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Computational thinking in solving mathematical problems in secondary education

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Abstract

Advances in mathematical problem-solving still face pedagogical limitations in implementing computational thinking. Therefore, this study analyzed the influence of computational thinking on mathematical problem-solving in secondary school. A review of methods revealed difficulties associated with rotated memorization and a weak connection between routine and complex skills. A mixed-methods approach was adopted, combining a qualitative literature review with a quantitative phase. Articles published between 2015 and 2025 were identified using the Pearl Growing technique and the PRISMA 2025 guidelines. Relationships between terms were examined using VOSviewer 1.6.20, and constructs of computational thinking and its dimensions were defined. Based on this, two 23-item questionnaires were designed, one on computational thinking and the other on mathematical problem-solving. Both instruments used a 5-point Likert scale and were validated by five experts. Content validity was assessed using Aiken's V coefficient, yielding a result of 0.96. Mathematics teachers from Medellín and Valle de Aburrá, Antioquia, participated in the quantitative phase. Data was analyzed using SmartPLS 4.1.1.4 to estimate the formative structural model. The results confirmed theoretically supported hypotheses and showed high explanatory power, especially in problem-solving with computational tools and, to a lesser extent, without computational tools. Furthermore, abstraction, decomposition, algorithmic design, and pattern recognition showed significant effects on problem-solving. Taken together, the findings support the robustness and predictive power of the model, with better performance on problems mediated by computational tools, but also demonstrating that computational thinking skills influence the resolution of mathematical problems in secondary education without computational tools.

Keywords: computational thinking, mathematical problem-solving, PLS-SEM structural equation modeling

INTRODUCTION

The low levels of students in solving mathematical problems, related to the design of didactic activities that require them to repeat and memorize, instead of thinking and implementing logical reasoning skills (Cuesta, 2025; Panta & Antón, 2025), in addition to the lack of training of teachers in the implementation of active methodologies that link technological tools that promote analysis and understanding for solving mathematical problems (Calle et al., 2025; Ureta & Valencia, 2025), has led to an investigation of how these innovative strategies can contribute to the resolution of mathematical problems when implemented by teachers in the design of didactic activities. Several studies have shown that problem-solving (PC) constitutes a central axis for the development of mathematical connections and meaningful learning. Along these lines, Rodríguez-Nieto et al. (2025) demonstrate the potential of ethnomathematical approaches and mathematical connections to promote meaningful learning in future teachers when solving contextualized problems related to brickmaking. Complementarily, Rodríguez-Nieto and Moll (2025) analyze the mathematical connections

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Contribution to the literature

- The novelty of this study lies in exploring, through theory and in contrast with the empirical results of the structural equation model, the dimensions of CT that positively influence mathematical PC, according to teachers' perceptions.
- Based on the findings, perspectives are offered for the design of methods that contribute to the teaching process for mathematical PC, addressing a gap identified in the literature and practice regarding methods that enable students to improve their mathematical PC skills.
- Thus, this study comprises a theoretical section to define the current state of the topic, a methodological section with the characterization of the questionnaire, the sample, the findings section, and the discussions with the analysis of the validation of the hypotheses. Finally, future recommendations and theoretical implications are addressed.

mobilized in multivariable calculus classes and in solving problems involving vectors and partial derivatives, highlighting the importance of articulating representations and meanings. Likewise, the study by Rodríguez Nieto et al. (2023) shows how combining the extended theory of connections and the onto-semiotic approach allows for a deeper understanding of the relationships between mathematical objects when analyzing the graphs of f and f'. Finally, Santos-Trigo (2024) underscores that PC remains a central field of research, with new trends focused on integrating practice, modeling, and the use of technological tools. These contributions support the need for further research into how computational thinking (CT) can enrich PC processes in mathematics. Based on research conducted by Mullo et al. (2025) and supported by the perceptions of 170 secondary school mathematics teachers, CT is considered an innovative strategy for enhancing logical reasoning and for carrying out computer-based and non-computer-based activities for solving mathematical problems. A review of the literature establishes that the fundamental CT skills common to mathematics for PC include problem decomposition, pattern recognition, abstraction, and algorithm design (Lehmann, 2025; Mulyono et al., 2024; Wu et al., 2024).

Although studies have established different methods for developing PC skills (Polya, 1945; Schoenfeld, 1992), difficulties with PC skills continue to be observed among secondary school students (Alonso, 2021). This difficulty stems from the PC methods implemented by teachers, which can lead to inconsistent results regarding the problem posed, difficulties in identifying the process to follow in PC, and a lack of regulation of the skills necessary for PC (Silva Triana, 2024). Thus, difficulties in determining the path to solving the problem and a lack of skills prevent students from interpreting the problem situation, identifying the relationships between the question and the data, and finding the appropriate method to solve the problem.

Given that there are studies that focus on explaining processes of how to implement computer programming for the acquisition of mathematical knowledge and develop computer programming skills through programming processes (Ersozlu et al., 2023), using computational tools (Cui & Ng, 2021; Kallia et al., 2021) or without computational tools (Relkin & Strawhacker, 2024), the need to use them for teaching mathematics and PC at different educational levels, secondary, university (Cui & Ng, 2021; Ersozlu et al., 2023; Navas, 2024; Ye et al., 2023), is highlighted at the same time.

LITERATURE REVIEW

Computational Thinking

CT is defined as a way of thinking that involves formulating and decomposing problems, structuring and communicating solutions in such a way that they can be understood by humans and processed by machines (Waterman et al., 2020). It is worth noting that in the 1960s and 70s, CT was called the procedural thinking approach (Papert, 1980), which aimed to enhance students' cognitive skills (Huerta & Velasquez, 2021). This approach was revisited by Wing (2006), who, based on his studies, named it CT and sought to integrate it into the curriculum.

Currently, factors related to CT play an important and fundamental role in educational development (Zhang & Nouri, 2019). This contrasts with the fact that theory suggests their implementation in areas such as computer science, science, and mathematics through skills such as problem decomposition, pattern recognition, abstraction, and algorithm design (Cui & Ng, 2021; Kallia et al., 2021; Relkin & Strawhacker, 2024; Subramaniam et al., 2022; Wu & Su, 2021; Ye et al., 2023). These factors have also been used both with computational tools (Cui & Ng, 2021; Kallia et al., 2021) and without computational tools (Relkin & Strawhacker, 2024). **Table 1** shows the PC factors and their definitions.

Therefore, the implementation of CT dimensions in mathematics leads to a deeper understanding of the problem, discovering related concepts, as well as much simpler and sequential ways to solve it. This integration of CT into mathematics could favor teaching methods, which are directly involved in the mathematical problem-solving (MPS) process (Vilchez & Ramón,

Table 1. CT related dimensions

Factors	Definition	Supporting bibliography
Problem decomposition	Problem decomposition is defined as the process of separating the complex problem into parts that can be understood and solved more easily.	Lehmann (2025), Maciej (2024), Obando et al. (2024), Ramaila and Shilenge (2023)
Pattern recognition	Mathematical process that allows applying rules, patterns, and sequences in the solution of the problem, in addition, it includes identifying similarities in any complex or simplified problem.	Lehmann (2025), Maciej (2024), Ramaila and Shilenge (2023)
Abstraction	Ability to focus on essential aspects of the problem without considering irrelevant elements, thus making it possible to filter relevant elements and parts of a problem, and eliminating unnecessary parts to understand what it is about to solve.	Avello et al. (2020), Lehmann (2025), Maciej (2024), Obando et al. (2024), Ramaila and Shilenge (2023)
Algorithm design	Clear, precise mathematical procedures, sequence instructions for solving the problem.	Alonso (2021), Lehmann (2025), Maciej (2024), Pérez (2025)
Problem decomposition	Problem decomposition is defined as the process of separating the complex problem into parts that can be understood and solved more easily.	Lehmann (2025), Maciej (2024), Obando et al. (2024), Ramaila and Shilenge (2023)

Table 2. Computer-free and computer-based PC methods

PC methods	Definition	Supporting bibliography
Computer-free tools	It is the heuristic that constantly requests a series of metacognitive steps and processes that lead the student to evaluate their resolution strategy and the skills they implement to define in a timely manner if there is another process that makes a faster and more effective solution possible.	Carrillo et al. (2022), Diaz and Caballero (2020), Silva (2020)
Computer-based tools	It is the heuristic that requires the development of a series of steps that involve thinking skills and implementation of software for PC.	Cabra and Ramírez (2022), Molina et al. (2022)

2024). In addition, using CT for MPS can lead people to structure their thinking based on the simplest foundations, such as serialization, order, classification, grouping, patterns. At the same time, it would enable developing mathematical skills, interpret, identify, recode, calculate, algorithmize, graph, define, and demonstrate (Argoti, 2024).

