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PAPER

A Systematic Review on Learning, Teaching, and Assessing Computational Thinking Skills for Secondary Education

Leidy Carvajal-Ortiz (✉),
Deisy Chaves,
María Trujillo

Universidad del Valle, Cali, Colombia

leidy.carvajal.o@correounivalle.edu.co

ABSTRACT

Computational thinking (CT) has become a fundamental skill in the 21st century, especially within secondary education. However, integrating CT into teaching and learning requires the participation of teachers specialized in this area. This systematic review identifies and analyzes the most effective methods, strategies, and activities used to teach and assess secondary-level CT skills. To ensure broad and rigorous coverage of relevant research, a literature search was conducted in Scopus, Web of Science, and ScienceDirect databases, covering studies published between 2020 and 2024. The review synthesizes current educational practices, highlighting approaches such as Game-Based Learning, gamification, and assessment activities such as the Bebras Challenge. Findings reveal diverse pedagogical strategies and ongoing challenges, particularly regarding validating assessment instruments and teacher professional development. Besides, this review underscores the need for more robust, standardized assessment methods and further research to advance CT education. The insights provided are valuable for educators, policymakers, and researchers seeking to enhance CT education and its integration into engineering pedagogy.

KEYWORDS

assessment, computational thinking (CT), engineering pedagogy, K-12, learning, skills, systematic review, secondary education, teaching strategies, teachers

1 INTRODUCTION

Computational thinking (CT) was introduced in 2006 by Jeannette Wing [1] as a process that involves three aspects: 1) solving problems, 2) designing systems, and 3) understanding human behavior, based on fundamental concepts of computer science. However, in 2008 Wing [2] argued that CT is a way of thinking that includes a series of essential and valuable skills for all people in different professional fields. CT promotes critical thinking, organization to solve problems effectively, and is considered one of the most demanded skills of the 21st century [3] [4]. There is growing interest in integrating CT into secondary education due to its potential to enhance

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problem-solving and analytical thinking in adolescents. When CT is incorporated into STEM (Science, Technology, Engineering, and Mathematics) disciplines, it enables students to enhance their divergent thinking skills. It allows them to discover, create, and innovate through analysis and problem-solving [5] [6].

However, an obstacle to integrating CT into teaching and learning is the need for teachers' knowledge, skills, and perceptions regarding this topic [7–9]. To effectively incorporate CT into secondary education, teachers should have CT skills [10]. Secondary education is perhaps a fundamental base for the transition into vocational education.

Worldwide, the integration of CT into secondary education has gained significant momentum, particularly in Europe, North America, and Australia. Educational policies and curriculum reforms in these regions emphasize the importance of computational skills for future workforce readiness [96] [97]. For instance, the European Commission CompuThink studies and curricular updates in Australia underscore the need for embedding CT across mathematics, science, and technology subjects [98] [99]. The ISTE (International Society for Technology in Education) and CSTA (Computer Science Teachers Association) standards have provided frameworks for North America CT integration and teacher training.

Studies from Western educational systems also demonstrate the effectiveness of innovative pedagogical approaches. In Greece, pair programming proved to be more effective than solo programming for novice secondary students, leading to improved understanding and [100]. Similarly, game-based learning approaches in European secondary schools significantly enhance student motivation and CT skills [101]. Moreover, recent meta-analyses and reviews [102] [103] support the positive impact of unplugged and game-based pedagogies in fostering CT across diverse classroom settings.

Although progress has been made, the adoption of CT in teaching is still limited by persistent obstacles, such as inadequate teacher training, expertise, and materials.

In Colombia, since 2019, the Ministry of National Education (MEN) and the Ministry of Information and Communications Technologies (MinTIC) have been promoting STEM training, including CT. This initiative aims to develop skills of the 21st century, such as critical thinking and problem resolution. To achieve this goal, they have implemented several STEM projects and short courses focused on CT, programming, and the development of educational materials, such as primers and guides, to ensure that teachers in the classroom effectively impart this knowledge [11] [12]. Additionally, educational innovation laboratories, short courses in CT and programming, and project competitions that integrate STEM have created training opportunities for students [13] [14] [15]. In March 2024, MinTIC launched the "Colombia Programa" strategy, which utilizes the "Learning by Doing" methodology [16]. This strategy encompasses subjects and topics such as programming and CT, with active involvement from rural regions and a gender-focused approach to address the digital talent gap in the country.

The main objective of all these efforts is to acquire algorithmic thinking skills [17], but, to promote CT in the classroom, teachers should first have a solid understanding of its core skills: abstraction (understanding a problem), decomposition (breaking down complex problems into simpler ones), and algorithmic thinking (solving problems step-by-step) [18]. Additionally, they need to acquire the ability to design teaching and learning activities that integrate these skills meaningfully into their practice [19]. Furthermore, it is essential that teachers learn how to teach and assess CT skills within the context of their subject areas, using appropriate digital tools and technologies [20] [5] [21] [22] [23].

Based on these motivations, this review addresses the following research questions:

- Research Question 1 (RQ1): What are the most frequently used methods, strategies, and activities for teaching and learning CT skills in secondary education?
- Research Question 2 (RQ2): What methods and tools are used to assess CT skills in secondary education, and what are the challenges associated with their implementation?

The remainder of this paper is structured as follows: Section 2 details the methodology employed for the systematic review. Next, we analyze the main models, strategies, methods, and activities used for teaching CT, followed by discussing strategies and activities focused on CT assessment. Section 3 presents the results obtained in response to the research questions, including an analysis of the impact of COVID-19 and the implications for engineering education pedagogy. Finally, Section 4 offers the study's conclusions, highlighting the main challenges identified and outlining directions for future research.

1.1 Previous reviews

Existing systematic reviews on CT skills [24–29] highlight the growing importance of CT in secondary education, especially at the K-9 and K-12 levels. However, significant gaps in research and practice are also identified, particularly in assessing and validating CT skills and preparing teachers to teach these competencies. In [24] is presented a literature review on professional development programs in CT. The review concludes that many studies focus solely on teachers understanding of concepts because they do not explore how participants evaluate or create learning activities. An additional conclusion is that excluding classroom observations from the program limits our understanding of how these programs work. Despite the efforts made, teacher training in CT remains a challenge, as it requires a significant investment of time and dedication to ensure effective learning of CT in the classroom.

In [25] a review of the development of CT in primary education in South American countries is presented, covering educational studies, policies, methodologies, languages, tools, and assessments. This review highlights the importance of CT as an essential 21st-century skill. However, the implementation and approach of CT in primary education in South American countries vary significantly, underscoring the necessity for a uniform and practical approach to integrating CT into primary education. In [26] the assessment of CT in K-12 (i.e. educational level from kindergarten to twelfth grade) is addressed through a review of 39 studies. Although educators integrate CT into K-12 curricula worldwide, researchers have yet to catch up on its assessment. They focus on interventions that promote CT concepts and practices, using quasi-experimental designs and selected-response tests. The lack of validation of these assessments in educational settings indicates the necessity of developing more comprehensive and validated assessment tools.

In [27] the development of CT through Scratch programming for K-9 students (i.e. educational level from 1 to 9 grade) was reviewed using the Brennan and Resnick framework. Through a review of 55 studies, acquired CT skills were identified, and the original framework, such as human-computer interaction and predictive thinking, did not capture additional skills. The authors discuss the challenges in assessing and progressing these skills and issues in study design. The recommendations include two key elements. Firstly, researchers should expand the existing framework to include these additional skills. Secondly, they should address the current gaps in research.

