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Computational thinking in STEM education: current state-of-the-art and future research directions

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The knowledge society exists mainly due to advancing technology and the exponential development of professionals' capabilities. Digital transformation and new technologies generate complex environments demanding high-level skills. This work analyzes the current state of pedagogical approaches with a special focus on project-based learning that develops computational thinking in STEM students. A Systematic Literature Review examined the current state of pedagogical approaches along with project-based learning aimed at enhancing computational thinking within the context of higher education. Results allowed us to infer that (a) computational thinking promotes sustainable development through STEM education and novel teaching practices; (b) it is a fundamental skill for the problem-solving processes that evolve with technological progress; (c) its development is a global concern, not limited to a country's development level; and (d) its introduction at an early stage provides opportunities for the advancement of vulnerable groups. Outlining, this study conducts a Systematic Literature Review (SLR) using PRISMA 2020 guidelines to analyze pedagogical approaches including project-based learning for enhancing computational thinking in STEM higher education, identifying global research trends, common strategies, and areas for improvement, while proposing a framework to align computational thinking skills with emerging technological challenges and promote sustainable educational practices. This study presents relevant results on the construction of state-of-the-art computational thinking and education; it is valuable for curricular design underpinning disciplinary and interdisciplinary approaches.

KEYWORDS

complex thinking, stem education, educational innovation, higher education, computational thinking

1 Introduction

The knowledge society of today exists mainly due to advancing technology. This advancement requires training professionals with new skills, especially in digital technologies. Among the new competencies is the development of complex thinking (Ramírez-Montoya et al., 2024) so that real problems can be addressed holistically through systematic, critical, scientific, and innovative thinking competencies. Multi-, inter-, and transdisciplinary teamwork has become imperative precisely because digital transformation and new technologies are generating complex environments that demand the development of high-level skills (Farias-Gaytan et al., 2023). Thus, educational systems must evolve to foster the necessary skills and collaborative approaches students need to navigate and excel in increasingly intricate and dynamic landscapes. Computational thinking is a primary competency within complex thinking that must be developed.

According to Wing (2006), computational thinking involves solving problems, designing systems, and understanding human behavior. She argues that computational thinking is a fundamental skill that everyone needs. It allows students to strengthen their systematic thinking to solve complex problems. Complex and computational thinking aim to develop specific skills and sub-competencies in individuals that enable them to thrive in challenging environments (Alfaro-Ponce et al., 2023). In that sense, the development of computational thinking skills is crucial in any area of knowledge because computational thinking aligns scientific and mathematics instruction with contemporary professional disciplines (Chen et al., 2023). Notably, computational thinking does not necessarily require using a computer to generate these competencies; as Chichekian et al. (2023) comment, the focus of computational thinking has shifted from non-digital to more digital approaches to problem-solving, leveraging Information and Communication Technologies (ICT) tools, which have improved STEM education.

STEM is an acronym for science, technology, engineering, and mathematics. According to UNESCO (2017), "STEM underpins the 2030 Agenda for Sustainable Development, and STEM education can provide learners with the knowledge, skills, attitudes, and behaviors required for inclusive and sustainable societies" (p. 11). STEM education has the goal of enhancing employability and practical skills development; it emphasizes a broad understanding of scientific and technical disciplines, spans various educational levels, and is offered in both theoretical and practical contexts (Wang et al., 2022). STEM programs are also designed to foster innovation, critical thinking, and creativity. When students explore these areas, they can develop new ideas and solve complex problems better.

In STEM areas, computational thinking is critical for developing systematic thinking. Remember that the sub-competencies of computational thinking include abstraction, decomposition, pattern recognition, and algorithm design. UNESCO (2017) emphasizes that it is imperative to close the gender gap for more accessibility to women interested in STEM careers. Torres-Torres et al. (2024) showed that computational thinking is crucial to advance in STEM fields but noted a gap between females and males interested in Computational Thinking and STEM. Much work must be done to close this gap. Preparing students for participation in science "is critical not only to meet the growing needs for individuals to pursue STEM academic and career pathways but also to position a greater diversity of youth as innovators who can support STEM-empowered communities that fully engage in our increasingly computational world" (Krakowski et al., 2023, p. 1). Addressing this disparity is essential for an inclusive, equitable STEM environment where all individuals, regardless of gender, contribute to and benefit from advancements in computational thinking and STEM fields.

The implementation of computational thinking is not new; as Dúo-Terrón (2023) refers, the use of Scratch software for block programming as an introduction to STEM areas is already 20 years old. However, much work must be done systematically to know best practices. One instructional approach is project-based learning, which combines active and collaborative learning and involves students in projects to explore and solve authentic, real-world problems (Crawford et al., 2024). By refining these instructional methods and continuously evaluating their effectiveness, educators can ensure that computational thinking skills are effectively cultivated, preparing students to excel in STEM fields to address future complex challenges.

The integration of computational thinking (CT) into education has been widely explored, as demonstrated by various systematic literature reviews. Yeni et al. (2024) examined the interdisciplinary integration of CT into K-12 education and found that the majority of studies focus on science and mathematics, often using active learning strategies and block-based tools. Despite the potential for transformative learning, integration mostly occurs at the substitution level rather than achieving deeper educational impacts. Similarly, Giannakoulas and Xinogalos (2024) focused on the use of educational games to cultivate CT skills in primary school students. Their findings revealed that educational programming games are effective in improving students' CT skills and programming concepts while also fostering positive attitudes toward learning. However, the review identified gaps in research methods and called for methodological improvements to strengthen future studies.

The development of CT in pre-service teacher education has also been a prominent focus. Dong et al. (2024) conducted a systematic review of CT training for pre-service teachers, highlighting six effective training methods and a positive correlation between training and improved CT abilities. Their study suggested practical ideas for designing training modules to better prepare teachers for integrating CT into their teaching practices. Meanwhile, Yun and Crippen (2024) investigated CT integration in pre-service science teacher education, identifying problem-based learning and engineering design as key pedagogical strategies. They emphasized the importance of modeling, simulation, and unplugged activities for a holistic approach to CT integration.

The synergy between artificial intelligence (AI) and CT has been another emerging area of research (Tariq et al., 2024). Weng et al. (2024) explored how AI tools facilitate CT learning through student-centered instructional designs. Their findings highlighted the dual role of AI in enabling both disciplinary knowledge integration and the use of AI tools to enhance CT development. Similarly, Jin and Cutumisu (2024) mapped the deeper learning domains of CT, including cognitive, interpersonal, and intrapersonal skills. Their results emphasized the cognitive domain, particularly in STEM disciplines, where block-based programming tools such as Scratch were prevalent interventions.

From a gender perspective, Torres-Torres et al. (2024) conducted a systematic review of didactic strategies for CT education, highlighting the urgent need for gender-inclusive approaches to eliminate biases and promote female participation in CT learning. They introduced "minimum actions" as a strategy to integrate girls and women into the CT learning process. In parallel, Asfani and Chen (2024) reviewed problem- and project-based computer-supported collaborative learning practices in computer education. They identified interactive technologies, learning management systems, and group formation techniques as central elements of these pedagogies, though they noted that CT, critical thinking, and problem-solving skills remain underexplored.

The role of professional development in CT education was examined by Espinal et al. (2024), who identified significant gaps in teacher preparation programs, particularly in classroom implementation and assessment. Using the TPACK framework, they revealed that existing programs often focus on conceptual understanding but fail to prepare teachers to create and evaluate learning activities effectively. Likewise, Rao and Bhagat (2024) analyzed tools, pedagogical strategies, and assessment practices for promoting CT. Their findings showed a predominance of CT integration in science, mathematics, and programming tasks but a lack of focus on AI and non-STEM domains.

In K-12 education, Sunday et al. (2024) explored the role of co-design pedagogical techniques in fostering CT learning. Workshops and collaborative techniques were the most utilized methods, with tools such as NetLogo proving effective for co-design learning environments. Similarly, Ching and Hsu (2024) reviewed the use of educational robotics to develop CT in young learners, identifying collaborative, project-based, and embodied learning strategies as highly effective approaches. Their findings emphasized the role of LEGO Mindstorms and other robotics kits in fostering key CT skills like sequencing, debugging, and algorithmic thinking.

The application of CT in language education has also gained traction. Yu et al. (2024) examined the integration of CT into foreign language learning, demonstrating its positive impact on grammar and writing skills. Tools such as Scratch and educational robots were found to be particularly effective. Li et al. (2024) further explored CT integration into primary English curricula, noting the importance of pedagogical frameworks like CT-TPACK for aligning content knowledge, technology, and instructional strategies.

For early childhood education, Pollarolo et al. (2024) analyzed teachers' pedagogical strategies when using coding toys, highlighting positive outcomes for children's cognitive and socio-emotional development, including problem-solving and CT skills. Similarly, Stamatios (2024) reviewed the educational value of ScratchJr for preschoolers, concluding that while not a complete solution, it effectively supports early CT and coding skill development.

Finally, Montuori et al. (2024) conducted a meta-analysis on the cognitive effects of CT interventions, revealing significant improvements in problem-solving, planning, inhibition, and working memory among children. The results emphasized the effectiveness of structured virtual coding and educational robotics, particularly for younger learners. Additionally, Yin et al. (2024) highlighted collaborative learning as a dominant pedagogy for CT education in K-12 settings, identifying diverse instructional strategies and group compositions as critical factors for success.