Problem-Solving

PC is conceived as a process that allows students to gain confidence in using mathematics, increasing their ability to communicate mathematically and developing their skills (Carrillo et al., 2022; MEN, 1998). Throughout history, various PC methods have been implemented for solving mathematical problems, including non-computer-based methods such as the Polya (1945) method and the Schoenfeld (1992) method, as well as methods using computational tools. **Table 2** lists these PC methods and their definitions. Thus, Polya's (1945) method consists of a sequence of steps that initially seeks to understand the problem, leading to the development of a plan, the execution of the plan, and finally, the verification of the solution. It has been implemented as a process that improves the understanding of MPS, enhancing logical thinking and reasoning in secondary school students (Silva Triana, 2024).

Unlike Polya's (1945) method, the process proposed by Schoenfeld (1942) incorporates some of its principles but establishes that the same heuristic structure cannot be applied to all problems. It is necessary, within its dimensions, to continuously develop metacognition to allow students to establish general strategies that may be useful in solving mathematical problems (Diaz & Caballero, 2020).

Influence of Computational Thinking on Solving Mathematical Problems

Abstraction, pattern recognition, algorithm design, and problem decomposition, as skills related to CT and described by Maciej (2024), have implicitly and operationally influenced the PC process in areas such as computer science and mathematics (Argoti, 2024; Vilchez & Ramón, 2024). In this way, abstraction has been implemented in PC without computational tools, making it possible to select the relevant elements and parts of a problem, eliminating the unnecessary and allowing for a greater understanding of the problem to be solved (Lehmann, 2025). It can also be considered the process of mentally separating data and phenomena, isolating the essential qualities within them (Alonso, 2021). Abstraction promotes the understanding of problems through their segmentation, leading to the recognition of relevant elements that, when related, result in a solution. Thus, the following hypothesis is proposed in an exploratory manner.

H1. Abstraction influences computer-free MPS.

Abstraction is fundamental in the process of analyzing key elements that make up pseudocodes and algorithm design when solving problems using computational tools. From the programming software and conditions of the problem, it is sought to establish key procedures and structures that, when properly related, make it possible to solve the posed situation (Avello et al., 2020; Obando et al., 2024). Abstraction acquires relevance in analysis and synthesis processes; it is important for associating computational and mathematical elements in the computational algorithmizing process (Alonso, 2021). Therefore, it is proposed that:

H2. Abstraction influences computer-based MPS.

Pattern recognition makes it possible to identify trends and repetitions common within PC. It enables ordering mathematical processes by finding sequences that guide students to establish connections between similar problems and experiences (Ramaila & Shilenge, 2023). Pattern recognition allows recognizing identical data, characteristics or conditions that are sequentially replicated in PC. Thus, it is proposed that:

H3. Pattern recognition influences computer-free MPS.

Pattern recognition also helps identify sequences of algorithms and regularities of data, process them, and classify them according to the programming language used. When implemented in an orderly and logical way, it makes it possible to solve problems (Lehmann et al., 2025). Pattern recognition enables sequential construction of programming by previously establishing generic patterns or structures that make it up in an orderly manner. Therefore, it is proposed that:

H4. Pattern recognition influences computer-based MPS.

Algorithm design is evidenced when the student develops a sequential and organized process to solve a problem (Maciej, 2024). The process of designing mathematical structures, from simple to complex processes, leads to identifying the problem, developing an understandable solution, writing the situation in mathematical language, and finally optimizing it as necessary (Pérez, 2025). The constant practice of this procedure can lead to reusing previously developed algorithm designs to articulate them with solutions to various problems. Thus, it could be considered that:

H5. Algorithm design influences computer-free MPS.

In addition, algorithm design involves following a series of steps in a programming language, namely:

(1) analyzing the problem, which leads to understanding it, identifying data, and sequences to solve it,

(2) designing the algorithm by establishing sequences, and order of the operations to be carried out,

(3) establishing the relationships between the previously planned procedures that contain relevant data to the problem, and finally,

(4) testing and validating results to verify them, make improvements and adjustments if necessary.

To carry out each step, skills such as interpreting, comparing, identifying, defining, graphing, hierarchically structuring, validating, and optimizing are required. When intertwined and applied correctly and effectively, they can lead to the optimal resolution of the problem (Alonso, 2021). Therefore, it is hypothesized:

H6. Algorithm design influences computer-based MPS.

Problem decomposition appears in PC when the student formulates a sequential strategy by separating the initial problem into simpler parts (Maciej, 2024). Considering the problem as a whole with the intention of understanding it involves separating it into parts to examine it and, at the same time, find a solution. This process is evident when parts of the proposed situation are analyzed in a global and particular way in order to recognize the elements, their relationship, and procedures to solve the problem. Therefore, it is proposed that:

H7. Problem decomposition influences computer-free MPS.

Moreover, decomposition is integrated into PC because it allows students to form more simplified problems, which can be understood, evaluated, and combined to obtain the solution to the initial problem (Lehmann et al., 2025). Problem decomposition allows understanding it, identifying relevant parts, and developing a plan to solve it using computational tools. Hence:

H8. Problem decomposition influences computer-based MPS.

Based on the proposed definitions that relate CT to computer-free MPS, the hypothetical approach is presented below (see **Figure 1**).

In formative models, indicators cause or form the construct, rather than being reflected as in reflective models. In this sense, abstraction (AB), pattern recognition (PR), algorithm design (AD), and problem decomposition (PD) dimensions behave as components that form the CT construct. Similarly, computer free and computer based MPS are built from distinct processes, not necessarily correlated, but together they define the PC competence.

Thus, the model was thought of with formative constructs because theoretically defined dimensions abstraction, pattern recognition, problem decomposition

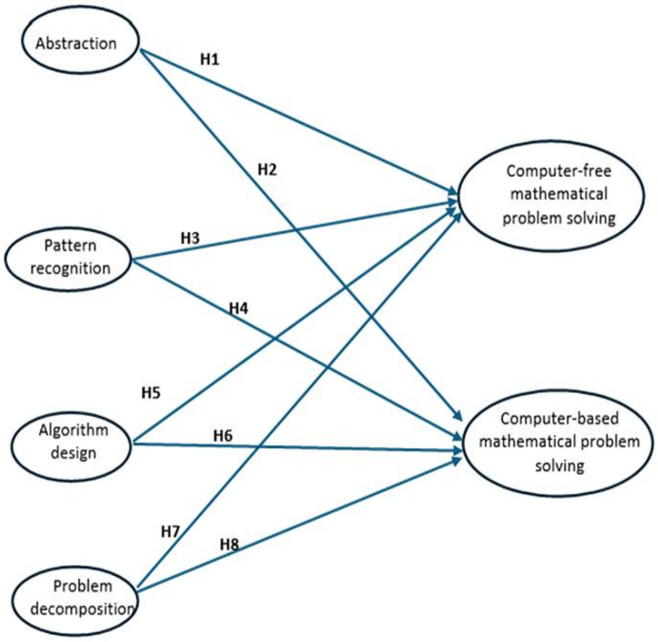

Figure 1. CT influence on computer-free and computer based mathematical PC–Hypotheses proposal (Source: Authors' own elaboration)

and algorithm design make up the CT construct. This training specification conforms to the guidelines of (Hair et al., 2022), who propose that training models are appropriate when the indicators determine the construct and are not necessarily correlated, as confirmed by multicollinearity VIF values.

METHODOLOGY

This study employed a mixed qualitative and quantitative methodology, beginning with a literature review to develop a tool for measuring the constructs. Two questionnaires were designed: one with 17 items for PC and another with 6 items for RPM, both using a 5-point Likert scale. The qualitative phase of the research involved documentary and content analysis. For the document analysis, a search query was created following the Pearl growing citation technique (Hadfield, 2020), using Scopus between 2015 and 2025. This query yielded 582 records:

("computational thinking" OR "computational skills" OR "computational problem-solving" OR "computational thinking problem-solving skills" OR "dimensions of computational thinking in problem-solving") AND ("mathematical problem-solving" OR "problem-solving in mathematics" OR "math problem-solving" OR "problem-solving") AND ("secondary education" OR "middle school" OR "high school").

The data were then processed using VOSviewer software version 1.6.20 to identify connections and co-occurrence indicators. Subsequently, the titles, abstracts, keywords and methodological approaches focused on the definition of PC and RPM were defined as units of analysis to be filtered using the PRISMA method (Paget et al., 2021), for document filtering and proceeding to content analysis (see **Figure 2**).