In [30], programming and CT teaching advances are examined across five continents, revealing varied implementation in rich versus poor countries. Latin America and Africa, CT teaching has to be more advanced and present in some countries. The authors highlight the need for educational policies that promote CT for technological and economic development.

In [28], various studies are reviewed to analyze specific CT assessments from different perspectives, including educational context, assessment construct, assessment type, and evidence of reliability and validity. The results indicate a lack of sufficient CT assessments for high school and college students and professional development programs for teachers. CT assessments focus primarily on programming or computing skills, using traditional tests and performance assessments. The need to collect and report more evidence of reliability and validity in future studies is highlighted, which is crucial to conceptualize and assess CT skills effectively.

In [29], a review of professional development programs in CT highlights the importance of preparing teachers to integrate CT into K-12 classrooms. Using the TPACK framework, the learning outcomes, assessment methods, pedagogical approaches, and pedagogical tools used in these programs are analyzed. The results suggest that existing evidence is limited to developed countries. Many studies focus solely on teachers understanding of concepts without exploring how they assess or create learning activities. Researchers need to conduct more studies that include classroom observations and examine the transfer of learning to professional programming languages.

Unlike previous CT reviews [24–29], our study provides a more up-to-date and comprehensive review from 2020 to 2024, covering a broader domain of the teaching and assessment of CT skills. Therefore, this review is a supportive guide for teachers on the teaching and assessment of CT. This work also highlights the importance of high school students and teachers in creating learning and teaching activities that develop CT skills. Table 1 compares our review with the literature on the topic.

Table 1. Comparison of our review with existing systematic reviews on CT skills

Art	Strategy/Method/ Activity	Skills	Education Level	Bibliometric Analysis
Curasma et al., 2020 [25]	Studies and policies, methodologies designed for the teaching of CT, languages, and tools used and the techniques or methods for assessment of CT	Design and implement solutions; test and debug; model and simulate systems; analyze and communicate effectively; use appropriate vocabulary; recognize and navigate between levels of abstraction; collaborate in problem-solving; and innovate across disciplines.	K-9	Until March 2019
Cutumisu et al., 2019 [26]	Empirical studies for assessing CT	Algorithmic thinking, abstraction, problem decomposition, logical thinking, and data	K-12	From 2014 to 2018
Zhang et al., 2019 [27]	Learning CT through Scratch	Loop, sequence, conditionals, variables, coordination	K-9	From 2007 to January 2018
Tang et al., 2020 [28]	Studies for assessing CT	Does not apply	K-elementary, Middle, High, College and Teacher	Until August 2019
Belmar et al., 2022 [30]	Teaching of computer programming and CT in the 5 continents	Abstraction, decomposition, algorithmic, debugging, and problem-solving	Primary, secondary and tertiary	From October 2016 to December 2020

(Continued)

Table 1. Comparison of our review with existing systematic reviews on CT skills *(Continued)*

Art	Strategy/Method/ Activity	Skills	Education Level	Bibliometric Analysis
Espinal et al., 2024 [29]	Professional development programs in CT	Abstraction, decomposition, algorithms and automation	Teachers	From 2006 to 2022
This work	Studies for teaching, learning and assessing CT	Algorithmic thinking, abstraction and decomposition	K-12	From 2020 to December 2024

In particular, this study examines how CT skills are taught and assessed in secondary education. Students and teachers need to develop these skills as they enable them to approach complex problems in a structured and logical way. Applying computer science principles is highly valued in a digitalized world. Teaching CT enhances students' technological competence and fosters problem-solving, critical thinking, a creativity. Assessing these skills helps teachers identify areas for improvement and adapt their teaching methods for practical and relevant learning.

Additionally, by summarizing methods, strategies, and activities to promote CT, we provide helpful information for educators seeking to improve their pedagogical practices. Understanding teaching and assessment approaches is crucial since CT encompasses critical problem-solving and innovative thinking skills, particularly in STEM disciplines. Therefore, this review highlights current trends and gaps in CT education and suggests future research directions.

2 METHODOLOGY

The research methodology adopted in this study was a systematic review aimed to identify and analyze relevant literature on the teaching and assessing CT skills in secondary education. The review followed the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology [32], which provides a standardized checklist and flowchart for enhancing transparency and reproducibility in systematic reviews. The methodology comprises five key phases, detailed below and summarized in Figure 1. The PRISMA 2020 Checklist is provided in Appendix A.

Fig. 1. Overview of the systematic review process

Notes: This review did not require ethical approval or informed consent, as it analyzed publicly available literature. All references were managed and organized using Zotero reference management software.

1. Search strategy: Develop and execute a comprehensive search plan to identify relevant studies. This includes selecting appropriate academic databases, defining search terms and Boolean operators, and applying filters such as publication date, language, and document type.
2. Identification of inclusion and exclusion criteria: Establish precise criteria to include or exclude studies, considering factors such as type of studies, population, interventions, comparators, and relevant results.

3. Data extraction: Search academic databases and other relevant sources, record the studies found, and filter those that meet the inclusion criteria.
4. Synthesis and reporting: Analyze and synthesize the data from the included studies and present the findings systematically in a structured report, highlighting the main conclusions.

These phases guide the structure of the following subsections, where each stage is described in more detail.

2.1 Search strategy

To identify relevant strategies for learning, teaching, and assessing CT skills, a systematic search was conducted in three academic databases: Scopus, Web of Science and ScienceDirect, covering the period from January 2020 to December 2024. The search terms included combinations of keywords such as "computational thinking," "abstractly," "21st-century skills," "teach," "teaching," "teacher," "learn," "learning," "assess," "assessment," "secondary education," "education middle school" and "secondary school." These terms were combined a refined using Boolean operators (AND, OR) to ensure the most relevant results. The detailed search queries and direct database links are presented in Table 2.

Table 2. Summary of search queries and database links

Database	Search in	String
Scopus	TITLE-ABS-KEY	TITLE-ABS-KEY (("computational thinking" OR abstractly OR "21st century skills") AND (teach* OR learn* OR assess*) AND ("secondary education" OR "middle school" OR "secondary school")) [Link]
Science Direct	All Fields	("computational thinking" OR "21st Century skills") AND ("secondary education" OR "middle school" OR "secondary school") AND (teaching OR assessment) [Link]
Web of Science	All Fields	ALL=(("computational thinking" OR abstractly OR "21st century skills") AND (teach* OR learn* OR assess*) AND ("secondary education" OR "middle school" OR "secondary school")) [Link]

We generated bibliometric visualizations to provide an overview of the initial literature retrieved (see Figures 2–5). These figures illustrate the distribution of publications by country, document type, publication year, and subject area offering insight into the global and thematic scope of the identified studies before the screening and data extraction phases.