These systematic reviews provide a comprehensive understanding of the current state of computational thinking research. They highlight the effectiveness of various pedagogical strategies, the need for inclusive approaches, and the growing importance of integrating CT into different educational contexts, from early childhood to higher education. Furthermore, it is also required to identify significant gaps, such as the limited investigation of pedagogical strategies like project-based learning, the insufficient focus on the integration of computational thinking in the higher education context, and the need for a deeper understanding of geographical trends and methodological approaches, thereby providing a foundation for future research directions. Consequently, the goal of this research is to analyze the current state of pedagogical approaches, including project-based learning, for developing computational thinking in STEM education at the higher education level, identifying trends, key strategies, and areas for future research.

The selection of the research questions is grounded in the need to address significant gaps in the existing literature regarding the development of computational thinking in STEM education, particularly at the higher education level. While prior systematic reviews have explored computational thinking, few have focused specifically on the pedagogical approaches, including project-based learning, that facilitate CT skill development in STEM contexts. To provide a structured and comprehensive understanding of the field, this study identifies trends, key contributors, and effective methodologies to support the integration of CT into STEM education. The research questions are designed to analyze the progression of scholarly output, identify prominent themes, explore the geographical distribution of research, and assess the pedagogical strategies and research methods employed. By answering these questions, this study aims to highlight the current state-of-the-art, pinpoint existing challenges, and propose future research directions that align with emerging educational and technological needs. To achieve this, the following questions were considered:

1 What is the trend in the number of publications per year (2021–2024) about computational thinking in STEM education?
2 What is the distribution of publications in the top journals of computational thinking in STEM education?
3 Which academic journals have the highest number of publications on computational thinking in STEM education?
4 What are the most recurrent and relevant topics and keywords in recent research on computational thinking in STEM education?
5 Which countries have led the research on computational thinking in STEM education?
6 What is the network of relationships between different articles on computational thinking in STEM education?
7 How was the pedagogical approach implemented in developing the computational thinking skills of STEM students?
8 What research methodologies were used in the studies of computational thinking?
9 What is the key research on implementing project-based learning for computational thinking?

2 Research methodology

This section describes the stages and techniques for conducting a Systematic Literature Review (RSL) to address the research questions. To answer this question, literature research, and selection were carried out to examine the findings related to computational thinking and STEM education in higher education institutions.

In the present review, PRISMA-P 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) was used to analyze studies related to computational thinking and STEM education in higher education. PRISMA-P is a research protocol developed to improve the transparency, quality, and rigor of systematic reviews and meta-analyses (Shamseer et al., 2015). This method consists of two stages: planning and action (Vázquez et al., 2022).

Figure 1 provides a structured overview of a research framework aimed at investigating the current status of pedagogical approaches including project-based learning for developing computational

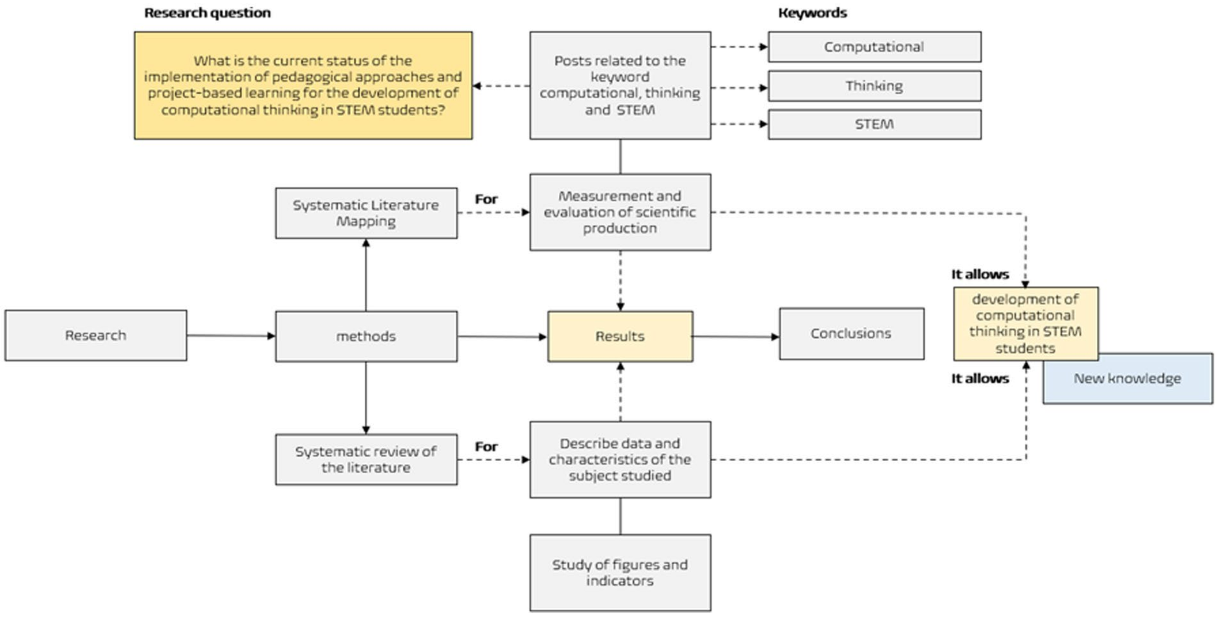

FIGURE 1
The strategy applied in the information search.

thinking in STEM students. The diagram is centered around a research question that seeks to understand how these educational strategies are currently implemented. This central question acts as the anchor for the entire research process depicted in the figure. The research begins with "Systematic Literature Mapping," a methodological approach designed to comprehensively gather and analyze existing literature on the topic. This step is crucial for identifying the breadth and depth of previous studies and for pinpointing areas that may require further investigation. Below the literature mapping, the "Research" box likely encompasses the conduct of the actual study, where various "Methods" are employed to gather new data or further analyze existing data. This could involve experimental designs, surveys, case studies, or observational studies that provide insights into effective pedagogical strategies for fostering computational thinking. The subsequent step, "Systematic Review of the Literature," suggests a more detailed and focused examination of the literature identified in the initial mapping phase. This review aims to synthesize and evaluate the findings from various studies, allowing for a more nuanced understanding of the topic. It emphasizes the measurement and evaluation of scientific production, as indicated by the vertical flow into the "Results" section. In the results section, the outcomes of both the literature review and any empirical research are analyzed and presented. This includes a description of the data and characteristics of the subject studied, supported by a study of figures and indicators which likely involve statistical analysis or thematic synthesis. The final element in the diagram, "Conclusions," flows from the results. Here, the implications of the findings are discussed, highlighting how the research contributes to the development of computational thinking in STEM students and opens avenues for new knowledge. This conclusion not only caps the study but also connects back to the initial research question, providing answers and possibly raising new questions for future research. Overall, the structure outlined in Figure 1 emphasizes a thorough and methodical approach to researching educational strategies, ensuring that the conclusions drawn are well-supported by empirical evidence and comprehensive literature analysis.

2.1 Research questions

Figure 2 illustrates a comprehensive two-stage framework designed for conducting a systematic literature review (SLR) on the implementation of pedagogical approaches including project-based learning for the development of computational thinking in STEM students. This figure can be described in the context of this research article as follows:

- Stage 1: Planning: The planning stage initiates with a clear objective to analyze the current state of implementation of pedagogical approaches including project-based learning strategies aimed at enhancing computational thinking among STEM students. This objective guides the formulation of nine specific research questions, which serve to direct the literature review and empirical investigation. These questions explore various dimensions of the research topic, including trends in publication over recent years, distribution and concentration of publications across journals, prevalent themes and keywords, methodological approaches used in the field, and the geographical distribution of the research. Each question is strategically designed to dissect different facets of the overarching research topic, ensuring a thorough exploration of the subject.
- Stage 2: Action: The action stage details the procedural steps of the systematic literature review, adhering to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines updated in 2020. This stage is meticulously structured into several phases: (a) Selection of Databases: Identifies Scopus and Web of Science as the primary sources for

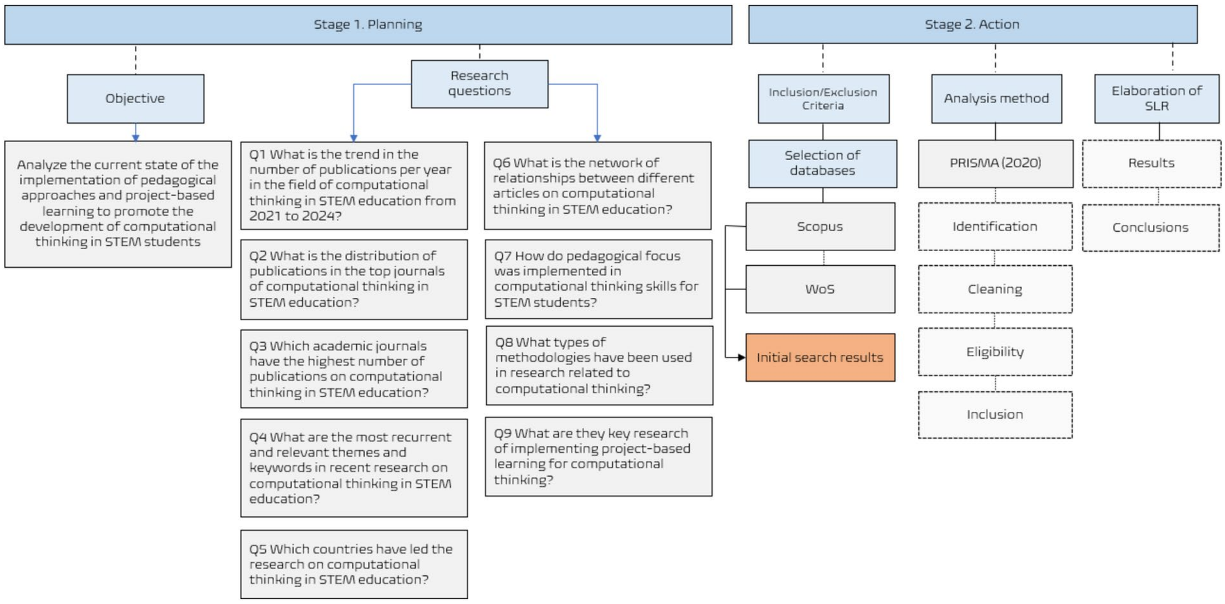

FIGURE 2
Stages and questions guiding the study.