Construction of the Measuring Tool

As previously established, to determine the dimensions related to CT and MPS in secondary education, a systematic literature review was conducted. This review identified four dimensions related to CT: problem decomposition, which involves dividing the problem situation into simpler parts, enabling a more

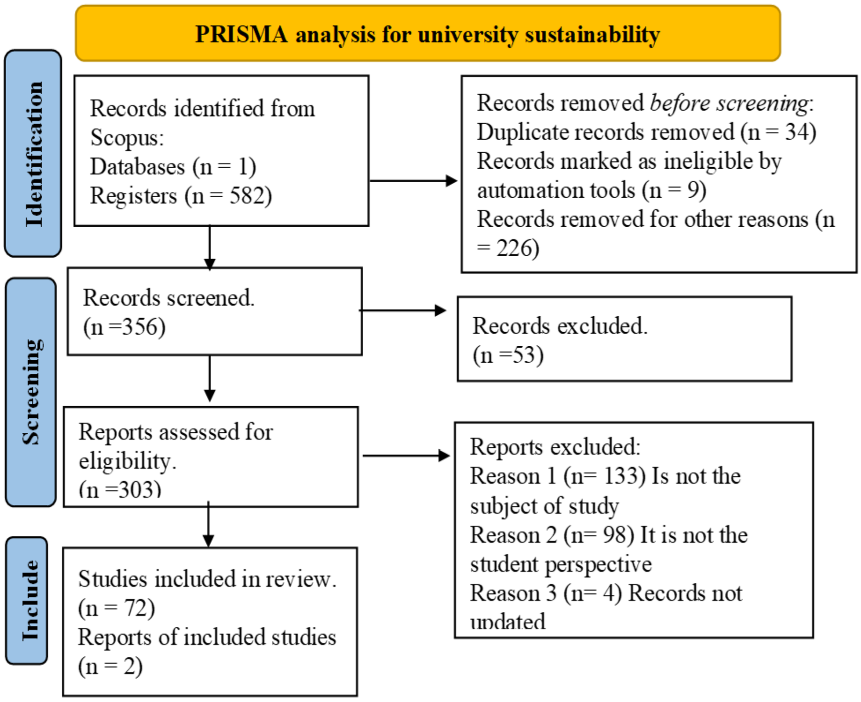

Figure 2. Selection of records PRISMA method 2021 (Source: Authors' own elaboration)

detailed understanding (Lehmann, 2025; Maciej, 2024; Obando et al., 2024; Ramaila & Shilenge, 2023), pattern recognition, where sequences of algorithms are recognized that are repeated within the steps leading to the solution (Lehmann, 2025; Lehmann et al., 2024; Maciej, 2024; Ramaila & Shilenge, 2023), abstraction, which allows delimiting the key mathematical and algorithmic elements within the problem situation, which when synthesized promote the relationship of key elements and in a simplified way of the problem (Avello et al., 2020; Lehmann, 2025; Maciej, 2024; Obando et al., 2024; Ramaila & Shilenge, 2023) and the design of algorithms, which corresponds to a series of steps and procedures that when oriented under a planned, ordered, sequential process, allows relating the patterns and key elements of the problem situation leading to its solution (Alonso, 2021; Lehmann, 2025; Maciej, 2024; Pérez, 2025).

Regarding MPS, a review of the literature reveals two dimensions. The first involves solving problems without the implementation of computational tools, where students implement steps that lead them to understand, develop a solution plan, and execute that plan (Carrillo et al., 2022; Diaz & Caballero, 2020; Oliveros et al., 2021; Silva Triana, 2024). The second dimension involves solving problems with computational tools, where the steps and processes are integrated with the implementation of technologies, software, and simulations that contribute to a different understanding of the problem situation (Ayuso, 2022; Cabra & Ramirez, 2022; Rodriguez et al., 2019).

Following a literature review using search equations, the construct was characterized and its domain established. A battery of questions was then developed for each of the six dimensions addressed in the literature, totaling 23 items, as shown in **Table 3**.

Table 3. Instruments relating CT to mathematical PC in secondary education

Construct	Dimension	Operationalization	Items	Authors
CT	DP	Breaking down problems involves separating a complex situation into parts that can be more easily understood and solved.	DP1. How often does the process where your students separate or break down a mathematical problem into simpler mathematical processes show evidence that they understand it more easily?	Lehmann (2025), Maciej (2024), Obando et al. (2024), Ramaila and Shilenge (2023)
			DP2. How often do math teachers have to explain and re-explain to their students the process of separating or breaking down a math problem into its simplest parts or mathematical processes to enable the solving of math problems?	
			DP3. How often do math students examine each of the component parts of the problem, identifying: characteristics, relationships, classifying them and knowing their functions in solving mathematical problems?	
			DP4. How often do students construct relationships of unknowns and more simplified and meaningful mathematical processes in solving mathematical problems?	
			DP5. How often do students succeed in interpreting the process of solving mathematical problems, assigning mathematical meanings to each of the parts into which it is divided?	
	AB	It allows you to focus on essential aspects of the problem without considering irrelevant elements, making it possible to filter the relevant elements and parts of a problem, eliminating what is unnecessary to understand what is being solved.	AB1. How often do students manage to identify the relevant sequences of operations that enable the resolution of mathematical problems?	Avello et al. (2020), Lehmann (2025), Maciej (2024), Obando et al. (2024), Ramaila and Shilenge (2023)
			AB2. How often do math teachers have to explain and re-explain to their students the processes that allow them to identify the sequences of operations that enable the resolution of mathematical problems?	
			AB3. How often do students manage to recognize the order or hierarchy that enables the resolution of mathematical problems?	
			AB4. How often do students identify mathematical processes and unknowns that, when related, enable the resolution of mathematical problems?	
	DA	These are mathematical procedures, clear and precise sequential instructions for solving the problem.	DA1. How often do students, based on the identification of sequences of operations and procedures, manage to plan the sequential process of solving mathematical problems?	Alonso (2021), Lehmann (2025), Maciej (2024), Pérez (2025)
			DA2. How often do math teachers have to explain and re-explain to their students' methods for designing sequences of operations and procedures that lead to efficient planning for solving math problems?	

Table 3 (Continued). Instruments relating CT to mathematical PC in secondary education

Construct	Dimension	Operationalization	Items	Authors
			DA3. How often do students develop a plan with a hierarchical sequence of mathematical operations for solving mathematical problems?	
			DA4. How often do students, after establishing hierarchical processes involving arithmetic operations, optimally relate them to solve the mathematical problem?	
	RP	Pattern recognition is the mathematical process that allows the application of rules, patterns, and sequences to problem-solving; it also includes identifying similarities in any.	RP1. How often do students manage to identify regularities in the processes when solving mathematical problems?	Lehmann (2025), Lehmann et al. (2024), Maciej (2024), Ramaila and Shilenge (2023)
			RP2. How often do teachers implement different methods to help students identify regularities in the mathematical processes of solving mathematical problems?	
			RP3. How often do students, after identifying common mathematical regularities and structures when solving mathematical problems, demonstrate that their understanding is facilitated?	
			RP4. How often do students, when solving mathematical problems, identify similar parts, processes, or sequences, leading them to subsequently develop general rules that they implement in solving mathematical problems?	
MPS	RPMSC	It is the heuristic that constantly requests a series of metacognitive steps and processes that leads the student to evaluate their problem-solving strategy and the skills they implement, to define in a timely manner if there is another process that enables a faster and more effective solution.	RPMSC1. How often do teachers use sequential and operational methods in teaching and solving mathematical problems, without the use of computational tools?	Carrillo et al. (2022), Diaz and Caballero (2020), Silva (2024)
			RPMSC2. How often do students demonstrate greater understanding in solving mathematical problems when implementing sequential and operational methods without the use of computational tools?	
			RPMSC3. How often do students independently implement sequential and operational methods in solving mathematical problems without the use of computational tools?	
	RPMCC	It is the heuristic that requires within its process the development of a series of steps that involve thinking skills and the implementation of software and hardware for PC.	RPMCC1. How often do teachers use sequential and operational methods in teaching mathematical problem-solving, with the use of computational tools?	Cabra and Ramirez (2022), Molina et al. (2022)
			RPMCC2. How often do students demonstrate greater understanding in solving mathematical problems when implementing sequential and operational methods using computational tools?	
			RPMCC3. How often do students independently implement sequential and operational methods in solving mathematical problems using computational tools?	

Expert Validation and Pilot Test

Once the theoretical review was completed, content validity was established through expert judgment by teachers and researchers with knowledge of CT and MPS, with experience in secondary and university education. The following aspects were evaluated:

(a) neutrality, which assesses whether the items are objective and do not seek to induce subjective responses or analyses;

(b) clarity, which analyzes whether the instrument's items are written in such a way that they comply with syntactic and semantic rules. Furthermore, the way each item is phrased is consistent with the sociocultural context and the characteristics of the sources;

(c) coherence, which verifies whether the instrument's items are related to the objective of the construct being analyzed; and

(d) relevance, which verifies whether the items have a good degree of theoretical and conceptual grounding in accordance with the research (Garrote & del Carmen Rojas, 2015).

The items were analyzed on a scale of 1 to 2, with the selection criterion being statistical modes equal to 1, which is related to the approval of each evaluated criterion. This assertion was empirically verified using

Aiken's V coefficient, which yielded a value of 0.96, indicating a high validity for the instrument (Aiken, 1980). After adjusting the questionnaire based on expert analysis and their approval of the proposed PC and RPM dimensions, the questions were revised to describe each PC dimension in greater detail. Subsequently, a pilot test was conducted with secondary school mathematics teachers from Medellín and the Aburrá Valley in Antioquia, Colombia (n = 30). Their feedback did not lead to any reduction or changes in the questionnaire questions. As a result of this validation process, the final version of the revised questionnaire was obtained.

