al., 2024). Another emerging area includes gamification, game-based learning, e-learning, and ChatGPT, which appear in lighter yellow, indicating a shift toward AI-integrated, engagement-focused learning. (Chen & Liang, 2022; Yazdi et al., 2024). Peripheral nodes such as critical thinking, problem-solving, and academic performance reflect CT's influence on cognitive skill development (Maharani et al., 2019; Uzumcu & Bay, 2021), while connections to STEAM, curriculum, and virtual reality indicate increased interdisciplinarity and pedagogical innovation. This network not only visualizes dominant and emerging topics but also highlights the trajectory of Computational Thinking (CT) as a driving force for educational transformation in science and physics education.

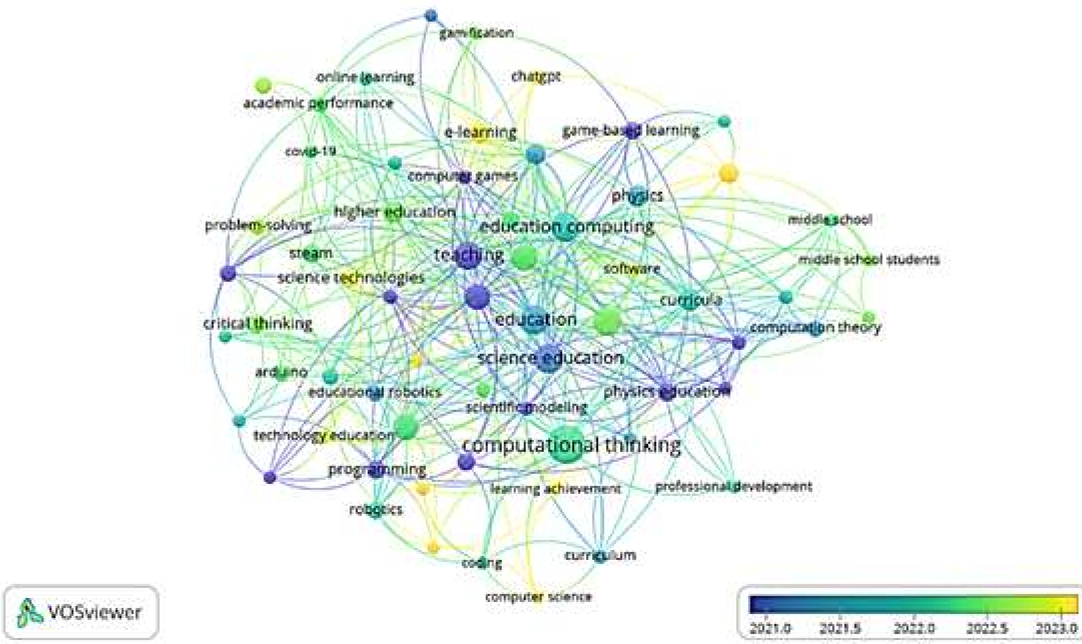

Figure 4. Network map of author keywords by year

RQ 4. What are the key research themes, and how have they evolved over the past decade in the context of CT integration in physics education?

In this section, we analyze the occurrence of keywords to identify the primary focus areas within Computational Thinking (CT) in physics education. Out of the 1,048 author keywords extracted from the 336 articles examined, 50 keywords meet the threshold of appearing at least three times. As illustrated in Figure 5, the keyword frequency analysis highlights the dominant themes shaping the landscape of Computational Thinking (CT) in physics education. The term "computational thinking" appeared 33 times (roughly 10% of the total keywords), reinforcing its central role as both a conceptual and methodological anchor in recent educational research. This frequency stems from the growing understanding of CT as a fundamental capability required to cultivate a student's analytical reasoning and problem-solving skills in STEM education (Khaeruddin & Bancong, 2022). Other frequently used phrases such as "augmented reality" (17 mentions), "STEM education" (16), "science education" (14), and "STEM" (14) show a growing emphasis on cross discipline integration and the use of blended learning technologies. The value placed on the use of augmented reality is particularly notable in its instructional effectiveness for visualizing intricate physical phenomena and improving students' conceptual understanding of physics within the learning environments (Dawana et al., 2024; Sonntag & Bodensiek, 2024).