retrieving relevant literature. These databases are chosen for their extensive coverage of quality peer-reviewed articles across various disciplines. (b) Inclusion/Exclusion Criteria: Establishes the criteria for selecting studies, ensuring that only the most relevant and quality research is reviewed. This step is crucial for maintaining the integrity and focus of the review. (c) Initial Search Results: This represents the collection of literature that preliminarily meets the search terms related to computational thinking in STEM education. (d) Analysis Method: Employs the PRISMA 2020 framework, which involves:

- o Identification: Initial identification of all potential articles that appear relevant to the research questions.
- o Cleaning: Removal of irrelevant or redundant data from the initial search results.
- o Eligibility: Further refinement of the search results by applying more stringent inclusion/exclusion criteria.
- o Inclusion: Final selection of studies that will be included in the review based on their relevance and contribution to answering the research questions.

Finally, the Elaboration of SLR leads to the synthesizing of data into coherent results, which are discussed to draw meaningful conclusions about the state of computational thinking in STEM education. This part of the framework ensures that the findings are not only reflective of the data collected but also provide actionable insights that could guide future research and practice in the field.

2.2 Database selection

Two electronic bibliographic databases were searched: Scopus and Web of Science. These search engines were selected because they are considered the largest databases recognized for the quality and impact of the research they contain (Ball, 2021). The consultation in both databases was carried out on April 19, 2024. The first step in this stage was to identify the relevant scientific production, for which the following keywords were used, limited exclusively to English terms: "computational," "thinking," and "STEM," thus guaranteeing their inclusion in the relevant databases. Table 1 shows the descriptors.

2.3 Inclusion and exclusion criteria

Inclusion and exclusion criteria were established for selecting articles in the systematic review. The inclusion criteria included the period 2021 through 2024, the search limited to research articles, the inclusion of search terms in the title, keywords, and abstract, and the restriction to publications in English. On the other hand, the exclusion criteria eliminated articles focused on reviews, such as systematic literature reviews, bibliometrics, and scope reviews; they excluded research that indirectly promoted computational thinking but lacked relevant information about measuring or developing computational thinking; they omitted articles not available in open access, and excluded entries marked as abstracts, posters, panels, or conferences.

In addition, quality criteria included articles related to higher education, the specific focus on the connection between computational thinking and STEM education, the selection only of complete articles classified as research, and the collection of empirical studies. These criteria were rigorously applied to ensure the relevance and quality of the studies included in the review.

2.4 Method of analysis

The PRISMA analysis method (Page et al., 2021) was used, which facilitates identifying and selecting relevant scientific documents. In the initial stage, 12,146 articles were identified in the Scopus and Web

TABLE 1 Descriptors for the database search.

Database	Descriptor
Scopus	TITLE-ABS-KEY (computational AND thinking AND stem) AND (LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2023) OR LIMIT-TO (PUBYEAR, 2024)) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (LANGUAGE, "english"))
Web of Science	"computational" (topic) AND "thinking" (Topic) AND "stem"(Topic)

of Science databases using only the selected keywords. However, after applying automated tools, it was determined that 11,753 articles did not meet the relevance criteria and were discarded.

Simultaneously, a curation process involved applying the inclusion and exclusion criteria in both databases, which resulted in 393 records. One hundred thirty-nine duplicate records were eliminated, leaving 254. Subsequently, the titles and abstracts of the remaining records were reviewed to determine their potential relevance to the review. Following this cursory review, 54 records that did not meet the predefined criteria were discarded, leaving 200 records.

From this point, an active search was conducted for specific documents relevant to the systematic review. This involved reading the titles and abstracts of these documents, followed by a detailed assessment to determine their eligibility for inclusion in the systematic review, applying the criteria of quality, inclusion, and exclusion. In this process, 177 records were discarded, leaving 23 relevant studies for the required analysis (see Figure 3).

These records were sequentially numbered and placed in a bibliographic Excel database. The fields included were the author(s), title of the work, year, number of citations, journal, authors' country, DOI, type of methodology, bibliographic data in APA style, abstracts, keywords, language, type of access, instruments used, and sample size.

3 Theoretical framework

The theoretical framework explains the primacy of CT in solving complex technological issues and the infusion of CT into STEM education. According to Wing (2006), CT is the ability to apply computational techniques to problem-solving, designing systems, and understanding human behavior by studying computation. These are essential skills for everyone, not just computer science majors. CT builds on the core elements of abstraction, decomposition, pattern recognition, and algorithm design, which build effective problem-solving abilities in complex environments. STEM education is designed so that learners acquire the knowledge, skills, attitudes, and behaviors to make informed decisions toward meaningful engagement in inclusive and sustainable societies (UNESCO, 2017). Integrating CT in STEM enhances students' capacity to apply computational approaches to scientific and technical problems, thus preparing them for careers that require advanced technical skills (Wang et al., 2022). For example, integrating CT into high school mathematics classes has significantly enhanced students' problem-solving skills and engagement. Project-based learning (PBL) is a student-centered pedagogy where students actively confront real-world problems and challenges. In effect, PBL nurtures CT skills through collaborative and practical student activities.

Constructivist theory holds that knowledge is constructed through experience and social interactions. An experiential and hands-on approach supports learning CT skills through collaboration and practical learning experiences. Learners acquire their understanding and knowledge through experiences and reflections. Within CT, this theory encourages a learning environment that fosters exploration, experimentation, and collaboration. The Cognitive Load Theory, proposed by Sweller in 1988, implies that to enhance learning, instructional design should target a reduction in extraneous cognitive load. In CT education, this refers to designing instructional materials and activities that pivot around content elements that facilitate efficient problem-solving by preparing learners' cognitive structures. Studies have established that reducing cognitive load by preparing suitable instructional materials immensely influences a student's ability to understand complex computational concepts.

Moreover, the models use analytical approaches guided by the theoretical framework for assessing CT in STEM education to improve teaching and learning under different pedagogical strategies. These models describe the state of the art of research and the way forward in CT in STEM education. This research proposes the theoretical framework that is the foundation for investigating CT integration into STEM education. This study borrows from constructivism, cognitive load theory, and PBL to suggest possible effective strategies to improve CT skills among STEM students who will develop sustainable practices. Figure 4 illustrates the theoretical framework with the core components of computational thinking embedded into STEM education, related educational theories, and best pedagogical approaches.

4 Results

This section details the results of the systematic literature review of computational thinking in STEM education from 2021 to 2024. The review focused on pedagogical approaches including project-based learning designed to enhance computational thinking skills in the context of higher education.

One part of the analysis draws on data displayed in Figures 5–7, which represent the publication trends over the years, distribution among top journals, and citation metrics, respectively, responding to the three research questions: (1) What is the trend in the number of publications per year (2021–2024) about computational thinking in STEM education? (2) What is the distribution of publications in the top journals of computational thinking in STEM education? (3)Which academic journals have the highest number of publications on computational thinking in STEM education?