Sample

The sample size was non-probabilistic and based on convenience sampling, given the accessibility and proximity of the target audience (Otzen & Manterola, 2017). In accordance with the research purpose, the instrument was shared via email only with secondary school mathematics teachers in the City of Medellín and the Aburrá Valley in Antioquia, Colombia. The intention to consider the perceptions of teachers in this specific geographic area stemmed from the fact that the Colombian Ministry of Information and Communication Technologies has implemented it as one of the training centers for computer-based and computer-free CT between 2021 and 2025. Therefore, it was considered relevant to gather the perceptions of mathematics teachers regarding the implementation of CT in MPS. The number of teachers who developed the instrument was determined using G*power V.3.1.9.7 software (Faul et al., 2009; Hair et al., 2017), with the F-test (linear multiple regression: fixed model, R^2, deviation from zero) (Hair et al., 2022; Kock & Hadaya, 2018; Sarstedt et al., 2022). According to the data obtained, the survey was distributed through online platforms such as Google Forms, through which 402 responses were collected from secondary school mathematics teachers in Medellín and the Valle de Aburrá subregion of Antioquia by June 2025. Finally, the empirical model was tested using structural equation modeling with SmartPLS 4.1.1.4 software.

RESULTS

Experts who validated the CT and MPS questionnaires considered that dimensions and the number of items 17 for CT and 6 for MPS were appropriate. They suggested some changes in style, particularly in CT questions. After making the corresponding changes, the pilot test was carried out with (n = 30) mathematics teachers from Medellín, Colombia, and continued with the same number of questions and without major changes in writing.

Table 4. VIF values and weights of training constructs

Constructs	Indicators	VIF	Weight
PD	PD1	1.188	0.255
	PD2	1.071	0.390
	PD3	1.517	0.359
	PD4	1.612	0.205
	PD5	1.275	0.377
AB	AB1	1.147	0.052
	AB2	1.072	0.369
	AB3	1.557	0.495
	AB4	1.447	0.450
AD	AD1	1.421	0.429
	AD2	1.019	0.236
	AD3	1.680	0.373
	AD4	1.558	0.348
PR	PR1	1.139	0.050
	PR2	1.089	0.052
	PR3	1.263	0.007
	PR4	1.260	0.984
CFMPS	CFMPS1	1.220	0.381
	CFMPS2	1.110	0.747
	CFMPS3	1.160	0.172
CBMPS	CBMPS1	1.125	0.001
	CBMPS2	2.730	0.002
	CBMPS3	2.634	1.000

Evaluation of the Measurement Model

Before carrying out the fieldwork, reliability of the training constructs was determined by establishing their collinearity, as shown in **Table 4**. It is expressed through the VIF value, which ranged between 1,019 and 2,730. Having as a reference value < 5, it is concluded that the indicators of the training constructs collinearity do not exceed critical levels and would not hinder the estimation of the training model due to the low correlation between indicators of CT and MPS constructs. Weight values are expressed in **Table 4**, which shows the contribution of each indicator to the construct (Hair et al., 2017).

Evaluation of the Structural Model

To evaluate the structural model, the relationship among constructs was determined by path coefficients; the acceptance or rejection of hypotheses by p-values, which were used to determine significance ($p \leq 0.05$), coefficients of determination (R^2) and adjusted R^2 (see **Figure 3**), in addition to the effect size (f^2), and predictive validity (Q^2) (Hair et al., 2017).

The predictive value of the model has been determined by R^2. Thus, in **Figure 3**, it is evident that 35.7% of the construct variance, computer-free mathematical problem-solving (CFMPS), and 99.6% of the construct variance, computer-based mathematical problem-solving (CBMPS), are explained by exogenous variables related to the CT construct (Hair et al., 2017). The strongest effects on the CFMPS construct were

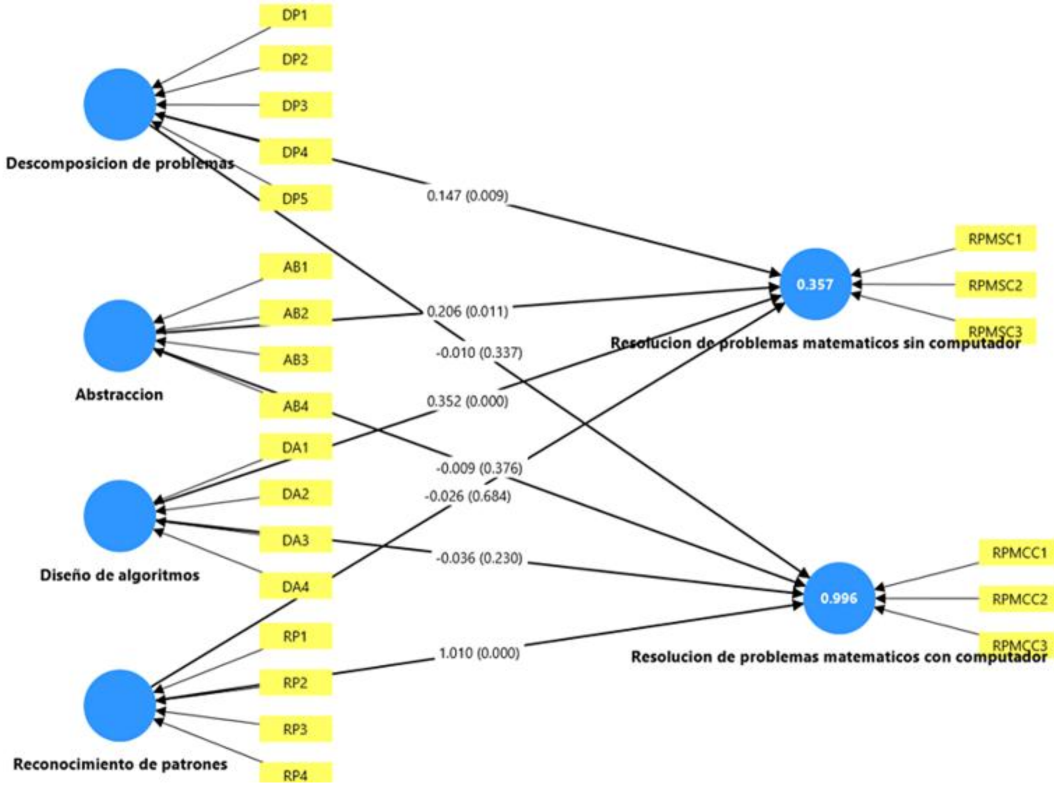

Figure 3. Estimated model of path values (p) between CT and MPS, and R^2 adjusted (Source: Authors' own elaboration)

Table 5. Structural model results

Path coefficients			f^2	H
Relationships	Path	p		
AB --> CFMPS	0.206	0.011	0.034	**H1**
AB --> CBMPS	-0.009	0.376	0.009	**H2**
PR --> CFMPS	-0.029	0.684	0.001	**H3**
PR --> CBMPS	1.000	0.000	0.211	**H4**
AD --> CFMPS	0.350	0.000	0.101	**H5**
AD --> CBMPS	-0.036	0.230	0.155	**H6**
DP --> CFMPS	0.164	0.009	0.022	**H7**
DP --> CBMPS	-0.009	0.337	0.015	**H8**

exerted by predictor variables, algorithm design (AD, 0.352), followed by abstraction (AB, 0.206), and problem decomposition (PD, 0.147). For the CBMPS construct, positive effect corresponded to pattern recognition (PR, 1.0).

To establish the statistical significance with respect to path coefficients and f^2 with respect to the relationships between exogenous and endogenous variables (Hair et al., 2017), a resampling (bootstrapping) was carried out with 10,000 subsamples. Results are shown in **Table 5**. Path coefficients are considered as substantial (≥ 0.75), moderate (≥ 0.50), and weak (≥ 0.25), while f^2 had values of 0.35, 0.15, and 0.02, corresponding to large, medium, and small effects, respectively. From the 97.5% confidence interval, hypotheses with $p \leq 0.05$ are accepted as significant (Hair et al., 2022).

To establish predictive validity, PLS predict was implemented (**Table 6**). The model shows strong global predictive capacity, especially in the computer-based mathematical problem-solving variable (CBMPS), where the indicators ($Q^2 = 0.825$; RMSE = 0.422; MAE = 0.339) show high explanatory power and low prediction deviation. In contrast, the CFMPS variable achieves moderate predictive capacity ($Q^2 = 0.325$) and higher errors (RMSE = 0.826; MAE = 0.629), thus suggesting that the intervention of computational tools enhances the predictive effectiveness of the model and improves PC in educational contexts.