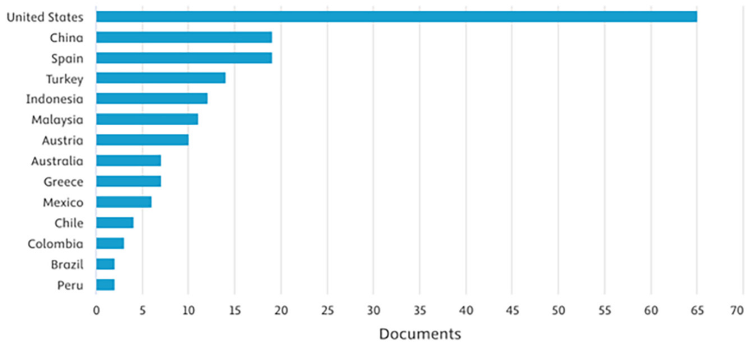

Fig. 2. Distribution of publications by country

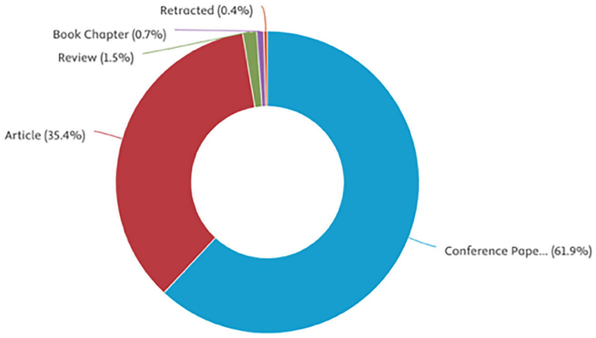

Fig. 3. Distribution of publications by type

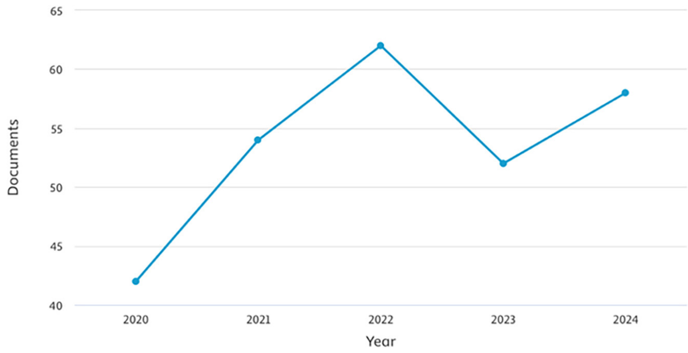

Fig. 4. Distribution of publications by year

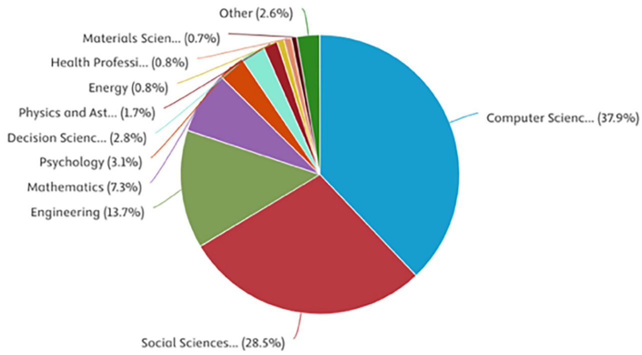

Fig. 5. Distribution of publications by subject area

2.2 Inclusion and exclusion criteria

To provide a comprehensive and update review of the teaching and assessment of CT skills, the papers selected for this study were chosen based on a set of rigorous inclusion criteria. We believe the following criteria are crucial for the quality and relevance of our research:

1. Studies published between January 2020 and December 2024
2. Studies related to the areas of computing and engineering
3. Studies that describe methods, strategies, and activities used in teaching and learning CT for the secondary education level
4. Studies that describe evaluation methods and strategies for CT at the secondary education level
5. Studies describing evaluation methods and strategies for CT for the target audience of adults

Subsequently, the next exclusion criteria are applied:

1. Studies that do not focus on the secondary education level
2. Studies not published in English or Spanish
3. Studies mention the term “computational thinking”; however, it appears only in the summary and references section
4. Studies that use robotics for teaching, learning, and evaluation of the CT

2.3 Data extraction

In the preliminary phase of the study, each publication title and abstract were reviewed independently. We conducted an initial skimming follows by a rigorous review of the most relevant papers. While some papers addressed ‘21st-century skills’ they were unrelated to CT skills, instead focusing on competencies like cooperation, creativity, teamwork, collaboration, and communication. We carefully examined each paper’s strategy, method, or activity to ensure they promoted CT skills such as abstraction, decomposition, and algorithmic thinking. We excluded papers that focused explicitly on robotics-oriented teaching and learning strategies, as our objective was to find a low-cost approach that does not rely on expensive materials for CT learning, teaching, and assessment in secondary education. Additionally, we prioritized identifying effective strategies. Studies centered solely on preschool or higher education were also excluded, as we focused on selecting papers relevant to the specific needs of secondary education students.

The paper selection process began with identifying 2129 works using specific search keywords. Then, we applied the inclusion and exclusion criteria to narrow the pool to 708 relevant papers. Further examination of the titles and abstracts narrowed the selection to 87. After removing duplicates, 55 papers remained. A meticulous review of their introductions and conclusions led to a final selection of 47 papers. We finally thoroughly read this final sample, ensuring our research's highest level of credibility.

The selected articles, which mainly focus on teaching computer skills, learning, and assessment strategies/methods/activities, particularly GBL and gamification, as well as assessment activities related to Bebras, were read, reviewed, and confirmed appropriately by our reviewers. The Bebras Challenge, an internationally recognized initiative known as "Bebras International Challenge in Computing and Computational Thinking," uses diagnostic tests and challenging tasks to measure CT skills in children and young people between five and 19 years old. This process, guided by their expertise, was deemed necessary to identify any relevant studies, including a review of the reference lists of each paper, as detailed in Figure 6, which outline the result of applying the inclusion and exclusion criteria following the PRISMA methodology.