The distribution of publications by various academic publishers from 2021 to 2024, as depicted in Figure 5, highlights a burgeoning interest and robust dissemination of research in the domain of computational thinking within STEM education. Notably, publishers such as MDPI, Springer, and John Wiley and Sons Inc. have published consistent and increasing contributions over the years, underscoring their pivotal roles in advancing this field. The year

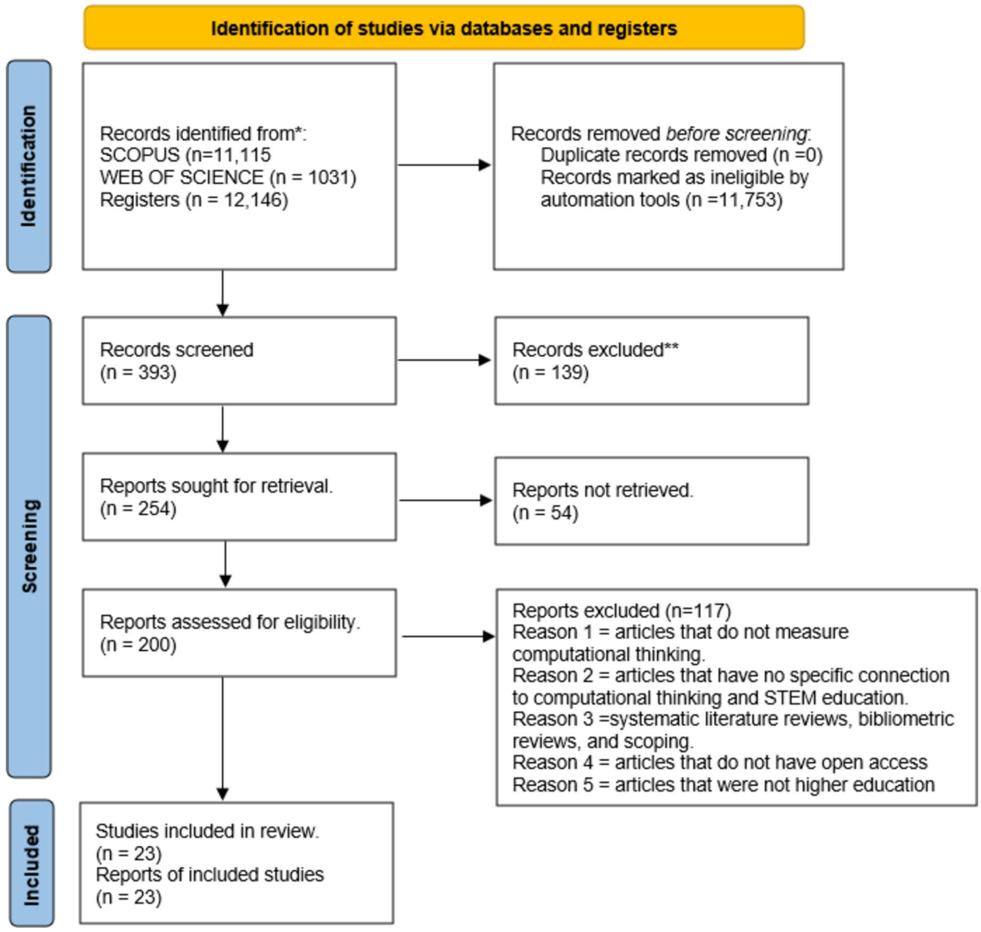

FIGURE 3
Application of the PRISMA method for preparing the study.

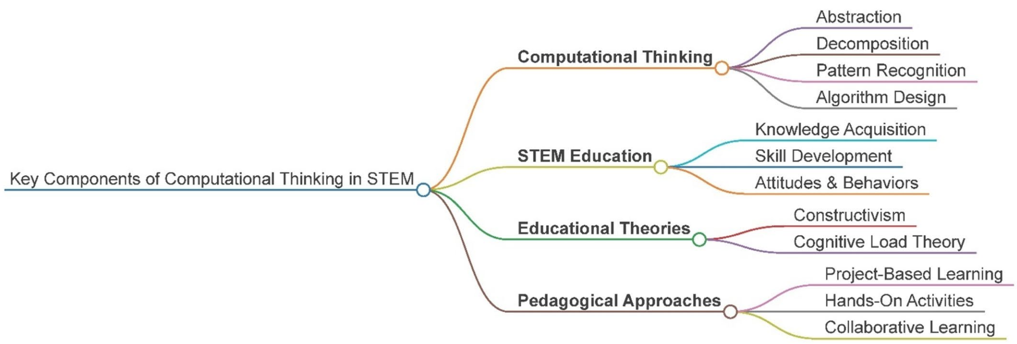

FIGURE 4
Key components and framework for integrating computational thinking in STEM education.

2022 marked a peak in publications, particularly from MDPI and Springer, reflecting heightened academic engagement and possibly emerging trends that align with global educational priorities for integrating computational skills into STEM curricula. This trend is indicative of the field's dynamic evolution and the growing recognition of its significance in equipping students with essential 21st-century skills.

The graphical representation of Figure 6 illustrates the distribution of publications on computational thinking in STEM education in various academic journals from 2021 to 2024. This diverse distribution underscores the interdisciplinary nature of computational thinking, manifesting its integration into multiple facets of STEM education research. 2021 marks a foundational year with publications in various journals, showing increasing interest in computational thinking in

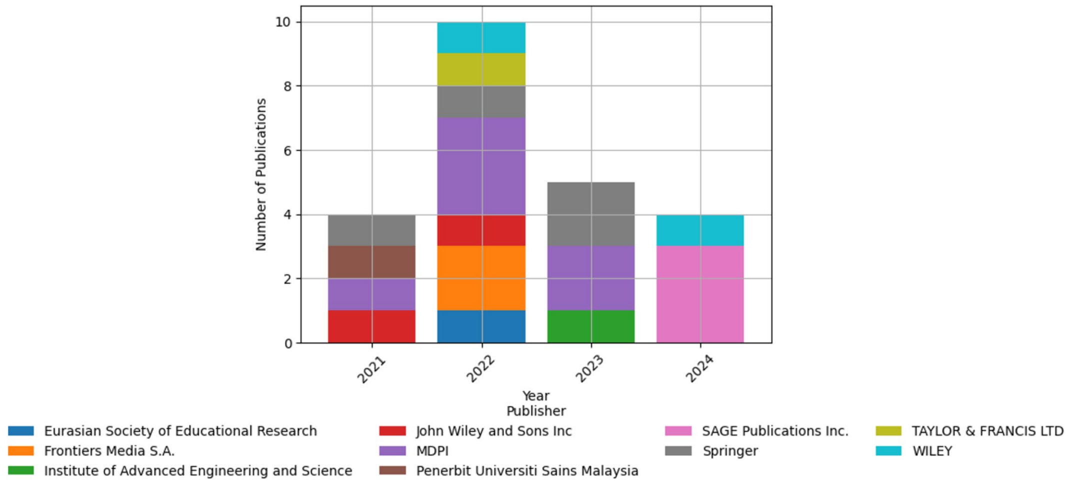

FIGURE 5
Yearly trends in the number of publications and the details of the publishing groups.

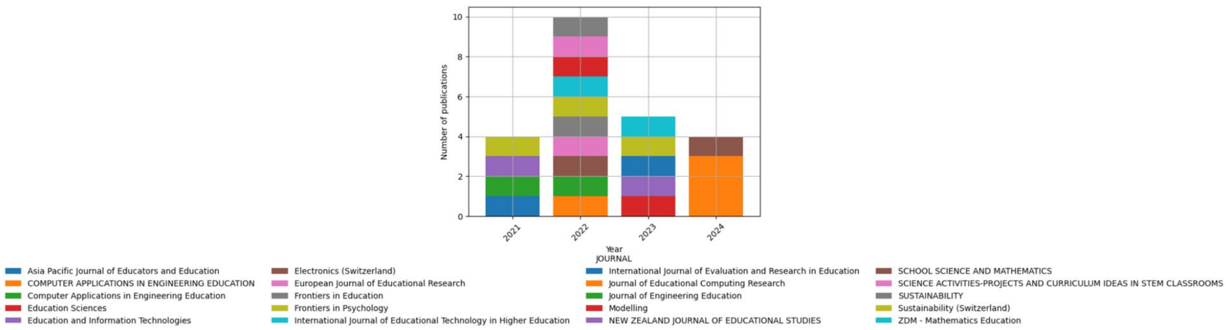

FIGURE 6
Yearly trend on the number of publications with the details of the publishing journal.

several educational contexts. Notably, journals such as the *European Journal of Educational Research* and *Computer Applications in Engineering Education* exhibited substantial engagement with the topic, focusing on applying computational methods within engineering and broader educational methodologies. By 2022, publications in the *Journal of Educational Computing Research* pointed to an increasing concentration on the technological aspects of education. Similarly, *Frontiers in Education* began to emerge as a central player, highlighting a growing interest in cutting-edge educational technologies and their application to STEM education. The year 2023 continued this trend, with *Frontiers in Education* taking a leading role, alongside sustained contributions from *Computer Applications in Engineering Education*. This shows a steady focus on advancing computational thinking capabilities through innovative educational tools and practices. In 2024, the trend appears to have stabilized, with contributions balanced across journals like *School Science* and *Mathematics and Sustainability*. This indicates a maturation in the field where computational thinking is extensively studied not only as a tool for enhancing STEM education but also for its role in promoting sustainable educational practices and policies. Overall, the analysis reveals a dynamic field where the publication venues reflect the evolving landscape of research interests and educational priorities, emphasizing the critical role of computational thinking in enhancing educational outcomes and preparing students for a technologically driven world.

Figure 7 displays the 10 most cited articles by year, which visually encapsulates the impact of key articles on computational thinking in STEM education from 2021 to 2024. The bar chart distinguishes articles per their publication year using a color-coded system, where articles published in different years are represented by distinct pastel colors. Analysis of the chart reveals a progressive increase in the number of citations in more recent articles, suggesting an escalating interest and recognition within the academic community. The two most cited articles appearing in 2024 have considerably higher citation counts (62 and 63, respectively), underscoring their probable pivotal role in advancing the discourse on computational thinking in STEM education. This trend might indicate that these recent publications are either highly innovative, addressing emerging trends, or they fill crucial gaps in the existing literature. Notably, the articles from earlier years, like 2021 and 2022, while less cited, establish a foundation that supports subsequent research evidenced by later citations.