Table 6. Summary of prediction of endogenous variables (PLS predict)

	Q^2 predict	RMSE	MAE
CBMPS	0.825	0.422	0.339
CFMPS	0.325	0.826	0.629

DISCUSSION

The objective of this research was to analyze the influence of CT on MPS in secondary education. Following empirical analysis, the hypotheses supporting the theoretical contribution of this research were both confirmed and rejected. Thus, **H1** abstraction influences the resolution of mathematical problems without computational tools. This has been demonstrated in previous studies that argue that abstraction, as a cognitive ability, can influence PC without the need for technological tools (Stephens & Kadijevich, 2020). Furthermore, abstraction is considered a fundamental skill in global society, which, along with analysis, can help students understand and solve problems effectively (Pinzón Pérez & González Palacio, 2022; Silva et al., 2020). This hypothesis is accepted in the present study based on the p-value (0.01) in **Table 5**, which expresses the significant contribution of abstraction to the RPMSC (resolution of mathematical problems with computer skills). Furthermore, according to the path value (0.206) and the f^2 value (0.034), it is argued that as the ability to abstract develops, it moderately influences and contributes to the RPMSC.

Regarding **H2**, abstraction influences the resolution of mathematical problems with computational tools. This is supported by some research showing that, as abstraction is a fundamental element of computer literacy, it promotes PC using technological tools and programming (Argoti, 2024; Marañón & González, 2021; Wing, 2006). Moreover, when implemented alongside other skills such as pattern recognition, it promotes the understanding of problem situations mediated by computational environments (Ospina Marín & Pirela, 2025). According to the values (p, 0.375), (path, -0.09), and (f^2, 0.009) shown in **Table 5**, the hypothesis is rejected in this study because, according to the results, abstraction does not contribute significantly, does not directly influence, and does not contribute to the RPMCC.

H3, pattern recognition, influences the resolution of mathematical problems without computational tools. It is proposed that problem analysis using integrated computer skills, including pattern recognition, contributes positively to PC without computers and to the development of logical reasoning. This skill contributes to MPS when combined with problem decomposition and abstraction, as it generates a greater understanding of the problem (Gretter & Yadav, 2016). Based on the values (p, 0.684), (path, -0.029), and (f^2, 0.001) presented in **Table 5**, the hypothesis is rejected in this study because, according to the results, pattern recognition does not significantly contribute to, nor does it directly influence, the RPMSC (reliability, proficiency, and scoring of mathematical problems).

Regarding **H4**, the hypothesis that pattern recognition influences the resolution of mathematical problems with computational tools is justified by the literature, which states that, considering pattern recognition as a fundamental skill within the process of analyzing problem situations, its understanding and resolution with the help of computational tools contributes to the RPM (Stephens & Kadijevich, 2020). Other authors conclude that, since pattern recognition is part of computational and algorithmic thinking, it aids mathematical thinking by recognizing key elements of problems in a computational context (Ospina Marín & Pirela, 2025). According to the values of (p, 0.00), (path, 1) and (f^2, 211) expressed in **Table 5**, the hypothesis is accepted in the present study, because according to the results, pattern recognition contributes significantly and at a high level, directly influencing and contributing to the RPMCC.

H5, that algorithm design influences the resolution of mathematical problems without computational tools, aligns with the literature, which supports the idea that following a sequence of pre-planned steps and processes to solve problems is fundamental in mathematics (Stephens & Kadijevich, 2020). Furthermore, the development of this skill promotes logical reasoning, which is key to PC (Ros et al., 2019). This information is also validated by the present study through the values of (p, 0.00), (path, 0.350), and (f^2, 101) shown in **Table 5**, confirming the acceptance of the hypothesis, since algorithm design significantly influences, directly influences, and moderately contributes to the RPMSC (reliability, proficiency, and scoring). According to **H6**, algorithm design influences the resolution of mathematical problems with computational tools, directly aligning with the theory that algorithm design is a crucial skill in solving problems in the technological, computer science, and programming fields (Rojas & García, 2020). This importance in computer-based PC lies in the need to develop a plan or process beforehand that guides the student through the sequence of steps to logically solve the algorithmic problem (Marañón & González, 2021). Despite this, the values (p, 0.230), (path, -0.036), and (f^2, 0.155) in **Table 5** lead to the rejection of the hypothesis in this study, as they indicate that algorithm design does not significantly influence, contribute to, or include the RPMCC (research, programming, computational, and computer-assisted problem-solving).

In **H7**, problem decomposition influences the resolution of mathematical problems without computational tools. This is considered theoretically feasible as a skill that enables the resolution of simple and complex mathematical problems without using a computer, since it promotes greater understanding when breaking them down into simpler problems. Based on the values of (p, 0.009), (path, 0.164), and (f^2, 0.022), the hypothesis is accepted, as these values indicate that problem decomposition significantly influences, contributes to, and moderately influences the RPMSC (research, problem, problem, and computer skills). Regarding **H8**, problem decomposition influences the resolution of mathematical problems with computational tools. Theoretically, problem decomposition in computer-based PC helps students visualize each part of the programming process in a simpler and more manageable way, enabling greater understanding (Rojas Lopera & Aravena Domich, 2023). Based on the values of (p, 0.337), (path, -0.009) and (f^2, 0.015), the hypothesis is rejected, because the values show that the decomposition of problems does not significantly influence, directly influence and contribute to the RPMCC.

Based on the R^2 values presented in **Figure 3**, it is evident that 35.7% of the variance in the construct (RPMSC) and 99.6% of the variance in the construct

(RPMCC) are explained by exogenous variables related to the CT construct (Hair et al., 2017). These values suggest that other indicators could also explain RPMSC. Consequently, when students demonstrate confidence in the face of complexity, persistence in tackling difficult problems, and the ability to communicate, engage in dialogue, and work collaboratively in teams, RPMSC is fostered (Argoti, 2024; Marañón & González, 2021). Similarly, a critical and active attitude promotes the exploration of resources, strategies, and the most appropriate methodology for PC, fostering creativity, continuous analysis, and interpretation (Vilchez & Ramón, 2024). Other research suggests that teacher training in pedagogical practices, combining technological skills, innovative teaching methods, appropriation and management of content, could promote students' RPM processes through teaching (Argoti, 2024; Obando et al., 2024; Vilchez & Ramón, 2024).

Regarding the predictive relevance (Q^2) shown in **Table 6**, the indicators corresponding to RPMCC1 ($Q^2 = 0.068$) and RPMSC3 ($Q^2 = 0.069$) indicate that the structural formative model predicts, albeit weakly, the frequency with which teachers use sequential and operational methods in solving mathematical problems supported by computational tools, and the frequency with which students autonomously use sequential and operational processes in solving mathematical problems without the use of computational tools. These results suggest that the majority of the mathematics teachers surveyed use other teaching methods without the use of computational tools, and that students, instead of solving mathematical problems autonomously, require sequential explanations and feedback from teachers during the PC process. Regarding the RPMCC2 ($Q^2 = 0.610$) and RPMCC3 ($Q^2 = 0.995$) indicators, the structural formative model clearly predicts, at a high level, the frequency with which students demonstrate greater understanding in solving mathematical problems by implementing sequential and operational methods using computational tools, and the frequency with which students autonomously implement these sequential and operational methods in solving mathematical problems using computational tools. These results highlight the importance of promoting the use of computational tools, as this fosters students' understanding and autonomy in solving mathematical problems. Regarding the RPMSC1 ($Q^2 = 0.145$) and RPMSC2 ($Q^2 = 0.260$) indicators, the model predicts, at an acceptable level, the frequency with which teachers use sequential and operational methods in solving mathematical problems without the use of computational tools, and the frequency with which students demonstrate greater understanding in solving mathematical problems when implementing sequential and operational methods without the use of computational tools. This confirms that the surveyed mathematics teachers mostly implement teaching methods without the use of computational tools, contributing acceptably to students' understanding and resolution of problems.

The results are based on the literature, which indicates that developing processes aimed at understanding, designing algorithms, and solving mathematical problems in secondary education requires cognitive abilities such as problem decomposition (PD), abstraction (AB), pattern recognition (PR), and algorithm design (AD). These skills are shared by CT and mathematical thinking, but the application of algorithmization as part of algorithm design promotes differentiation in its use with and without computers (Pinzón Pérez et al., 2023; Stephens & Kadijevich, 2020). Thus, computer-designed activities implement technological resources and the internet with programming environments for creating programming algorithms and games. Activities designed without computers, requiring no internet access or technological tools, are presented as a possibility that, through planned pedagogical practices, could lead not only to the development of computer skills but also to PC, as proposed by the bebras and discover coding strategies (Tonbuloğlu & Tonbuloğlu, 2019). Although the implementation of computer-based learning with and without computers is promoted in different school contexts, it is suggested that implementing them in an integrated way can lead to greater knowledge and development of computer and RPM skills.

In this regard, the limitations of the present study, based on research, confirm that the didactic implementation of CT by mathematics teachers for solving problems with and without computers still presents gaps and difficulties due to implications related to their teacher training (Rodrigues et al., 2025). Teachers' basic understanding of CT skills, such as problem decomposition and algorithm design, hinders their application through didactic activities for solving mathematical problems, a situation also related to the need for further training in this area (Zahid, 2025). Furthermore, the lack of access to technology prevents teachers from delving deeper into the implementation of CT skills in secondary education for solving mathematical problems through the design of connected activities (Djidu et al., 2025). Therefore, from the perspective of some authors, the effective practice of CT in solving mathematical problems requires promoting the integration of CT into the curriculum at a global level, also requesting the promotion of professional development in teachers of CT, along with pedagogical practices and skills that are relevant to each school level (Ayuso, 2022; Loureiro et al., 2022; Marañon & González, 2021).