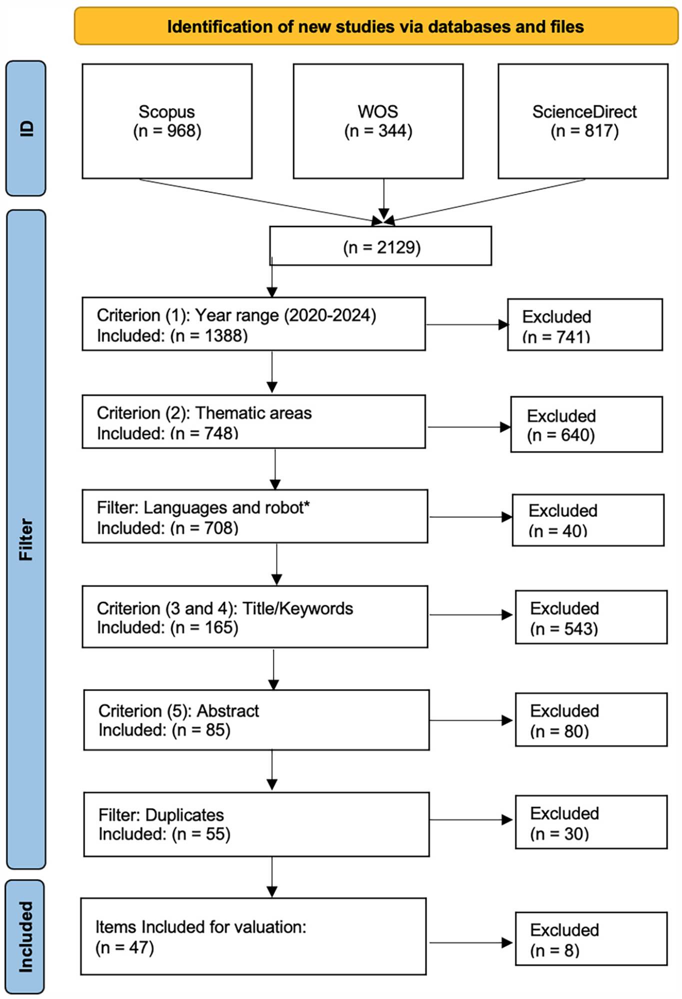

Fig. 6. PRISMA flow diagram for the systematic literature review

2.4 Synthesis and reporting

Full-text articles were assessed for eligibility according to predefined inclusion and exclusion criteria. After selecting eligible studies, we assessed their quality and bias based on criteria adapted from previous systematic reviews. Each study was evaluated based on the clarity of its research objectives, the transparency and replicability of its methodology, the suitability of the study design for the research questions, the sample size and participant selection, and, where applicable, the validity and reliability of the CT assessment instruments used. Studies that lacked sufficient methodological detail or used unvalidated instruments were considered limitations in the synthesis and discussion. This approach ensured that the evidence included in our review was as rigorous and reliable as possible. The selected studies were analyzed using a qualitative content analysis approach. The data extracted from each study was organized into thematic categories aligned with the two research questions (RQ1 and RQ2). For RQ1, the studies were categorized based on the teaching and learning strategies used to promote CT skills. These included the methods, activities, technologies employed in each study, and the specific CT skills targeted. For RQ2, the analysis focused on the evaluation strategies applied to assess CT skills, including the assessment methods and the CT skills evaluated.

3 RESULTS

This section presents the results obtained from the analysis of the selected studies. The findings are organized according to the two research questions (RQ1 and RQ2), focusing respectively on strategies for teaching and learning CT skills and on the assessment, approaches used in secondary education.

The selected works are detailed in Tables 3 and 4. Table 3 presents studies related to teaching and learning, addressing RQ1. This table includes the strategies, methods, or activities used to promote CT skills, the specific CT skills targeted, the inclusion of learning styles, the type of paper, the technology used (analog, digital, or mixed), the study results, and the characteristics of the target population. Table 4 focuses on the evaluation related to RQ2, detailing the evaluation strategy used, the skills assessed, a brief study description, the type of paper, the technology utilized, and the target population.

The analysis of papers addressing RQ1 (refer to Table 3) reveals a notable rise in publications in 2023, as illustrated in Figure 7. This growth results from the collective efforts of academic researchers, educators, and professionals in CT. Similarly, papers related to RQ2 (refer to Table 4) indicate an increase in publications in 2022, as showed in Figure 8, suggesting a heightened interest in CT in that year, potentially driven by changes in educational curricula or new research developments.

3.1 Teaching and learning strategies (RQ1)

Examining the findings related to RQ1, Table 3 highlights that a mix of analog and digital strategies is most commonly used to teach and learn CT skills, as illustrated in Figure 9. These strategies, such as game-based learning (GBL) (21.7%), disconnected activities (DA) (13%), serious games (13%), and gamification (13%), are not just theoretical concepts, but practical tools that can be readily implemented. Moreover, mixed strategies (17.4%), such as combining augmented reality with gamification and serious games with collaborative learning (CL), are also used.

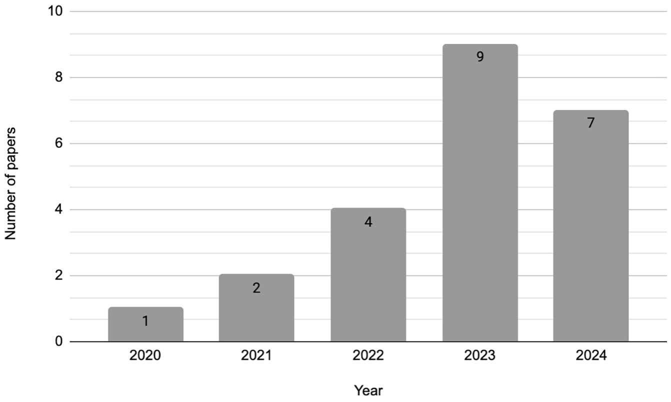

Fig. 7. Number of papers per year RQ1

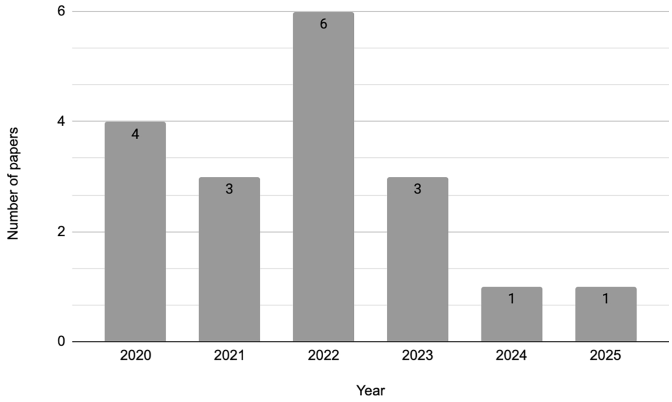

Fig. 8. Number of papers per year RQ2

GBL employs games and game elements to facilitate learning, motivating students, and developing skills such as problem-solving and human-computer interaction [33] [34] [35]. This strategy utilizes games such as Minecraft [36] and tools such as Scratch, Code.org, and MyClassGame [37] with block activities that address logic and programming exercises. DA, which includes board games and block games, are non-digital methods that make computing accessible and engaging [38] [39] [40].

Table 3. Selected papers on strategies, methods and activities to learning CT skills

Art	Strategy/ Method/Activity	Skills	Learning Styles	Type	Technology	Characterization Population
Cheng et al., 2023 [41]	GBL	– Decomposition – Pattern recognition – Abstraction – Algorithm design – Assessment	Does not apply	Platform	Based on Blockly with game prototypes	53 primary school students between 11 y 12 years old
Zhang et al., 2023 [42]	GBL	– Pattern recognition – Depuration – Simulation – Algorithmic thinking – Problem resolution – Creativity – Collaboration	Does not apply	Literature review	Does not apply	14 elementary schools and 12 middle schools with 24 participants
Chen et al., 2023 [43]	DA	– Abstraction – Algorithmic thinking – Problem resolution – Pattern recognition – Design-based thinking	Does not apply	Literature review	Board games, paper blocks, and worksheets	Students from kindergarten to high school
Olmo Muñoz et al., 2023 [37]	Gamification	– Abstraction – Algorithmic thinking – Decomposition – Assessment	Does not apply	Quasi experimental design	Code and MyClassGame	82 second grade primary school students divided into control and experimental groups
Z. Qu et al., 2023 [36]	GBL	– Algorithmic thinking – Problem resolution – Creativity	Does not apply	Case study	Minecraft	60 first year high school students

(Continued)

Table 3. Selected papers on strategies, methods and activities to learning CT skills *(Continued)*