Figures 8, 9, which are word clouds of the keywords and article titles, respectively, illustrate the prevalent topics and keywords in recent research on computational thinking in STEM education. The

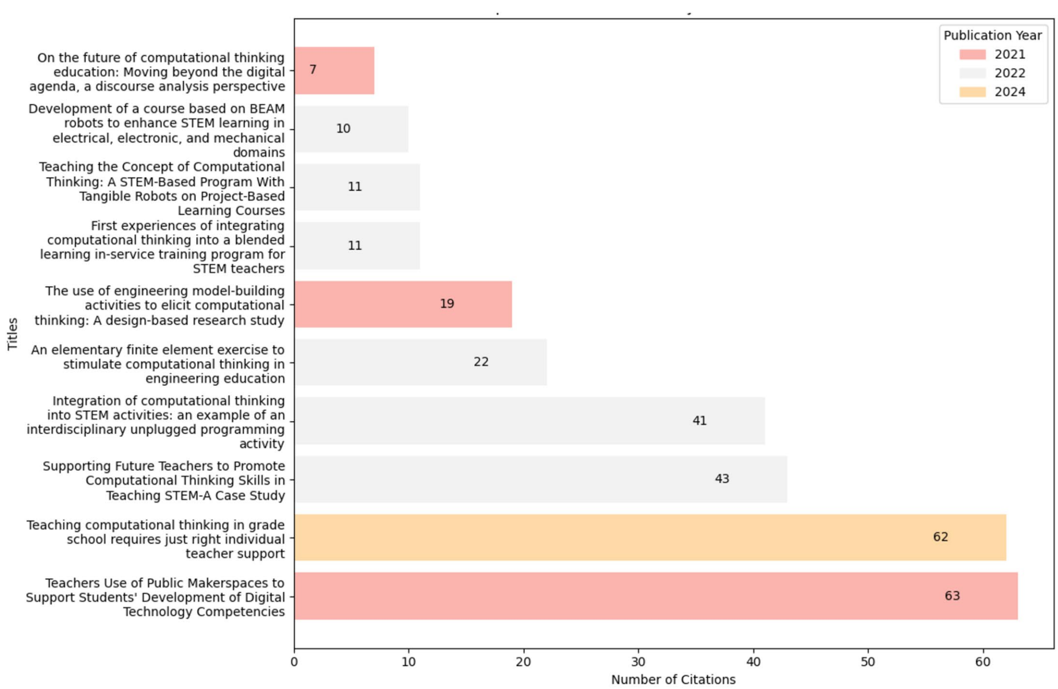

FIGURE 7
The trend of the number of citations per article published in each corresponding year.

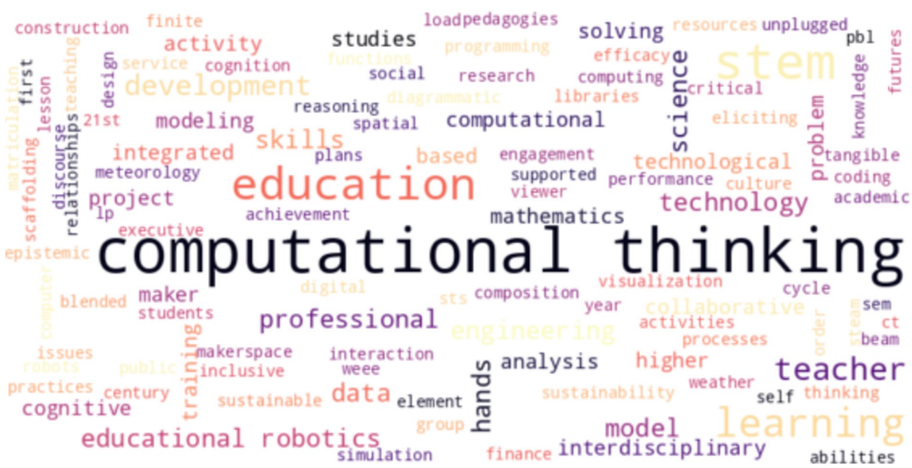

FIGURE 8
Word cloud using the keywords of the article.

visualizations illustrate a comprehensive overview of the thematic density and distribution in the field to answer the research question: *What are the most recurrent and relevant topics and keywords in recent research on computational thinking in STEM education?*

It is noted that both word clouds prominently feature "computational thinking" and "education," affirming them as the core focus areas. This suggests a significant academic emphasis on integrating computational thinking as a fundamental component of educational curricula. The abbreviation "STEM," often linked with "technology" and "engineering" in the clouds, underscores the interdisciplinary approach to incorporating computational thinking in various scientific disciplines. Keywords such as "learning," "skills," "teaching," and "students" highlight the pedagogical orientation of the research, indicating a robust focus on educational outcomes, teaching methodologies, and skills development. Terms like "technology," "robotics," "digital," and "engineering" reflect the integration of advanced tools and methods in teaching computational thinking, pointing to the adoption of practical, technology-driven approaches within STEM fields.

The geographical dispersion of research articles in a systematic literature review (SLR) plays a pivotal role in comprehensively understanding the global research landscape and identifying regional

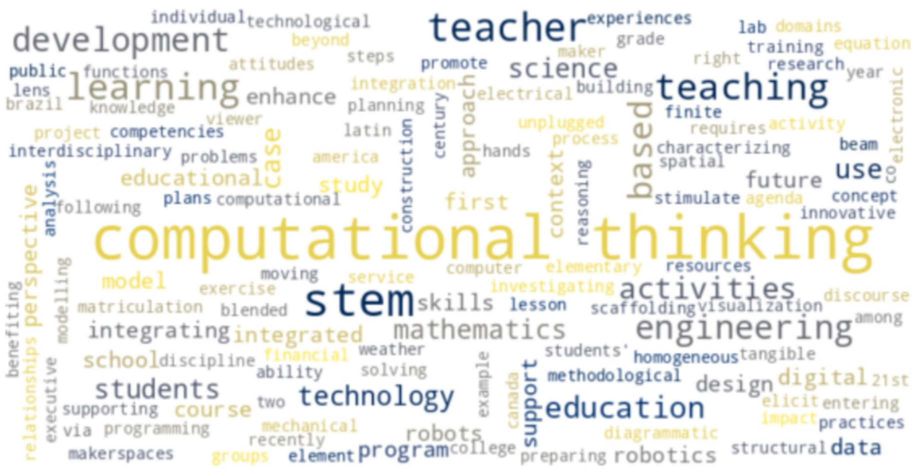

FIGURE 9
Word cloud using the title of the article.

trends, challenges, and opportunities within a particular domain. This dimension not only highlights which countries are contributing the most to a specific field but also reveals disparities in research outputs and priorities that may reflect underlying socio-economic, cultural, or technological factors. For example, in the study by Bayly-Castaneda et al. (2024), the geographical distribution of research on AI-mediated personalized learning paths revealed that countries such as China, India, and the United States lead in publication volume, reflecting their significant investment in education technology and AI. Similarly, Cayetano-Jiménez et al. (2024) demonstrated the geographical dispersion of studies on soft robotics in education, underscoring the concentration of research in K-12 education workshops in specific regions while identifying gaps in higher education contexts. Furthermore, García-Ruiz et al. (2023) observed global adherence to frameworks such as DIGCOMPEDU for assessing digital teaching competencies, highlighting geographical differences in the adoption and contextualization of these frameworks. By analyzing geographical dispersion, researchers can uncover regional strengths, such as China's focus on adaptive learning technologies or Europe's integration of standardized frameworks, while also identifying underrepresented regions and potential areas for collaboration and capacity-building. Thus, geographical dispersion provides a critical lens for understanding how research ecosystems interact globally and how innovations can be effectively scaled and localized. Therefore, it is also intriguing to visualize the geographical distribution of leading research contributions in the subject area to answer the research question: Which countries have led the research on computational thinking in STEM education? Figure 10 highlights in red a diverse array of countries actively publishing in this domain, from well-established research hubs to emerging contributors.

The United States is prominent, playing a significant role in pioneering and advancing research in computational thinking within STEM education. This is due to the country's solid educational infrastructure and strong emphasis on integrating technology and computational skills in academic curricula. Countries such as the United Kingdom, Germany, Italy, Hungary, Ireland, and Lithuania reflect a robust European interest and investment in computational thinking research. These nations represent a blend of advanced educational systems and policy-driven initiatives to incorporate STEM education at various levels of learning. In Asia, Taiwan and Hong Kong are notable for their contributions, indicating a focused development within technological education sectors. New Zealand also makes a mark, showing its commitment to including computational thinking skills in its educational frameworks. Turkey, Chile, and Panama have expanded research in computational thinking to regions with emerging educational technologies and methodologies. This broad involvement illustrates the global acknowledgment of computational skills as fundamental components of future educational systems.

Figure 11 is a thematic similarity analysis using network graph techniques to visualize interconnections among research articles based on shared keywords in the field of computational thinking in STEM education to answer the research question: *What is the relationship network of different articles on computational thinking in STEM education?* Each node in the graph represents an article, with edges indicating thematic overlaps through common keywords. Node sizes are proportional to the number of connections, highlighting articles with broader thematic influence, while color gradations differentiate the nodes based on their connectivity. This visualization effectively identifies central themes and potential clusters, aiding the understanding of the thematic structure and critical research areas within the dataset.