CONCLUSIONS

This study explored the influence of CT on computer-free and computer-based MPS in secondary education. The study confirmed, by the p and path values, the acceptance of four hypotheses and direct relationship among dimensions of CT such as abstraction, problem decomposition, and algorithm design with computer-free MPS. Likewise, the pattern recognition dimension is correlated with computer-based MPS. Next, based on p and path values, hypotheses that relate problem decomposition, abstraction, and algorithm design dimensions to computer-based MPS, and pattern recognition to computer-free MPS, were rejected. Therefore, this study answered the question about the influence of CT on solving mathematical problems in secondary education.

Limitations and Recommendations

Some limitations and recommendations for future research are related to the lack of training for mathematics teachers in secondary school that combines technological skills, innovative teaching, appropriation, and content management to favor students' MPS processes based on CT teaching. According to the results of this study, linking new teaching strategies that implement CT, and technological tools could promote students' understanding and autonomy for solving mathematical problems. In addition, it is limited to consider that the effective MPS in secondary education is linked only to the implementation of CT dimensions. This situation is contrasted with the moderate percentage of the R^2 for computer-free MPS. This suggests future research to consider other factors to strengthen MPS, such as positive attitudes on the part of students towards CT and mathematics. It is established that students with positive attitudes towards mathematics and CT can show all PC skills, but students with moderate and low attitudes can only show a few (Astuti et al., 2025; Richardo et al., 2025). Based on the literature review, an effective implementation of CT for solving mathematical problems is also considered fundamental and requires that teachers, in addition to having excellent content knowledge in mathematics and CT, are experts in pedagogy and be able to design timely didactic strategies for different school levels that contain CT practices in a connected and disconnected way (Listiaji & Molnár, 2025; Sabiha et al., 2024; Salinas et al., 2024; Sezer & Namukasa, 2023; Ung et al., 2022). Therefore, teachers' lack of understanding of CT, in addition to the absence of pedagogical strategies, hinder the implementation of CT in different school grades (Mumcu et al., 2023).

Theoretical Implications

From the theoretical implications, one of the contributions of the present study lies in establishing significant relationships among abstraction, decomposition, and algorithm design from the perceptions of surveyed mathematics teachers in computer-free MPS, in addition to the significant relationship of pattern recognition with computer-based MPS. Another contributions is related to evidencing the Q^2 and the f^2 from the value of the R^2. Abstraction, algorithm design and problem decomposition explain, predict, and contribute at a moderate level to computer free MPS and pattern recognition explains, predicts, and contributes at a high level to computer-based MPS. In addition, based on VIF values and weights of the indicators, it is confirmed that indicators of the measurement model do not evaluate the same but different aspects, thus demonstrating from the weight that each observable variable contributes to the constructs of CT and MPS.

Practical Implications

In terms of practical implications, CT in teaching and learning processes could require, in addition to its implementation, the design of pedagogical activities planned by trained teachers. It is important to consider that students sequentially develop skills that allow them to improve their understanding of the problem, while abstracting or delimiting key elements of the problem, by recognizing mathematical or algorithmic structures that, when ordered sequentially and according to the hierarchy of mathematical and computational processes, lead to the solution of the proposed situation (Bråting & Kilhamn, 2021; Lehmann, 2025; Listiaji & Molnár, 2025; Sezer & Namukasa, 2023; Ung et al., 2022).

Thus, CT could interact harmoniously in MPS, promoting the development of computer free or computer based strategies aimed at solving mathematical problems and articulating them with the curriculum in schools and training teachers to effectively design pedagogical practices that, with or without computers, solve problems while developing skills at different school levels (Gilchrist et al., 2021; Salinas et al., 2024).

Suggestion

Research is needed that considers not only the implementation of CT in MPS, but also other elements that promote improved PC skills, such as collaborative work and activities designed for different grade levels that foster positive student attitudes toward CT and mathematics, both with and without computational tools (Astuti et al., 2025; Richardo et al., 2025). Furthermore, the influence of CT on MPS also depends on its effective implementation. This requires that teachers, based on their content knowledge in mathematics and CT, as well as their extensive knowledge of teaching strategies, be able to design timely and practical activities that integrate CT with PC

(Molnár, 2025; Sabiha et al., 2024; Sezer & Namukasa, 2023). Therefore, teachers' lack of understanding of CT, coupled with the absence of didactic strategies, hinders its implementation and influence across different grade levels (Mumcu et al., 2023). Finally, from the perspective of other authors, it is proposed that in addition to implementing CT for the MPS, the proposed activities should consider developing metacognition in students so that, through a reflective process, they can orient themselves regarding the strategy and method to follow, the mathematical skill and process to implement, becoming aware of their mathematical process, how they are developing it, and what other activities and problems they can solve using the same steps (Morán et al., 2025; Sacón et al., 2025).

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REFERENCES

Aiken, L. (1980). Content validity and reliability of single items or questionnaires. *Educational and Psychological Measurement, 40*(4), 955-959. https://doi.org/10.1177/001316448004000419

Alonso, I. (2021). Sistema básico de habilidades para la algoritmización computacional [Basic skills system for computational algorithmization]. *Revista de Investigación, Formación y Desarrollo: Generando Productividad Institucional, 9*, Article 14. https://doi.org/10.34070/rif.v9i1.255

Argoti, J. (2024). El pensamiento computacional como soporte del pensamiento matemático, en la Institución Educativa Santo Domingo Savio de Chinchiná (Caldas, Colombia) [Computational thinking as a support for mathematical thinking, at the Santo Domingo Savio Educational Institution of Chinchiná (Caldas, Colombia)]. *Voces y Silencios. Revista Latinoamericana de Educación, 15*(1), Article 1. https://doi.org/10.18175/VyS15.1.2024.5

Astuti, A., Suryawati, E., Suanto, E., Yuanita, P., & Noviana, E. (2025). Charting a course: Exploring computational thinking skills in statistics content among junior high school students. *Journal of Pedagogical Research, 9*(1), 182-202. https://doi.org/10.33902/JPR.202531653

Avello, R., Lavonen, J., & Zapata, M. (2020). Codificación y robótica educativa y su relación con el pensamientocomputacional y creativo. Una revisión compresiva [Coding and educational robotics and their relationship with computational and creative thinking. A comprehensive review]. *Revista de Educación a Distancia, 20*(63). https://doi.org/10.6018/red.413021

Ayuso, A. M. (2022). *Contribución del pensamiento computacional con 'scratch' al proceso de enseñanza y aprendizaje de las matemáticas* [Contribution of computational thinking with 'scratch' to the teaching and learning process of mathematics] [PhD thesis, Universidad de Córdoba].

Bråting, K., & Kilhamn, C. (2021). Exploring the intersection of algebraic and computational thinking. *Mathematical Thinking and Learning, 23*(2), 170-185. https://doi.org/10.1080/10986065.2020.1779012

Cabra, M., & Ramirez, S. A. R. (2022). Desarrollo del pensamiento computacional y las competencias matemáticas en análisis y solución de problemas: Una experiencia de aprendizaje con Scratch en la plataforma Moodle [Development of computational thinking and mathematical skills in problem analysis and solving: A learning experience with Scratch on the Moodle platform]. *Revista Educación, 46*(1), 1-30.

Calle, M., Vivanco, M., Correa, D., Cristhiam, C., & Betancourt, V. (2025). Innovación didáctica con TIC en el aprendizaje de matemáticas: Estrategias interactivas para potenciar el pensamiento lógico y la resolución de problemas [Didactic innovation with ICT in mathematics learning: Interactive strategies to enhance logical thinking and problem solving]. *Revista Científica de Salud y Desarrollo Humano, 6*(2), 644-674. https://doi.org/10.61368/r.s.d.h.v6i2.625

Carrillo, J., Climent, N., Montes, M., & Muñoz, M. (2022). Una trayectoria de investigación sobre el conocimiento del profesor de matemáticas: Del grupo SIDM a la red Iberoamericana MTSK [A research trajectory on the mathematics teacher's knowledge: From the SIDM group to the Ibero-American MTSK network]. *Revista Venezolana de Investigación en Educación Matemática, 2*(2), 1-26. https://doi.org/10.54541/reviem.v2i2.41

Cuesta, R. G. (2025). Metodologías activas en la enseñanza de las matemáticas: Un enfoque basado en la tecnología [Active methodologies in mathematics teaching: A technology-based approach]. *Ciencia Latina Revista Científica Multidisciplinar, 9*(3), 1711-1733. https://doi.org/10.37811/cl_rcm.v9i3.17783

Cui, Z., & Ng, O. L. (2021). The interplay between mathematical and computational thinking in primary school students' mathematical problem-solving within a programming environment. *Journal of Educational Computing Research, 59*, Article 073563312097993. https://doi.org/10.1177/0735633120979930

Diaz, J., & Caballero, J. (2020). Problem solving from an epistemological approach. *Foro de Educacion, 18*(2), Article 2.