Art	Strategy/ Method/Activity	Skills	Learning Styles	Type	Technology	Characterization Population
Zitouniatis et al., 2023 [44]	ABE and heuristics for educational games (PHEG)	– Algorithmic thinking	Does not apply	Tool evaluation in progress	Twine, Quizzis, Project Euler, Kahoot, Replit, Discord, LMS	Secondary students
Aryan et al., 2023 [45]	ABP	– Abstraction – Decomposition – Pattern recognition	Mixed learning styles	Model	Does not apply	28 computer science engineering students
Lampropoulos et al., 2023 [46]	Augmented reality, gamification and serious games	– Algorithmic thinking	Does not apply	Mobile app	Android e iOS and Unity	117 higher educations students
Atmosukarto et al., 2021 [47]	Gamification	– Abstraction – Pattern recognition – Algorithm design	Does not apply	Platform	Unity and the language Blockly	54 1st year engineering students and 53 technology students enrolled in august 2020
Gerini et al., 2023 [48]	Virtual reality and Gamification	– Algorithmic thinking	Does not apply	Tool	VRCoding: Unity	Designed for secondary school students and tested on 15 university students
Harangus et al., 2020 [49]	DA	– Abstraction – Algorithmic thinking	Does not apply	Application	Does not apply	High school and college students
Asbell-Clarke et al., 2021 [50]	GBL	– Abstraction – Decomposition – Pattern recognition – Algorithmic thinking	Does not apply	Case study	Zoombinis Tool	45 students from grades 3 to 8
Theodoropoulos et al., 2022 [51]	Serious Games	– Algorithmic thinking	Does not apply	Case study	Game design and development App Inventor	41 high school students
Sun et al., 2022 [52]	Serious Games	– Abstraction – Decomposition – Pattern recognition – Algorithmic thinking	Does not apply	Methodology	Does not apply	7th and 8th grade students
Chen et al., 2022 [53]	DA	– Algorithmic thinking	Does not apply	Study	Does not apply	158 high school students and 1 teacher
Zhao et al., 2022 [54]	ABP	– Abstraction – Generalization – Decomposition – Algorithms – Analysis – Modeling – Assessment	Does not apply	Model	Does not apply	Primary and secondary school students
Marcum et al., 2024 [55]	Learnning environment	– Pattern recognition – Data abstraction – Data aggregation – Interpolation – Extrapolation	Does not apply	Case study	Mixed	306 eighth grade students ages (13–14)

(Continued)

Table 3. Selected papers on strategies, methods and activities to learning CT skills *(Continued)*

Art	Strategy/ Method/Activity	Skills	Learning Styles	Type	Technology	Characterization Population
Looi et al., 2024 [56]	CL	– Abstraction – Decomposition – Pattern recognition – Algorithmic thinking	Does not apply	Case study	Mixed	168 secondary school students aged 13 to 14 from a school in Singapore
Angraini et al., 2024 [57]	Augmented reality	– Abstraction – Decomposition – Algorithms thinking – Pattern recognition	Does not apply	Case study	Mixed	160 seventh grade students from four high schools in Indonesia
Saenboonsong et al., 2024 [58]	GBL	– Abstraction – Decomposition – Algorithms design – Pattern recognition	Does not apply	Study	Mixed	41 secondary school students
Dan Sun et al., 2024 [59]	Block-based and text-based programming	– Decomposition – Algorithms design	Does not apply	Course	Code4all and PyCharm	64 secondary school students
Rao et al., 2024 [60]	Augmented reality	– Abstraction – Decomposition – Algorithms thinking – Pattern recognition	Does not apply	Case study	CodAR	124 secondary school students from 6th and 7th grade (11–13 ages)
Tikva et al., 2024 [61]	Educational Games	– Algorithms thinking	Does not apply	Case study	aMazeD	57 secondary school students

Gamification integrates elements of the game into non-game contexts to enhance engagement and motivation [62] [63] [64] [65]. Serious games are digital games designed for educational purposes beyond entertainment, such as education, training, and skill acquisition [66] [67] [68]. Both, gamification and serious games are implemented through web and mobile applications to evaluate the impact of augmented reality using applications developed in Unity.

Finally, collaborative learning involves groups working together to solve problems or learn new concepts [69].

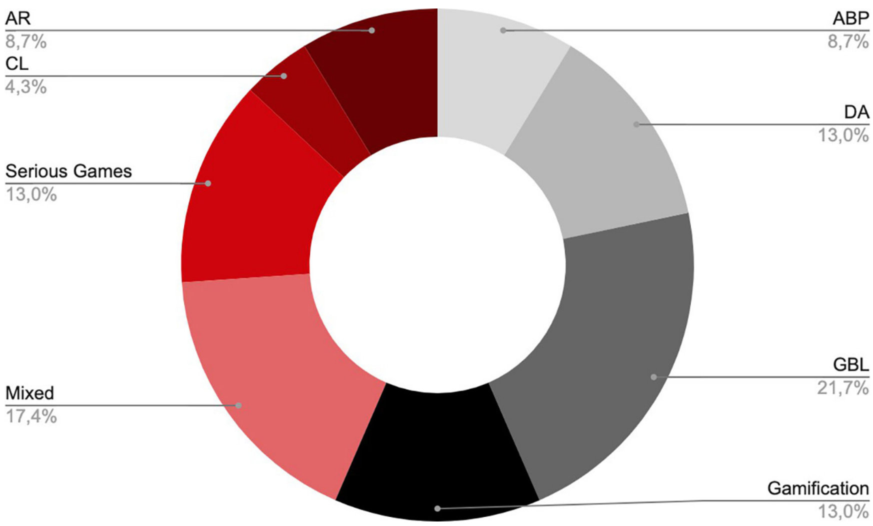

Fig. 9. Papers selected for RQ1 grouped according to teaching and learning strategies

Regarding learning styles, only one study [45] addresses this aspect by incorporating CT and project-based learning (PBL) without a formal model. Additionally, recent research has explored the use of ChatGPT in education, particularly in programming, where it provides automated code generation and scaffolding for CT. In [70] was found that while students had positive attitudes toward ChatGPT-based scaffolding, it improved CT however not problem-solving skills, suggesting more targeted strategies to enhance both aspects in intelligent learning systems.

Moreover, it is essential to highlight the importance of paying greater attention to this aspect in educational research. Understanding learning styles can provide valuable insights to improve the effectiveness of pedagogical strategies and the design of learning environments [71].