For instance, closely clustered nodes 4, 9, 3, and 11 denote articles with significant thematic similarities, suggesting a concentration of studies on methods of integrating computational thinking through educational initiatives and curricular activities. In contrast, isolated nodes like 8 and 12 represent more distinct topics within the field, indicating unique or less commonly shared thematic focuses. This visualization aids in identifying both central themes and outlier topics within the corpus, offering insights into the prevailing research directions and potential gaps in the literature on computational thinking in STEM education.

Table 2 provides a rich comparative analysis of various pedagogical approaches, activities, and methodologies used across different studies aimed at enhancing computational thinking among STEM students. Each entry in the table reflects a distinct research focus, illuminating

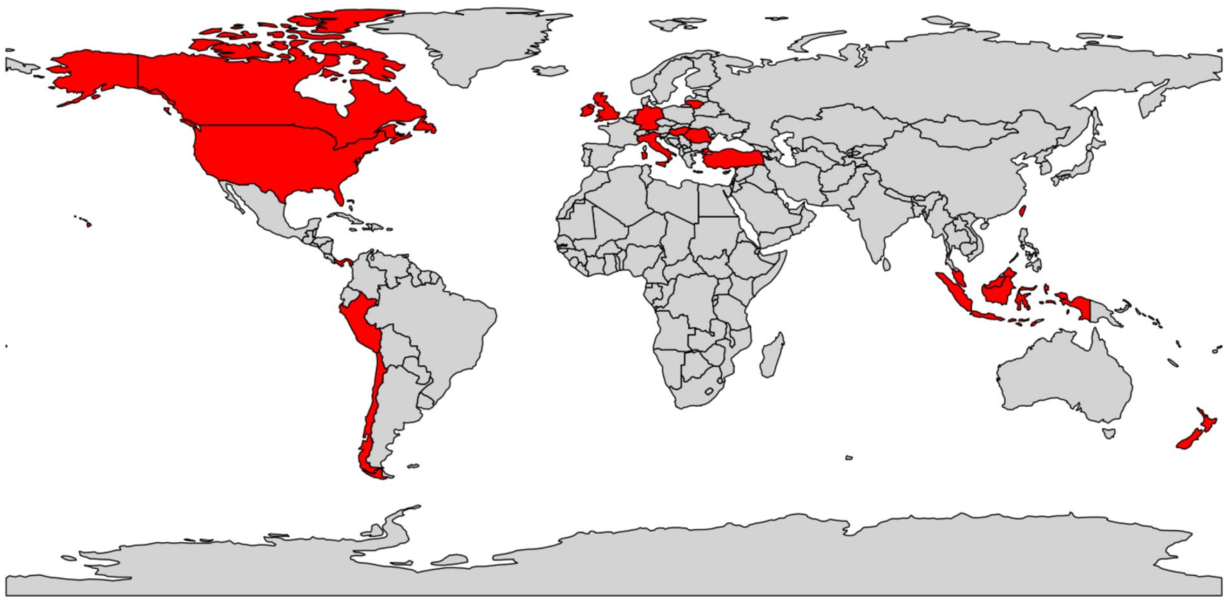

FIGURE 10
Specific countries have published research articles related to STEM education and computational thinking in higher education contexts.

the diverse ways in which computational thinking can be integrated into STEM education.

The authors have prioritized PBL as a key pedagogical approach due to its strong alignment with the objectives of CT in STEM education. PBL contributes towards active, student-centered learning, enabling students to engage with real-world problems and collaborative projects that develop essential CT skills such as abstraction, decomposition, pattern recognition, and algorithm design. Unlike traditional methods, PBL bridges the gap between theory and practice, offering experiential learning opportunities that enhance critical thinking, creativity, and problem-solving abilities—key competencies for addressing complex STEM challenges. This approach also promotes deeper understanding and long-term retention of CT skills by embedding them in meaningful, interdisciplinary contexts. Moreover, PBL supports global educational priorities, such as sustainability and equitable learning, by promoting inclusive, collaborative environments that prepare students to contribute to sustainable development. Given its effectiveness and alignment with the goals of STEM education, PBL was chosen as a central focus for examining its role in advancing CT competencies.

A notable trend in the table is the emphasis on practical, hands-on activities across several studies, aligning with the broad pedagogical focus on enhancing real-world problem-solving skills and technical competencies. For example, studies often involve collaborative laboratory practices, use of robotics, and computational modeling, which are designed to mimic real-life challenges students might face in their professional careers. This experiential learning approach is evident in entries such as the use of BEAM robots and project-based programming with tangible robots, highlighting a focus on engaging students directly with the material to foster deeper learning and retention.

The integration and effectiveness of PBL vary significantly among the studies. While some research explicitly utilizes PBL to foster an immersive learning environment—such as the projects involving robotics and STEM-based programming activities—others do not incorporate this method. The difference may stem from the study's objectives or from logistical constraints, such as the availability of resources or the curriculum's flexibility. PBL tends to be particularly effective in entries where it is used, as it not only improves computational thinking but also enhances collaborative skills and creativity, which are crucial for STEM fields.

Methodologically, the studies employ a range of approaches from quantitative and qualitative to mixed methods, reflecting the multifaceted nature of educational research. Quantitative methods are prevalent in studies assessing the effectiveness of specific interventions on students' skills development, while qualitative methods are used to explore deeper insights into the processes and experiences of learners and educators within the PBL environment. The use of mixed methods in some studies indicates an attempt to capture both the measurable outcomes of educational interventions and the nuanced experiences of participants, providing a more holistic understanding of the impacts of pedagogical strategies.

Geographical diversity in the studies also suggests varying educational priorities and approaches across different contexts. Studies from countries like the United States, Taiwan, and Lithuania demonstrate a strong inclination towards technology integration and innovative educational strategies, likely reflecting these regions' advanced educational technology infrastructure and policy support. Conversely, research from regions such as Latin America and parts of Europe focuses more on addressing educational challenges unique to their contexts, such as limited resources or specific educational standards.

Several implications can be learned from this, in which the first one highlights practical and collaborative activities, which involve implementing computational and collaborative laboratory practices to encourage computational thinking and problem-solving through student interactions. In addition, computation and problem-solving activities guide the co-construction of knowledge (Barana et al., 2023;

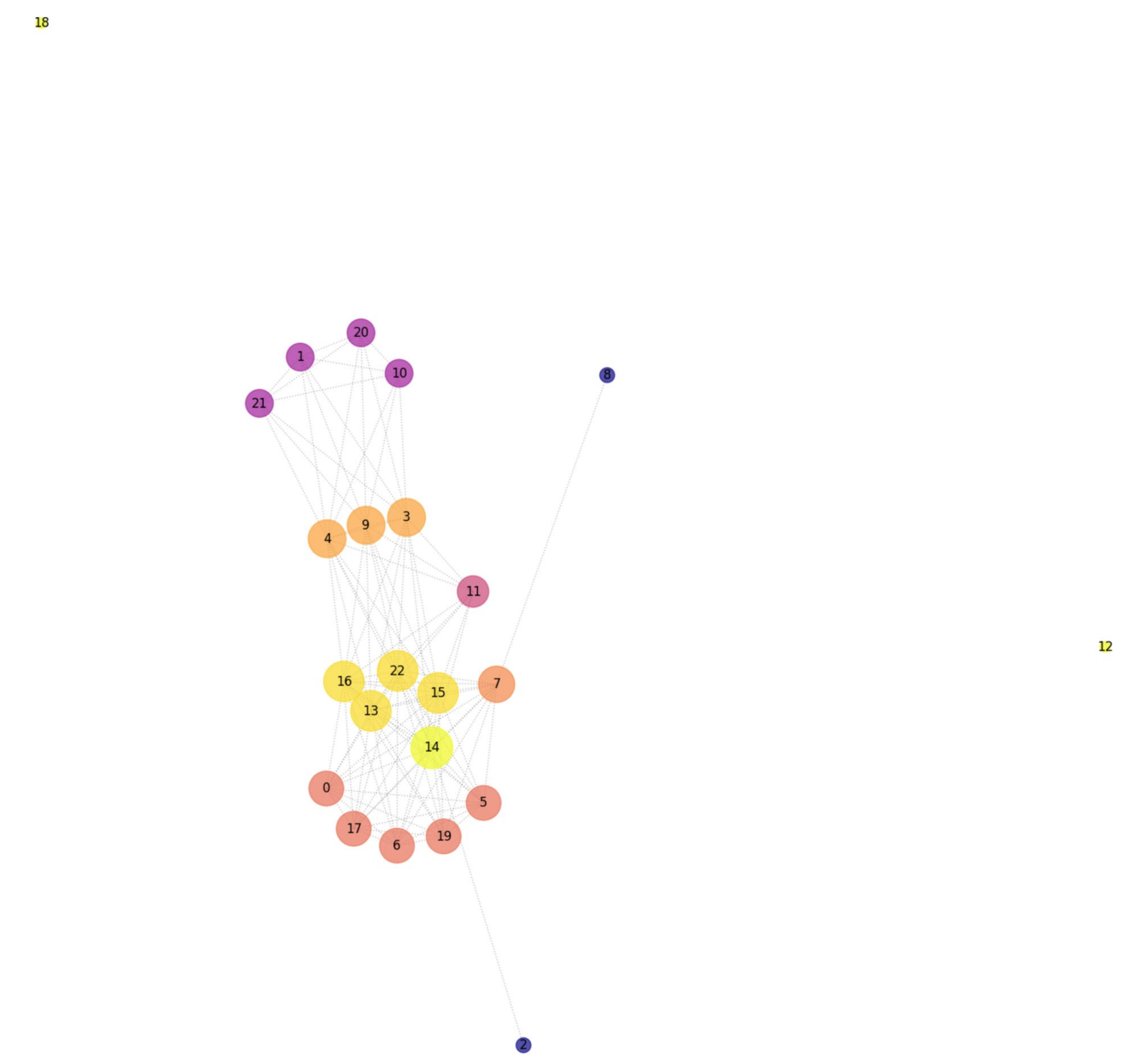

FIGURE 11
Thematic similarity analysis using network graph techniques. Each node on the network graph represents a specific article and its details are displayed in Appendix A.