Djidu, H., Retnawati, H., & Haryanto, H. (2025). Mathematics teachers' perspectives on computational thinking: Insights into knowledge, strategies, and challenges. *The Qualitative Report, 30*(7), 4019-4040. https://doi.org/10.46743/2160-3715/2025.6494

Ersozlu, Z., Swartz, M., & Skourdoumbis, A. (2023). Developing computational thinking through mathematics: An evaluative scientific mapping. *Education Sciences, 13*(4), Article 4. https://doi.org/10.3390/educsci13040422

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods, 41*(4), 1149-1160. https://doi.org/10.3758/BRM.41.4.1149

Garrote, P. R., & del Carmen Rojas, M. (2015). La validación por juicio de expertos: Dos investigaciones cualitativas en Lingüística aplicada [Validation by expert judgment: Two qualitative investigations in applied linguistics]. *Revista Nebrija de Lingüística Aplicada a la Enseñanza de Lenguas, 18*, 124-139. https://doi.org/10.26378/rnlael918259

Gilchrist, P. O., Alexander, A. B., Green, A. J., Sanders, F. E., Hooker, A. Q., & Reif, D. M. (2021). Development of a pandemic awareness STEM outreach curriculum: Utilizing a computational thinking taxonomy framework. *Education Sciences, 11*(3), Article 3. https://doi.org/10.3390/educsci11030109

Gretter, S., & Yadav, A. (2016). Computational thinking and media & information literacy: An integrated approach to teaching twenty-first century skills. *TechTrends, 60*(5), 510-516. https://doi.org/10.1007/s11528-016-0098-4

Hadfield, R. (2020). Pearl growing in systematic literature searching—What, why and how? *mediwrite*. https://www.mediwrite.com.au/medical-writing/pearl-growing/

Hair, J., Hult, G., Ringle, C., & Sarstedt, M. (2017). *A primer on partial least squares structural equation modeling (PLS-SEM)* (2nd Ed.). SAGE.

Hair, J., Hult, G., Ringle, C., & Sarstedt, M. (2022). *A primer on partial least squares structural equation modeling (PLS-SEM)* (3rd Ed.). SAGE. https://doi.org/10.1007/978-3-030-80519-7

Huerta, C., & Velásquez, M. (2021). Pensamiento computacional como una habilidad genérica: Una revisión sistemática [Computational thinking as a generic skill: A systematic review]. *Ciencia Latina Revista Científica Multidisciplinar, 5*(1), Article 1. https://doi.org/10.37811/cl_rcm.v5i1.311

Kallia, M., van Borkulo, S. P., Drijvers, P., Barendsen, E., & Tolboom, J. (2021). Characterising computational thinking in mathematics education: A literature-informed Delphi study. *Research in Mathematics Education, 23*(2), 159-187. https://doi.org/10.1080/14794802.2020.1852104

Kock, N., & Hadaya, P. (2018). Minimum sample size estimation in PLS-SEM: The inverse square root and gamma-exponential methods. *Information Systems Journal, 28*(1), 227-261. https://doi.org/10.1111/isj.12131

Lehmann, M., Cornelius, P., & Sting, F. (2024). *AI meets the classroom: When does ChatGPT harm learning?* SSRN. https://doi.org/10.2139/ssrn.4941259

Lehmann, T. H. (2025). Examining the interaction of computational thinking skills and heuristics in mathematical problem solving. *Research in Mathematics Education, 27*(2), 269-290. https://doi.org/10.1080/14794802.2025.2460460

Listiaji, P., & Molnár, G. (2025). Integrating computational thinking into teacher education: A systematic literature review. *International Journal of Educational Research, 133*, Article 102682. https://doi.org/10.1016/j.ijer.2025.102682

Loureiro, A., Meirinhos, M., Osório, A., & Valente, A. (2022). El pensamiento computacional en los marcos de competencia digital docente [Computational thinking within the frameworks of digital teaching competence]. *Revista Prisma Social, 38*, Article 38.

Maciej, M. (2024). Mathematical versus computational thinking with a computer in the background. In H. Fernau, I. Schwank, & J. Staub (Eds.), *Creative mathematical sciences communication. CMSC 2024. Lecture notes in computer science, vol 15229* (pp. 147-161). Springer. https://doi.org/10.1007/978-3-031-73257-7_12

Marañon, Ó., & González, H. (2021). Una revisión narrativa sobre el pensamiento computacional en educación secundaria obligatoria [A narrative review of computational thinking in compulsory secondary education]. *Contextos Educativos. Revista de Educación*, (27), 169-182. https://doi.org/10.18172/con.4644

MEN. (1998). Lineamientos curriculares [Curriculum guidelines]. *Ministerio de Educación Nacional de*

Colombia. https://www.mineducacion.gov.co/1621/article-89869.html

Morán, C. M., Vargas, E. V., Torres, B. T., Cáceres, J. C., & Garcés, C. G. (2025). Estrategias pedagógicas para fomentar la metacognición: Perspectivas y experiencias en el aula [Pedagogical strategies for developing critical thinking in children in early childhood education: Exploring practical approaches in the classroom]. *LATAM Revista Latinoamericana de Ciencias Sociales y Humanidades, 6*(2), 2769-2780. https://doi.org/10.56712/latam.v6i2.3865

Mullo, G., Guzman, L. S. G., Loachamin, J. R. L., & Herrera, D. X. H. (2025). El rol del pensamiento computacional en la resolución de problemas matemáticos: Un enfoque interdisciplinario [The role of computational thinking in solving mathematical problems: An interdisciplinary approach]. *Estudios y Perspectivas Revista Científica y Académica, 5*(1), Article 1. https://doi.org/10.61384/r.c.a..v5i1.872

Mulyono, B., Hapizah, H., & Cahyawati, D. (2024). Computational thinking skills in mathematics: A study of social arithmetic. *Journal of Honai Math, 7*(3), 451-468. https://doi.org/10.30862/jhm.v7i3.759

Mumcu, F., Kıdıman, E., & Özdinç, F. (2023). Integrating computational thinking into mathematics education through an unplugged computer science activity. *Journal of Pedagogical Research, 7*(2), 72-92. https://doi.org/10.33902/JPR.202318528

Navas, E. (2024). Relaciones entre la matemática, el pensamiento algorítmico y el pensamiento computacional [Relationships between mathematics, algorithmic thinking, and computational thinking]. *IE Revista de Investigación Educativa de la REDIECH, 15*, e1929-e1929. https://doi.org/10.33010/ie_rie_rediech.v15i0.1929

Obando, J., Valencia, M., Romero, C., & Reyes, S. (2024). Categorías y prácticas implicadas con el pensamiento computacional para la mejora de las habilidades en la resolución de problemas matemáticos en secundaria [Categories and practices involved with computational thinking for improving mathematical problem-solving skills in secondary school]. *AiBi Revista de Investigación, Administración e Ingeniería, 12*(2), Article 2. https://doi.org/10.15649/2346030X.4408

Ospina Marín, P. A., & Pirela, A. L. (2025). Competencias en resolución de problemas y pensamiento computacional: Un estudio en educación secundaria Colombiana [Competencies in problem-solving and computational thinking: A study in Colombian secondary education]. *Actas Iberoamericanas en Ciencias Sociales, 3*(1), 27-40. https://doi.org/10.69821/AICIS.v3i1.66

Otzen, T., & Manterola, C. (2017). Técnicas de muestreo sobre Una población a estudio [Sampling techniques for a study population]. *International Journal of Morphology, 35*(1), 227-232. https://doi.org/10.4067/S0717-95022017000100037

Paget, M., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S. … Alonso-Fernández, S. (2021). Declaración PRISMA 2020: Una guía actualizada para la publicación de revisiones sistemáticas [PRISMA statement 2020: An updated guide for the publication of systematic reviews]. *Revista Española de Cardiología, 74*(9), 790-799. https://doi.org/10.1016/j.recesp.2021.06.016

Panta, G. M. P., & Antón, C. A. C. (2025). Desempeño docente en la enseñanza de la matemática: Revisión sistemática [Teacher performance in mathematics education: A systematic review]. *Aula Virtual, 6*(13), 1308-1335. https://doi.org/10.5281/zenodo.16986601

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

Pérez, I. (2025). Algoritmos para la resolución de problemas [Algorithms for problem solving]. *Vida Científica Boletín Científico de la Escuela Preparatoria No. 4, 12*(24), 14-15. https://doi.org/10.29057/prepa4.v12i24.12802

Pinzón Pérez, D., Román, M., & González, E. (2023). Algorithmic thinking as a didactic strategy for developing problem-solving skills in the context of secondary basic education. *Revista De Educación a Distancia, 23*, 1-22. https://doi.org/10.6018/red.542111