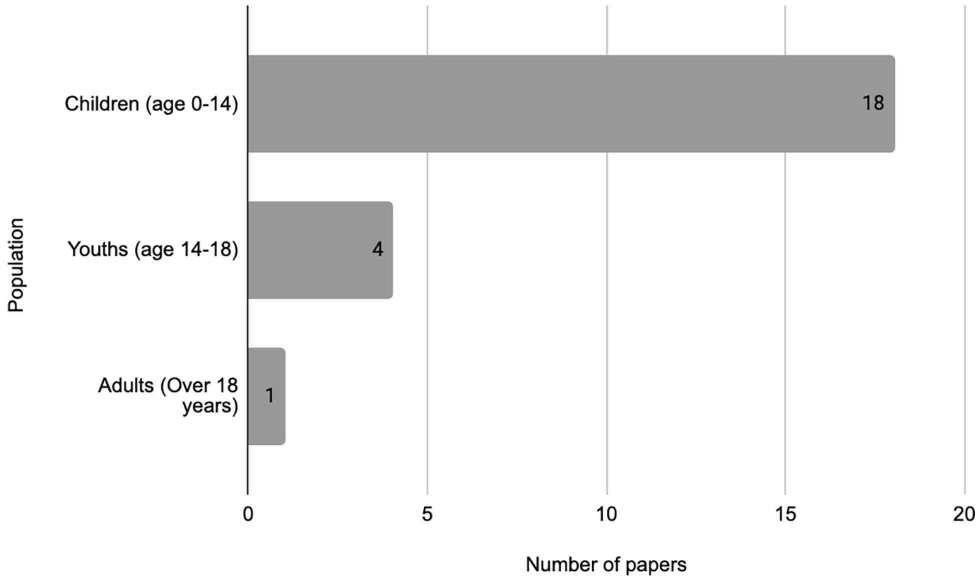

Fig. 10. Papers selected for RQ1 by population type

Besides, it is important to note that efforts to promote CT skills have mainly focused on primary and secondary education, targeting children aged 0 to 14 and adolescents aged 14 to 18, as shown in Figure 10. However, the absence of efforts to train adults, especially teachers, in these skills is notable. Educator training has largely centered on attending specific courses or programs to build skills. However, less emphasis has been placed on recognizing and incorporating those skills into daily classroom practice.

Reviewed studies reviewed demonstrate that the skill of algorithmic thinking or algorithm design. Is fundamental within CT because it implies the ability to design and apply steps to solve a problem. Nevertheless, possessing this skill alone, without abstraction and decomposition, can lead to difficulties in addressing more complex problem-solving tasks.

3.2 Assessment methods (RQ2)

Figure 11 and Table 4 shown the methods used to assess CT skills. Among these, questionnaires designed explicitly for CT assessment are prominent. In particular, Marcos Román multiple-choose questionnaire in 2015 [72] is a notable example test, designed for students aged 12–13, it measures CT aptitude through questions on sequence, loops, conditionals, functions, and other programming concepts. The test includes 28 items with a maximum completion time of 45 minutes. Another example is the Bebras Challenge, an international initiative that assesses skills such as abstraction, algorithmic thinking, decomposition, evaluation, and pattern recognition through diagnostic tests. It is also used to determine CT skills in children and young people.

It is essential to note the need for more consensus on the skills and definitions that make up CT. As seen in Table 5, all studies offer different definitions. Some conceptualize CT comprehensively, while others include a variety of additional skills such as pattern recognition, evaluation, and algorithm design. The most recurrent CT skills reported in the reviewed studies are abstraction, decomposition, and algorithmic thinking. However, the diversity of approaches can affect the interpretation of the results and make comparing studies difficult.

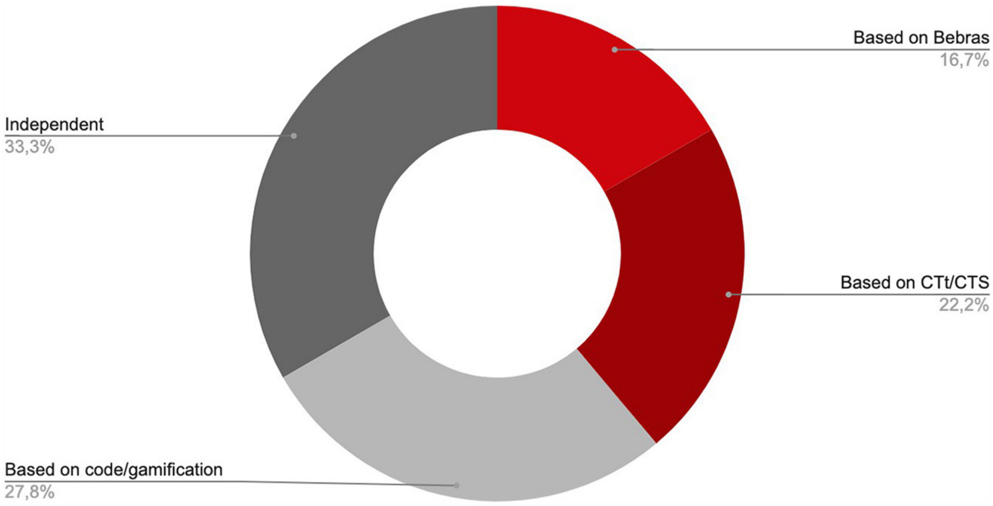

Fig. 11. Papers selected for RQ2 grouped according to assessment strategies

Table 4. Selected papers on strategies, methods and activities to assessment CT skills

Art	Strategy Used	Skills Assessed	Short Description	Type	Technology (Analog, Digital or Mixed)	Population
Guggemos et al., 2023 [73]	CTt and CTS (self-appraisal) questionnaires	– Critical thinking – Cooperativeness – Algorithmic thinking	Questionnaire containing 29 questions to evaluate and self-assess CT	Assessment	Analog	202 high school students from Switzerland and 90 minutes for the test
Muñoz et al., 2022 [74]	Gamification	– Algorithmic thinking	Platform to manage learning activities and evaluation for CT development	Design and implementation process of a tool for CT evaluation	Digital	71 students: 36 fourth grade, 19 fifth and 16 sixth grade age range between 9 and 13 years
Chen et al., 2022 [75]	GBL	– Abstraction – Decomposition – Simulation – Generalization – Algorithms – Assessment	Game design using Bebras	Methodology	Digital	Does not apply

(Continued)

Table 4. Selected papers on strategies, methods and activities to assessment CT skills *(Continued)*

Art	Strategy Used	Skills Assessed	Short Description	Type	Technology (Analog, Digital or Mixed)	Population
Wong et al., 2020 [76]	GBL	– Abstraction – Decomposition – Algorithms	Development of an evaluation framework	Frame	Digital	Does not apply
Lehtimaki et al., 2022 [77]	Bebras	– Abstraction – Decomposition – Assessment – Algorithmic thinking	Module to be completed in 24 hours	Module	Digital	Young people from 15 to 16 years old
Kircali et al., 2023 [78]	Programming	– Algorithmic thinking	Use of tools with connected and disconnected activities	Case study	Digital	109 6th grade high school students
Hijon-Neira et al., 2023 [79]	Visual programming (Scratch), text programming (Java) and IA	– Algorithmic thinking	– A visual environment that uses Scratch and Java to teach programming concepts and improve CT	Model	Digital	23 secondary school teaching students at two universities, one in Spain, and in Galway Ireland
M. Zapata, et al., 2020 [80]	BCTt	– Algorithmic thinking: loops and conditionals	Questionnaire containing 25 items to evaluated in 40 minutes with three response alternatives	Assessment	Digital	299 children between 5 and 12 from a Spain primary school
Yin, et al., 2020 [81]	Design of maker activities and formative evaluation strategies	– Abstraction – Decomposition – Algorithmic thinking – Pattern generalization	Improve and evaluate CT in the integration of STEM areas, through maker activities integrated with physics and engineering	Case study	Digital	16 1st year and 16 second year high school students
Rowe, et al., 2021 [82]	GBL	– Abstraction – Decomposition – Pattern recognition – Algorithm design	Behavior and activity detectors are created within the Zoombinis game that allow measuring implicit learning	Case study	Digital	797 students in grades 3 to 8
Chan, et al., 2020 [83]	CTt	CT	Provide a reference case for scholars and researchers in assessing CT skills among students	Case study	Digital	153 Grade 9 and 10 secondary school students from 4 Singapore schools aged 15–16
Srael, et al., 2022 [84]	Learning Analytics	– Algorithmic thinking	It proposes an assessment based on four key variables using data from the online platform (Kodetu). Providing a richer formative assessment	Case study	Digital	189 secondary school students