Evidenced by the keywords "education," "gender," "higher education," and "physics," each noted less than 10 times, implies that scholarly attention is increasingly directed toward the educational landscape surrounding the implementation of CT (Computational Thinking). These concerns focus on equity and access, as well as the need for diverse educational and instructional design across grade levels and learner populations (Mohtar et al., 2019). The collocation of terms "STEM education" and "science education" indicates that there is some form of a shift towards more integrated and cross disciplinary forms of education for preparing learners for future scientific and technological

Figure 5. Top-50 author keywords, frequency, & proportion

activities (Permanasari et al., 2021; Wahono et al., 2023). Broadly speaking, the treated scattering of keywords illustrates an active and evolving research agenda which, in addition to highlighting computational fluency, calls for relevance and inclusiveness across levels and contexts in education (Sari & Ardianto, 2023). This shows a change in how CT is conceived and used in physics instruction as focus shifts to holistic, integrative, interdisciplinary, and technology enriched teaching approaches.

Figure 6 illustrates the development over time of the research on Computational Thinking (CT) in the context of physics education for the

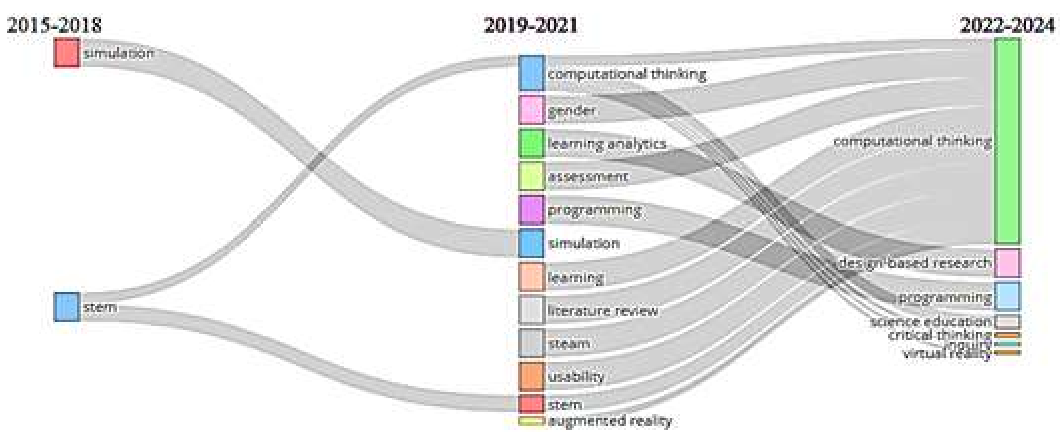

Figure 6. Thematic evolution 2015-2024

years 2015–2024, which is separated into three periods: 2015–2018, 2019–2021, and 2022–2024. In the first period, research seemed to focus more on the basic and foundational themes “simulation” and “STEM,” which shows early research on CT in science education and its relevance to education. During the second period, the discipline advanced to include additional topics such as “programming,” “learning analytics,” “gender,” “augmented reality,” and “assessment,” suggesting increased interest in teaching and greater attention on diversity among students. In the third phase (2022–2024), there was still variation in thematic changes with the addition of "design-based research," "critical thinking," "virtual reality," and "science education." This diversification demonstrates increased integration across disciplines as well as sophistication within the focus of research. It indicates a move away from implementation focused on tools toward approaches that are more responsive to the factors of learner need, technology, and context in the teaching of CT (Çavuº et al., 2023; Yazdi et al., 2024).