Namukasa et al., 2023; Paucar-Curasma et al., 2023). This is followed by curricular integration and teaching programming skills, which integrates critical competencies, comprehensive programming teaching, and the promotion of computational thinking skills in various educational disciplines (Osztián et al., 2022; Tripon, 2022).

Another prominent approach is interdisciplinary and transversal, which involves integrating computational thinking into disciplines such as mathematics, physics, chemistry, and others. It focuses on active learning, problem-solving, project-based learning, the application of hands-on activities, and the integration of technology, such as software, simulations, and programming. Likewise, collaboration and monitoring are promoted (Dolgopolovas and Dagiene, 2021; Law et al., 2021; Özdinç et al., 2022; Knie et al., 2022). In addition, the research design approach and model-building activities involve implementing computational model-building activities that focus on abstraction, algorithmic thinking, and evaluation (Aleyaasin, 2021; Lyon and Magana, 2021).

Blended learning and using technology are also highlighted, with the structuring of alternate digital and face-to-face phases, the use of interactive online modules focusing on computational thinking, and the integration of technology to influence attitudes and knowledge about computational activities positively. Likewise, the integration of modeling activities and problem-solving in the classroom is highlighted (Knie et al., 2022; Lyon et al., 2022). Studies also highlight the constructivist approach and data visualization, which encourage creativity and self-directed exploration, programming, and problem-solving project work, and using tools such as Scratch and weather data visualization to promote computational thinking (Sun et al., 2024).

TABLE 2 Pedagogical approaches and activities that develop computational thinking.

No.	Title	Pedagogical focus	Activities addressed	Project-based learning?	Methodology	Country
1	Investigating the Knowledge Co-Construction Process in Homogeneous Ability Groups during Computational Lab Activities in Financial Mathematics	Practical activities.	Computational and collaborative laboratory practices.	There was no project-based learning process.	Mixed	Ireland
2	On the computational thinking and diagrammatic reasoning of first-year computer science and engineering students.	Integration of key transversal competencies in the curriculum.	Plugged-in and unpluggable methods, practical and theoretical activities.	There was no project-based learning process.	Quantitative	Romania
3	On the Future of Computational Thinking Education: Moving Beyond the Digital Agenda, a Discourse Analysis Perspective	Interdisciplinary pedagogical approach based on research design.	Collaboration in artifact production and project-based learning.	PBL links with CT and promotes creativity and hands-on learning. This pragmatist approach values hands-on experience and community work, facilitating the development of digital competencies and problem-solving skills (Dolgopolovas and Dagiene, 2021).	Qualitative	Lithuania
4	The use of engineering model-building activities to elicit computational thinking: A design-based research study	Research design approach.	Computational model-building activities.	There was no project-based learning process.	Design-based research methodology	United States
5	Supporting Future Teachers to Promote Computational Thinking Skills in Teaching STEM—A Case Study	Student-centered approach.	Experimentation, play, digital narratives, and active learning.	There was no project-based learning process.	Mixed	Romania
6	Use of Technological Resources for the Development of Computational Thinking Following the Steps of Solving Problems in Engineering Students Recently Entering College	Problem-based approach, fostering computational thinking practices, design-based research.	Hands-on activities, problem-solving, collaboration, thematic analysis of student-produced artifacts, and modeling activities.	There was no project-based learning process.	Quantitative	Peru
7	First experiences of integrating computational thinking into a blended learning in-service training program for STEM teachers	Transdisciplinary blended learning approach.	Online self-study.	There was no project-based learning process.	Quantitative	Germany
8	The Relationship between Executive Functions and Computational Thinking	Constructivist approach, project-based learning.	Programming projects.	The studio used project-based learning (PBL) through creative programming and debugging sessions in Scratch, where students worked on individual projects. Creative programming sessions encouraged self-expression and decision-making, while debugging sessions allowed for the application of analysis and problem-solving skills (Liu, 2024).	Quantitative	United Kingdom

(Continued)

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TABLE 2 (Continued)

No.	Title	Pedagogical focus	Activities addressed	Project-based learning?	Methodology	Country
9	Integrating Computational Thinking Into Scaffolding Learning: An Innovative Approach to Enhance Science, Technology, Engineering, and Mathematics Hands-On Learning	Computational thinking scaffolding approach.	Hands-on activities, Jupyter Notebook environment, an interactive web application.	There was no project-based learning process.	Quantitative	Taiwan
10	Preparing Teachers for Teaching Spatial Computational Thinking With Integrated Data Viewer Visualization of Weather Data: A Discipline-Based Perspective of Computational Thinking	Data Visualization.	Visualization of real weather data.	There was no project-based learning process.	Mixed	United States
11	An elementary finite element exercise to stimulate computational thinking in engineering education	Problem-based approach.	Manually solving engineering problems with computational modeling using software.	There was no project-based learning process.	Quantitative	United Kingdom
12	Teaching the Concept of Computational Thinking: A STEM-Based Program with Tangible Robots on Project-Based Learning Courses	Project-based learning.	Use of tangible robots, projects, and multi-sensory methods.	Project-based learning (PBL) is effective in developing computational thinking, especially when integrating tangible robots. This approach significantly improves students' academic performance without increasing their cognitive load, allowing them to interact practically and visually with concepts. In addition, PBL encourages creativity and problem-solving, essential for STEM development (Hsieh et al., 2022).	Quantitative	Taiwan
13	A Methodological Approach to Teaching STEM Skills in Latin America through Educational Robotics for School Teachers	Constructivist approach, methodology based on the 5E model (Engage, Explore, Explain, Elaborate, and Evaluate).	Interactive workshops, use of the Arduino platform, the realization of practical projects, and problem-solving.	Project-based learning (PBL) is an effective methodology for developing computational thinking in educational robotics. It facilitates the understanding of theoretical concepts through the creation and programming of robots, fosters problem-solving skills, and promotes collaboration among students. In addition, PBL's practical and creative approach increases student motivation and engagement (Cano, 2022).	Mixed	Chile and Colombia
14	Characterizing Computational Thinking in the Context of Model-Planning Activities	Modeling Activities.	Modeling work, problem-solving.	There was no project-based learning process.	Qualitative	United States
15	Computational Thinking in STEM Education among Matriculation Science Students	Interdisciplinary approach, practical activities, collaboration, use of technological tools	Use of software, simulations and programming, and problem-solving.	There was no project-based learning process.	Quantitative	Malaysia
16	This is a self-archived version of an original article. This version may differ from the original in pagination and typographic details.	Hands-on robotics activities.	Robot construction and programming, algorithm development.	There was no project-based learning process.	Qualitative	Finland

(Continued)

TABLE 2 (Continued)

No.	Title	Pedagogical focus	Activities addressed	Project-based learning?	Methodology	Country
17	Development of a course based on BEAM robots to enhance STEM learning in electrical, electronic, and mechanical domains	Project-based learning: a constructivist, practical, and collaborative approach.	Problem-solving, collaboration, building and programming robots	Project-based learning is an effective strategy for developing computational thinking, especially in building BEAM robots. Students face challenges in design and construction, encouraging problem-solving and learning through trial and error. These experiences motivate students and promote the construction of complex entities and the generalization of knowledge. In addition, using recycled elements in the evaluation and design of robots enriches the teaching environment and stimulates creative thinking through a better understanding of technological systems (Boya-Lara et al., 2022).	Mixed	Panama
18	Integration of computational thinking into STEM activities: an example of an interdisciplinary unplugged programming activity	Interdisciplinary approach, problem-based learning	Troubleshooting, offline programming activity	There was no project-based learning process.	Qualitative	Turkey
19	Teachers Use of Public Makerspaces to Support Students' Development of Digital Technology Competencies	Hands-on, collaborative learning	Sessions in makerspaces, construction of specific robots, robotics-related challenges, and designing objects for 3D printing.	There was no project-based learning process.	Qualitative	New Zealand
20	The impact of STEM attitudes and computational thinking on 21st-century via structural equation modelling	Project-based and problem-solving learning	Guided learning and mentoring, problem-solving, and collaborative projects	Project-based learning is mentioned as an effective STEM model that enhances computational thinking and 21st-century skills. Through STEM-based activities, educators guide students in meaningful projects, developing computational thinking skills through learning and mentoring. These learning models, including problem-based learning, are effective in improving these skills (Richardo et al., 2023).	Quantitative	Indonesia
21	Computational Thinking Development: Benefiting from Educational Robotics in STEM Teaching	Collaborative learning	Hands-on activities with robots, teamwork, and problem-solving	There was no project-based learning process.	Qualitative	Indonesia
22	Teacher development in integrated STEM education: Design of lesson plans through the lens of computational thinking	Computational Thinking Scaffolding (CTS)	Phases of the approach: decomposition, pattern recognition, abstraction, algorithm design, and evaluation.	There was no project-based learning process.	Quantitative	Taiwan
23	Technology maker practices in mathematics learning in STEM contexts: a case in Brazil and two cases in Canada	Research design methodology	Co-design strategies	There was no project-based learning process.	Qualitative	Brazil, Canada

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Computational Thinking Scaffolding (CTS) is another essential approach that integrates computational thinking as a fundamental tool in practical activities to improve problem-solving skills and the application of interdisciplinary knowledge (Lee et al., 2024; Mumcu et al., 2023). In addition, there is the real project and problem-based approach, which promotes meaningful learning by applying computational thinking in real situations with strategies such as project- and problem-based learning, collaborative teamwork, direct experience, and joint resolution of problems (Budiyanto et al., 2022; Boya-Lara et al., 2022; Paucar-Curasma et al., 2023; Richardo et al., 2023).