(Continued)

Table 4. Selected papers on strategies, methods and activities to assessment CT skills *(Continued)*

Art	Strategy Used	Skills Assessed	Short Description	Type	Technology (Analog, Digital or Mixed)	Population
Bubica, et al., 2022 [85]	evidence-centered design approach	– Abstraction – Decomposition – Algorithmic thinking	Model to assess abstraction and algorithmic thinking regardless of prior experience with programming languages and the student's gender	Model	Digital	407 students aged 12 from 10 secondary schools
Huang, et al., 2022 [86]	Bebras	– Abstraction – Decomposition – Pattern recognition – Algorithmic design – Generalization	Programming with Scratch. Key findings indicate that students significantly improved their CT skills at the end of the course	Case study	Digital	101 secondary school students
Tsai, et al., 2021 [87]	CTS	– Abstraction – Decomposition – Algorithmic thinking – Evaluation – Generalization	The 19-item CTS has good item reliability, internal consistency, and construct reliability for measuring CT	Scala	Digital	472 secondary school students
Lai, et al., 2021 [88]	CT Challenge	– Abstraction – Decomposition – Algorithmic thinking – Generalization – Depuration	The study demonstrated the feasibility of extending traditional assessment methods to integrate multiple contexts, problem types, and item formats to measure CT proficiency in a comprehensive manner	Method	Digital	119 students from British senior secondary schools
Monteyne et al., 2025 [89]	Framework of Fraillon et al. 2023	– Abstraction – Decomposition – Pattern recognition – Generalization – Algorithms – Modeling – Testing and debugging	Questionnaire containing 16 items	Instrument	Digital	352 secondaries. schools teachers grade 7 and 8
Kastner-Hauler et al., 2024 [90]	Bebras	– Abstraction – Decomposition – Pattern recognition – Algorithms – Evaluation and debugging	Case study	Learning environment	Digital	240 students between 10 and 14 years old (grades 5th to 8th)

Therefore, reviewed studies suggest that CT skills in secondary education can be assessed through various methods, including selected-response questionnaires, performance- based tasks, and programming-based challenges, focusing on skills such as algorithmic thinking.

Table 5. Definitions of core CT Skills

Art	Skills CT		
	Abstraction	Decomposition	Algorithmic Thinking
Cheng et al., 2023 [41]	Generate abstraction patterns according to several regular and repetitive rules	Decomposition of the original problem to be solved into several subproblems	Design an algorithm to loop through each generated abstraction pattern and follow the established procedure to achieve the solution for that objective
Olmo-Muñoz et al., 2023 [37]	Simplifying complex problems involve identifying crucial aspects and ignoring unimportant details. Helps students focus on the main elements of a problem, making it more understandable and accessible	This skill involves breaking complex problems into smaller and more manageable parts. By breaking down a problem into its components, students can address each. Part separately, ultimately making the overall problem easier to solve	This skill involves creating clear, step-by-step procedures or algorithms to solve problems systematically. Students learn to break tasks into smaller steps, organize these steps logically, and perform them in the correct order
Z. Qu et al., 2023 [36]	Does not apply	Does not apply	Design algorithms to form solutions to problems
Zitouniatis et al., 2023 [44]	Does not apply	Does not apply	Computational expression, coding and problem solving
Asbell-Clarke et al., 2021 [50]	It involves generalizing from observed patterns and establishing general rules or classifications about objects, tasks, or information by discerning relevant information	It consists of reducing the complexity of a problem by dividing it into smaller, more manageable parts	It consists of establishing reusable procedures that solve sets of problems
Theodoropoulos et al., 2022 [51]	Generalize and identify general principles that produce patterns	Break complex data and problems into smaller parts	Develop a solution step by step (instructions)

3.3 Impact of COVID-19 on CT Teaching and Assessment (2020–2023)

The COVID-19 pandemic (2020–2023) profoundly disrupted educational systems worldwide, forcing a rapid transition from face-to-face to remote and hybrid learning environments. This shift accelerated the integration of digital tools and online platforms in secondary education. It also exposed significant challenges, such as the digital divide, unequal access to devices and connectivity, and the need for teachers to adapt their pedagogical practices quickly [91] [92]. Assessment practices also changed, with online quizzes, digital portfolios, and project-based evaluations replacing traditional in-person tests. However, these adaptations raised concerns about validity, reliability, and equity, especially for students with limited internet access [91] [94].

Despite these challenges, the crisis stimulated pedagogical innovation. Teachers adopted game-based and unplugged activities, online coding communities, and collaborative projects to maintain student engagement and promote CT skills [92] [95]. The experience underscored the importance of teacher professional development in digital pedagogy and, the critical need for robust, equitable assessment strategies in the face of the pandemic.

Besides, recent studies demonstrate that integrating real-world problems, such as modeling pandemics, into CT instruction is feasible and effective for developing students problem-solving and analytical skills [92]. Addressing the digital divide and investing in teacher training are essential to ensure resilient and inclusive CT education.

3.4 Implications for engineering education pedagogy

The integration of CT into engineering education is increasingly acknowledged as essential for preparing students to tackle complex, real-world challenges in a digital society. CT skills such as abstraction, decomposition, and algorithmic thinking are foundational for problem-solving and innovation in engineering, enabling students to design, analyze, and optimize systems across diverse domains [106]. Active learning strategies, including project-based learning, inquiry-based learning, and problem-based learning, have proven effective in fostering CT among engineering students [108]. These approaches allow learners to apply CT concepts to real-life contexts, enhancing not only their computational proficiency but also critical thinking, creativity, and collaboration [101]. Additionally, integrating CT into core subjects like mathematics and science, as well as through extracurricular and unplugged activities, supports engagement and accessibility, particularly for underrepresented groups [100].

Successful CT integration also relies on well-prepared faculty. Therefore, continuous professional development is essential to prepare educators with the technical skills and pedagogical approaches needed to create effective CT learning experiences [109]. However, recent studies emphasize a shortage of standardized tools for assessing CT in engineering contexts [107] [110]. Robust, validated assessment frameworks such as authentic performance tasks and mixed-methods evaluations are needed to accurately monitor students CT development. Ultimately, integrating CT into engineering education enhances students' technical, analytical, and collaborative skills, promotes educational equity, and prepares future engineers to meet the evolving demands of the 21st-century workforce. Continued research, curricular innovation, and faculty development are critical to optimizing this integration.

3.5 Critical analysis and synthesis of findings

The effectiveness of CT teaching strategies varies significantly depending on contextual factors such as gender, socio-economic status, and teacher expertise. While approaches like project-based learning, educational, game-based activities are generally effective in enhancing CT skills, their impact is not uniform across all student populations or educational settings. Persistent gender gaps remain in STEM and CT fields, with studies showing that girls often have lower CT performance and self-perception compared to boys, influenced by factors such as lack of female role models and enduring stereotypes [79]. Socio-economic disparities also play a crucial role; students from higher-income backgrounds or schools with better resources tend to have greater access to technology and more opportunities to engage in CT activities, leading to better outcomes [111]. Teacher expertise is another critical factor, as countries investing in continuous professional development for educators have achieved greater progress in integrating CT into curricula [106].