These thematic shifts were likely influenced by multiple underlying reasons. Researchers began looking into the use of Computation Thinking (CT) for gaming and fully immersive environments like Augmented Reality (AR) and Virtual Reality (VR) because the digital learning environment's adoption skyrocketed during the COVID-19 pandemic (Chen & Liang, 2022). At the same time, the worldwide focus on 21st century skills particularly problem-solving, computational fluency, and innovation have raised CT to an important competency within the policies and frameworks of STEM education (Permanasari et al., 2021; Wahono et al., 2023). Additionally, the occurrence of the terms "gender" and "inclusivity" indicates that there is increasing attention given to issues of fairness and equity in relation to access and diversity within CT integration, which relates to general educational objectives regarding inclusiveness in science education (Bonner et al., 2024; Mohtar et al., 2019). These innovations underscore the maturation of the research domain, CT's pedagogical value, and its relevance to interdisciplinary, learner-centered, as well as equity-oriented frameworks. There is a particular significance within the findings regarding the future of teaching physics. The narrowing focus on CT, especially in relation to STEM education, indicates that CT could be quite beneficial toward science education's future development. The use of CT in teaching physics enhances the problem solving capabilities of the students when dealing with multi-faceted physical problems via computation (Chen, 2021; Dong et al., 2023; Orban & Teeling-Smith, 2020; Wing, 2006). Like augmented and virtual reality, CT research makes use of new technologies which enable learners to be immersed in a real world environment at work and engage actively. Such technologies assist in helping students master challenging Physics concepts (Chen, 2021; Dinata, 2022; Hutchins et al., 2020).

Furthermore, this study highlights the importance of collaboration for the advancement of Computation Thinking (CT) research. The existence of strong international co-authorship networks reveals that collaboration of researchers from diverse institutions and cultures significantly accelerates the creation, adaptation, and dissemination of tools and technologies for teaching CT (Demir, 2023; Reis et al., 2021). Regular collaboration results in new sophisticated interdisciplinary methods for solving complex STEM educational issues. Also, the evolution of the themes over the study period indicates that CT research integration with broader educational objectives aims at promoting problem-solving skills and new technology application. These trends coincide with the international movement aimed at preparing learners to tackle complex scientific and technological challenges of the 21st century (Nouri et al., 2020; Ogegbo & Ramnarain, 2022; Phuong et al., 2023).

However, some of the constraints need mentioning. Firstly, the exclusive use of the Scopus bibliographic database for the study may have omittedsome relevant articles from other databases, which might have skewed the dataset towards journals with greater international exposure. Furthermore, the study's focus may have neglected significant research published in other languages or through alternate channels, including, but not limited to, conference proceedings, book chapters, or non-peer-reviewed journals, as it concentrated only on English language peer-reviewed journals. Furthermore, as is common in bibliometric approaches, the current study accentuates quantitative measures, such as volume of publication, citation counts, and keyword co-occurrence. Although these indicators reveal a lot of identification, the collaboration patterns of research and do not examine the rigorous methodology and empirical quality other individual studies within a body of work (Demir, 2023). The impact and quality of research regarding Computational Thinking in physics education can be evaluated more effectively by integrating bibliometric analysis with systematic literature review techniques. This approach could further enhance future studies.

CONCLUSION

This research emphasizes the growing importance of Computational Thinking (CT) in relation to physics teaching and its possible impact on pedagogy and learning results. CT's scope is still widening, and so it is hoped that subsequent work takes more targeted approaches as guided by the gaps this bibliometric analysis has surfaced and moves beyond general exploration. For example, empirical research is needed on the application of Computational Thinking in advanced physics topics such as electromagnetism, quantum mechanics, and thermodynamics, where abstract reasoning plays a crucial role. Additionally, comparative studies examining the relative effectiveness of various CT-based instructional tools such as PhET simulations, microcontroller programming (e.g., Arduino), and visual coding platforms like Scratch or Python are also necessary. Furthermore, analyses exploring the impact of national education policies on the adoption of Computational Thinking across various educational systems could reveal systemic opportunities and challenges, particularly in underrepresented regions.

Regarding practical implications, the findings provide valuable insights for physics educators and curriculum developers. The recurrent presence of keywords like "gamification," "augmented reality," and "STEAM" indicates a movement toward interactive, student-centered learning environments that promote deeper engagement with scientific content. Educators are encouraged to incorporate Computational Thinking concepts, including abstraction, decomposition, and algorithmic thinking, within problem-based and inquiry-driven learning frameworks. For curriculum developers, it is crucial to design CT instruction that is progressively scaffolded across grade levels, ensuring that foundational skills are established before students tackle more complex applications. Ultimately, integrating CT into physics education offers the potential to enhance higher-order thinking, deepen conceptual understanding, and better prepare students for the challenges of an increasingly computational and interdisciplinary scientific environment.

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