The 5E methodology model facilitates meaningful learning through practice and experimentation, contextualized problem-solving, and the application of knowledge in practical projects (Cano, 2022). Finally, the use of tangible robots and makerspaces integrates robots into project-based learning courses and promotes practical learning of robotics practices, programming, algorithm development, and collaborative teamwork to develop computational thinking (Budiyanto et al., 2022; Macann and Carvalho, 2021). These categories encompass a variety of pedagogical approaches to developing computational thinking in different educational contexts and STEM disciplines.

Regarding the question: What research methodologies were used in the studies of computational thinking? The analysis reveals that research with a quantitative approach predominates, totaling 10, followed by qualitative research (7) and mixed research (5). A study using the design methodology was also identified.

Finally, question 9 of this review focuses on knowing the critical research on the implementation of project-based learning (PBL) for computational thinking. Various studies highlight its effectiveness. Dolgopolovas and Dagiene (2021) reported that PBL fosters creativity and hands-on learning, aligning with CT through hands-on experience and community work. Liu (2024) shows how PBL, through creative programming and debugging using Scratch, promotes self-expression, decision-making, and problem-solving, which are essential for CT. Hsieh et al. (2022) highlight that using tangible robots in PBL improves academic performance and reduces students' cognitive loads, facilitating the practical understanding of CT concepts. Cano (2022) emphasizes the practical application of theoretical concepts in the creation and programming of robots, encouraging problem-solving and collaboration. Boya-Lara et al. (2022) points out that the challenges in building BEAM robots promote learning through trial and error and the generalization of knowledge. Finally, Richardo et al. (2023) suggests that PBL in STEM contexts produces positive results in developing computational thinking and twenty-first-century skills through the guidance and mentorship of educators.

Future lines of research on computational thinking in STEM education could focus on evaluating and measuring the development of these skills. The reviewed studies show various pedagogical and methodological approaches, including practical activities, such as computational labs in Ireland and programming projects in the United Kingdom, as well as interdisciplinary and research design approaches in Lithuania and the United States. Investigating how these specific methodologies affect the learning and retention of computational thinking will facilitate the development of more accurate assessment tools and the adaptation of pedagogical approaches to maximize educational impact. In addition, differences in the development of these skills between groups of students from different academic levels and socioeconomic backgrounds could be explored, providing a basis for more inclusive and equitable approaches.

Another promising line is research on integrating emerging technologies and new pedagogical approaches to teach computational thinking. Studies in Peru and Taiwan highlight the use of advanced technological platforms and innovative teaching methods, such as project-based learning and data visualization. Expanding this research could include the utilization of artificial intelligence, augmented and virtual reality, and online learning environments, as seen in online self-study programs in Germany. In addition, the impact of gamification and educational games could be investigated, like the Romanian approaches focused on experimentation and digital narratives. These explorations could offer new ways to engage students and make the acquisition of computational thinking more engaging and effective, preparing students better for future technological challenges.

5 Discussion

First, the analysis conducted showed that computational thinking and education are a potent combination (Figure 7) and a relevant concern of scholars, especially recently. Figures 6, 7 show that computational thinking has been proposed to promote sustainable development through STEM education and novel teaching practices (Ramírez-Montoya et al., 2024). The rapid evolution of technology requires this and a shift in curricular development to prioritize preparing students for a future driven by complex environments that require high-level skills (Farias-Gaytan et al., 2023). Education currently faces one of its most profound transitions, and educators worldwide are taking on the challenge with great courage.

Second, computational thinking is a fundamental skill for the problem-solving processes that will evolve as technology advances, enabling individuals to thrive in challenging environments (Alfaro-Ponce et al., 2023) in all domains of knowledge, including contemporary (Chen et al., 2023) and future professional disciplines. Figure 7 illustrates that the year 2024 will likely represent the peak in citations. This is because recent publications are rapidly addressing emerging gaps in the existing literature, allowing us to prepare ourselves, as educators and researchers, for the generation of new knowledge to understand the behavioral keys that humans employ when interacting with technology.

Third, the necessity for training in computational thinking competency is a global concern, regardless of a country's development level; workforces must prepare to address the complexities associated with changes in production and management and be diligent with resources. As illustrated in Figure 10, the scientific output concentrated primarily in the United States aligns with the country's robust educational infrastructure and a strong emphasis on integrating technology and computational skills in academic curricula. However, the global acknowledgment of computational skills as fundamental components of future educational systems suggests that the off-line approach for computational thinking development (Chichekian et al., 2023) and scientific production could be a relevant topic for emerging economies to explore in the future.

Finally, developing countries can benefit from early experiences reported in the literature. This is illustrated in the cluster formed by documents 13, 14, 15, 16, and 22 in Figure 11, which reveals the initial approaches of students to computational thinking. As stated by Krakowski et al., it is crucial to open STEM academic and career pathways for young people to build STEM-empowered communities (2023, p. 1), a powerful way to push the technological development of disfavored populations so they can address and resolve complex challenges (Crawford et al., 2024). The introduction of computational thinking at an early stage in the education of vulnerable individuals may prove to be the sole opportunity to prevent continuing the skills gap among the following generations.

As a series of recommendations, future studies should explore the integration of CT into non-STEM domains, such as humanities, social sciences, and arts education, to develop interdisciplinary pedagogical models that broaden students' skill sets. Several other recommendations are listed as follows:

- Research should focus on using emerging technologies, such as AI, augmented and virtual reality (AR/VR), and gamification tools, to enhance the teaching and learning of CT in STEM and non-STEM education.
- Longitudinal research is needed to assess the sustained impact of pedagogical approaches, including PBL and educational robotics, on students' computational thinking skills over time. These studies should examine how CT competencies are applied in real-world problem-solving contexts.
- There is a need to investigate how socio-economic, cultural, and institutional factors influence the implementation of CT in STEM education. This includes identifying barriers to adoption in under-resourced settings and developing scalable, context-specific strategies to address these challenges.
- Further studies should examine the development of inclusive teaching frameworks that address gender disparities in computational thinking and STEM fields. This research should focus on designing gender-sensitive pedagogical strategies and assessment tools to promote equitable learning opportunities.
- Research should aim to evaluate the effectiveness of integrating CT into early education curricula to determine how early exposure to CT concepts influences students' engagement and skill development across their academic trajectory.

6 Conclusion

This study presented the current state of pedagogical approaches including project-based learning for developing computational thinking in STEM students, revealing relevant progress but different degrees of adoption across educational contexts. The reviewed research indicates that computational thinking has been integrated into new curricula, allowing students to understand computational concepts but also fostering problem-solving skills, which are very much needed for future challenges.

The study also revealed that pedagogical approaches employed in enhancing computational thinking skills among STEM students include a wide range of alternatives, the most relevant and valuable being the Project Based Learning approach. Other learnings to improve students' ability to solve computational problems are practical and collaborative, inquiry-based, and sometimes interdisciplinary. These approaches help students develop critical thinking and analytical skills essential for embracing complex problems in computational thinking. Furthermore, the integration of real-world issues into the curriculum has proven to be a powerful motivator, engaging students, and helping them see the relevance of computational thinking in their everyday lives and future careers.

This study highlights the interdisciplinary nature of the methodologies applied to computational thinking research. Quantitative, qualitative, and mixed methods have been used to measure and analyze the effects of teaching strategies. This diversity in research methodologies underscores the complexity of computational thinking and highlights the need for continued investigation to refine and optimize educational strategies in this area. Future research will surely include analysis using AI, as another possible area of research is the integration of emerging technologies and innovative pedagogical approaches in the teaching of computational thinking.

This study has presented relevant results on the state of the art in computational thinking and education, which are valuable for curricular development using disciplinary and interdisciplinary approaches. However, the study has some limitations. First, only two databases were searched, and even though Scopus and Web of Science databases are sufficient for general scanning, other databases could provide additional information relevant to the study. Second, the research questions give an overview that is aligned with the authors' interests and needs related to a larger project. However, there could be other focuses to explore relevant aspects of computational thinking and how it is applied in STEM education. Future research can address significant topics uncovered in this study.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

RT: Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing, Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration. BA: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. JR: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. IA-I: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. FN: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcomp.2024.1480404/full#supplementary-material

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