International comparisons reveal that the local curricula, policy frameworks, and cultural factors shape the success of CT strategies. For example, nations like Austria, Denmark, and Hungary emphasize logical thinking and problem-solving, while Finland and Turkey balance process-based and skill-based learning goals [106]. Methodologically, research in this area is diverse, employing quantitative, qualitative, and mixed methods approaches to evaluate the effects of teaching strategies. This underscores the complexity of CT education and the need for adaptable, context-sensitive interventions. Overall, these findings highlight the importance of inclusive policies, targeted teacher training, and ongoing research to address equity and maximize the impact of CT education across different educational systems [79] [106].

4 CONCLUSION

This systematic review analyzed 47 papers to identify the most used methods, strategies, and activities for teaching, learning, and assessing CT skills in secondary education. Key skills addressed decomposition, abstraction, and algorithm thinking. The review highlights strategies such as GBL, disconnected activities, and gamification, proving effective in promoting abstract thinking, problem-solving, and logical reasoning. Also, it is observed that CT enhances cooperation, creativity, collaboration, and communication across disciplines and educational levels through programming.

Nonetheless, the review reveals a major gap in the standardization of CT skill definitions, which complicates efforts to assess them effectively in both students and educators. Therefore, establishing, validated assessment tools and standardized frameworks is essential to evaluate CT competencies and improve educator preparation comprehensively.

Despite growing international consensus on the importance of CT and the positive impact of innovative strategies, the effectiveness of these approaches is shaped by contextual factors such as gender, socio-economic status, and teacher expertise. Moreover, policymakers should implement inclusive policies that ensure equitable access to CT education and integrate CT across subjects, while teacher education programs must emphasize both, CT concepts and adaptable pedagogical methods. Also, a significant gap persists in CT training for adult learners and in-service teachers. Thus, future initiatives should prioritize flexible, modular training and leverage blended and online learning to facilitate lifelong upskilling. Further research is needed to develop robust assessment instruments, examine the long-term impact of CT interventions, and explore scalable models for integrating CT into adult and teacher education. Advancing CT education will require coordinated efforts among policymakers, educators, and researchers to ensure all learners, regardless of background, can acquire essential computational skills for the digital age.

4.1 Challenges

This review suggests that the key challenges in education and technology should prioritize the promotion and assessment of CT skills, particularly within K–12 contexts. Some studies suggest that CT skills should include human-computer interaction. Teacher development programs should emphasize the importance of understanding CT concepts and actively creating and assessing practical learning activities. This hands-on approach will engage educators and ensure that the research directly applies to their teaching.

Additionally, incorporating classroom observations into research will offer insights into the real-world impact of these programs and help to refine practical tools for integrating CT across various subjects. Research should also establish standardized definitions and instruments for assessing CT skills. Moreover, investigating the long-term outcomes of CT education on students' academic and career success is equally important, as this will guide our future planning and evaluation.

4.2 Future research lines

Grounded in the challenges highlighted throughout this review, future research should advance the integration of CT in secondary education through theoretically robust and contextually grounded approaches. Moreover, emphasis should be placed on investigating pedagogical models that promote conceptual understanding of CT, including dimensions such as human-computer interaction and predictive reasoning, and facilitate the design and evaluation of authentic learning experiences. Besides, the professional development of teachers will be critical, especially in fostering their capacity to implement and assess CT within diverse disciplinary contexts. Incorporating empirical studies in classroom environments will yield valuable insights into CT-focused interventions practical implementation and efficacy. These efforts should contribute to establishing consistent theoretical frameworks, validated assessment tools, and long-term perspectives on the impact of CT education on students' academic trajectories and future competencies. Finally, addressing these gaps through validated assessment tools, scalable models for CT integration in adult and teacher education, and research into long-term impacts will help ensure that all learners are equipped with the computational skills necessary for success in the digital age.

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7 APPENDIX A. PRISMA 2020 CHECKLIST

Section and Topic	Checklist Item	Location Where Item is Reported
Title	**1.** Identify the report as a systematic review.	Title page
Abstract	**2.** Provide a structured abstract with objectives, data sources, methods, results.	Abstract
Introduction	**3.** Describe the rationale and context for the review.	Introduction (Section 1)
	4. State the review’s objectives/research questions.	End of introduction (Section 1)
Methods	**5.** Specify eligibility criteria (inclusion/exclusion).	Methodology (Section 2)
	6. List all databases, registers, websites searched.	Methodology (Section 2)
	7. Provide search strategy (full search queries).	Methodology (Section 2)
	8. Describe selection process (screening, eligibility).	Methodology (Section 2), Figure 1 and Figure 6
	9. Describe data collection process.	Methodology (Section 2)
	10. List and define data items (variables).	Methodology (Section 2)
	11. Assess risk of bias in individual studies.	Methodology (Section 2)
	12. Specify methods for handling effect measures.	Not applicable (qualitative synthesis)
	13. Describe synthesis methods.	Methodology (Section 2)
	14. Assess reporting bias.	Not applicable
	15. Assess certainty of evidence.	Not applicable

(Continued)

Section and Topic	Checklist Item	Location Where Item is Reported
Results	**16.** Present results of study selection (PRISMA flow diagram).	Methodology (Section 2), Figure 6
	17. Present characteristics of included studies.	Results (Section 3), Table 2 and Table 3
	18. Present risk of bias assessment results.	Results (Section 3)
	19. Present results of syntheses (themes, patterns).	Results (Section 3)
	20. Present reporting biases.	Not applicable
	21. Present certainty of evidence.	Not applicable
Discussion	**22.** Interpret results in context of objectives and existing knowledge.	Conclusion (Section 4)
	23. Discuss limitations of the review.	Conclusion (Section 4)
Other information	**24.** Provide registration and protocol details.	Methodology (Section 2)
	25. Describe sources of funding.	Acknowledgments (Section 5)
	26. Declare conflicts of interest.	Acknowledgments (Section 5)
	27. Provide data/code availability statement.	Methodology (Section 2)

8 AUTHORS

Leidy Carvajal-Ortiz is a PhD candidate in Computer Science at Universidad del Valle, where she also serves as a part time lecturer. She graduated from the same university with a degree in Systems Engineering and a Masters degree with an emphasis in Systems and Computer Engineering. Her doctoral research focuses on software development, computational thinking, and gamification in adults (E-mail: leidy.carvajal.o@correounivalle.edu.co).

Deisy Chaves is Professor at Universidad del Valle. She holds a PhD in Computer Vision from the University of London, United Kingdom; a Masters degree in Statistics from Colegio de Postgraduados, Mexico; and an undergraduate degree in Statistics from Universidad del Valle. She has participated in several research projects where the input data are images. Her scientific production and supervision of human resources classify her as a Senior Researcher recognized by Minciencias (E-mail: deisy.chaves@correounivalle.edu.co).

María Trujillo is Professor at Universidad del Valle. She holds a PhD in Computer Vision from the University of London, United Kingdom; a Masters degree in Statistics from Colegio de Postgraduados, Mexico; and an undergraduate degree in Statistics from Universidad del Valle. She has participated in several research projects where the input data are images. Her scientific production and supervision of human resources classify her as a Senior Researcher recognized by Minciencias (E-mail: maria.trujillo@correounivalle.edu.co).