Pinzón Pérez, D. F., & González Palacio, E. V. (2022). Incidencia de las habilidades de pensamiento algorítmico en las habilidades de resolución de problemas: Una propuesta didáctica en el contexto de la educación básica secundaria [Impact of algorithmic thinking skills on problem-solving skills: A didactic proposal in the context of basic secondary education]. *Estudios Pedagógicos (Valdivia), 48*(2), 415-433. https://doi.org/10.4067/S0718-07052022000200415

Polya, G. (1945). *How to solve it; a new aspect of mathematical method*. Princeton University Press. https://doi.org/10.1515/9781400828678

Ramaila, S., & Shilenge, H. (2023). Integration of computational thinking activities in grade 10 mathematics learning. *International Journal of*

Research in Business and Social Science, 12(2), 458-471. https://doi.org/10.20525/ijrbs.v12i2.2372

Relkin, E., & Strawhacker. (2024). Unplugged learning: Recognizing computational thinking in everyday life. In M. Bers (Ed.), *Teaching computational thinking and coding to young children* (pp.41-62). Information Science Reference. https://doi.org/10.4018/978-1-7998-7308-2.ch003

Richardo, R., Murti, R., Wijaya, A., Adawiya, R., Ihwani, I., Ardiyaningrum, M., & Aryani, A. E. (2025). Computational thinking skills profile in solving mathematical problems based on computational thinking attitude. *Journal of Education and Learning, 19*(2), 1157-1166. https://doi.org/10.11591/edulearn.v19i2.21643

Rodrigues, R. N., Costa, C., Brito-Costa, S., Abbasi, M., & Martins, F. (2025). Impact of a training program on developing computational thinking in pre-service primary school teachers: From theory to practice. *Educational Process International Journal, 14*, Article e2025037. https://doi.org/10.22521/edupij.2025.14.37

Rodríguez-Nieto, C. A., Rodríguez-Vásquez, F. M., & Moll, V. F. (2023). Combined use of the extended theory of connections and the onto-semiotic approach to analyze mathematical connections by relating the graphs of f and f'. *Educational Studies in Mathematics, 114*(1), 63-88. https://doi.org/10.1007/s10649-023-10246-9

Rodríguez-Nieto, C. A., & Moll, V. F. (2025). Mathematical connections promoted in multivariable calculus' classes and in problems-solving about vectors, partial and directional derivatives, and applications. *Eurasia Journal of Mathematics, Science and Technology Education, 21*(4), Article em2619. https://doi.org/10.29333/ejmste/16187

Rodríguez-Nieto, C. A., Pabón-Navarro, M. L., Cantillo-Rudas, B. M., Sudirman, & Moll, V. F. (2025). The potential of ethnomathematical and mathematical connections in the pre-service mathematics teachers' meaningful learning when problems-solving about brick-making. *Infinity Journal, 14*(2), 419-444. https://doi.org/10.22460/infinity.v14i2.p419-444

Rojas Lopera, S., & Aravena Domich, M. (2023). Pensamiento computacional (PC) en la educación: Aprendizajes y desempeño académico [Computational thinking (CT) in education: Learning and academic performance]. *Franz Tamayo–Revista de Educación, 5*(13), 9-26. https://doi.org/10.61287/revistafranztamayo.v.5i13.1

Rojas, A., & García, F. J. (2020). Evaluación del pensamiento computacional para el aprendizaje de programación de computadoras en educación superior [Assessment of computational thinking for learning computer programming in higher education]. *Revista de Educación a Distancia, 20*(63), Article 63. https://doi.org/10.6018/red.409991

Sabiha, Y., Nijenhuis, J., Saeli, M., Barendsen, E., & Hermans, F. (2024). Computational thinking integrated in school subjects–A cross-case analysis of students' experiences. *International Journal of Child-Computer Interaction, 42*, Article 100696. https://doi.org/10.1016/j.ijcci.2024.100696

Sacón, J. M. S., Tigselemae, I. A. T., Vega, G. J. V., & Vinces, L. S. V. (2025). El desarrollo de habilidades metacognitivas a través de la resolución de problemas matemáticos [The development of metacognitive skills through mathematical problem solving]. *Ciencia Latina Revista Científica Multidisciplinar, 9*(1), 3971-3990. https://doi.org/10.37811/cl_rcm.v8i6.15765

Salinas, C., Seckel, M. J., Breda, A., & Espinoza, C. (2024). Integrating computational thinking into mathematics class: Curriculum opportunities and the use of the Bee-bot. *International Journal of Educational Methodology, 10*(1), 137-149. https://doi.org/10.12973/ijem.10.1.937

Santos-Trigo, M. (2024). Problem solving in mathematics education: Tracing its foundations and current research-practice trends. *ZDM Mathematics Education, 56*, 211-222. https://doi.org/10.1007/s11858-024-01578-8

Sarstedt, M., Hair, J. F., Pick, M., Liengaard, B. D., Radomir, L., & Ringle, C. M. (2022). Progress in partial least squares structural equation modeling use in marketing research in the last decade. *Psychology & Marketing, 39*(5), 1035-1064. https://doi.org/10.1002/mar.21640

Schoenfeld, A. H. (2017). Learning to think mathematically: Problem solving, metacognition, and sense making in mathematics. *Journal of Education, 196*(2), 1-38. https://doi.org/10.1177/002205741619600202

Sezer, H., & Namukasa, I. K. (2023). School and community practices of computational thinking in mathematics education through diverse perspectives. *Journal of Research in Science, Mathematics and Technology Education, 6*(SI), 137-160. https://doi.org/10.31756/jrsmte.617si

Silva Triana, E. L. (2024). *La resolución de problemas en el área de matemáticas mediado por la comprensión del método Pólya* [Problem solving in the area of mathematics mediated by an understanding of Pólya's method] [PhD thesis, Universidad Pedagógica Experimental Libertador].

Silva-Calpa, F. I., Tonguino-Quiroz, E. E., & Mantilla-Guiza, R. R. (2020). El pensamiento computacional en la resolución de problemas matemáticos en básica primaria a través de computación desconectada [Computational thinking in solving mathematical problems in elementary school through offline computing]. In *Proceedings of the Computer Science Workshop at School* (pp. 151-160). https://doi.org/10.5753/cbie.wie.2020.151

Stephens, M., & Kadijevich, D. M. (2020). Computational/algorithmic thinking. In S. Lerman (Ed.), *Encyclopedia of mathematics education* (pp. 1-6). Springer. https://doi.org/10.1007/978-3-030-15789-0_100044

Subramaniam, S., Maat, S. M., & Mahmud, M. S. (2022). Computational thinking in mathematics education: A systematic review. *Cypriot Journal of Educational Sciences, 17*(6), Article 6. https://doi.org/10.18844/cjes.v17i6.7494

Tonbuloğlu, B., & Tonbuloğlu, İ. (2019). The effect of unplugged coding activities on computational thinking skills of middle school students. *Informatics in Education, 18*(2), 403-426. https://doi.org/10.15388/infedu.2019.19

Ung, L., Labadin, J., & Mohamad, F. S. (2022). Computational thinking for teachers: Development of a localised e-learning system. *Computers & Education, 177*, Article 104379. https://doi.org/10.1016/j.compedu.2021.104379

Ureta, K. T. M., & Valencia, E. V. O. (2025). Metodologías activas para el desarrollo de habilidades matemáticas: Un análisis bibliográfico [Active methodologies for the development of mathematical skills: A bibliographic analysis]. *LATAM Revista Latinoamericana de Ciencias Sociales y Humanidades, 6*(2), 3431-3450. https://doi.org/10.56712/latam.v6i2.3917

Vilchez, J., & Ramón, J. (2024). Influencia del pensamiento computacional y visual en el aprendizaje de la matemática en estudiantes universitarios [Influence of computational and visual thinking on mathematics learning in university students]. *Información Tecnológica, 35*(4), 13-24. https://doi.org/10.4067/s0718-07642024000400013

Waterman, K., Goldsmith, L., & Pasquale, M. (2020). Integrating computational thinking into elementary science curriculum: An examination of activities that support students' computational thinking in the service of disciplinary learning. *Journal of Science Education and Technology, 29*, 53-64. https://doi.org/10.1007/s10956-019-09801-y

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

Wu, S., & Su, Y. (2021). Visual programming environments and computational thinking performance of fifth- and sixth-grade students. *Journal of Educational Computing Research, 59*(6), 1075-1092. https://doi.org/10.1177/0735633120988807

Wu, T.-T., Asmara, A., Huang, Y.-M., & Permata Hapsari, I. (2024). Identification of problem-solving techniques in computational thinking studies: Systematic literature review. *Sage Open, 14*(2). https://doi.org/10.1177/21582440241249897

Ye, H., Liang, B., Ng, O. L., & Chai, C. S. (2023). Integration of computational thinking in K-12 mathematics education: A systematic review on CT-based mathematics instruction and student learning. *International Journal of STEM Education, 10*, Article 3. https://doi.org/10.1186/s40594-023-00396-w

Zahid, M. Z. (2025). Mathematics teachers' perceptions of computational thinking and its integration into mathematics education. *LUMAT: International Journal on Math, Science and Technology Education, 13*(1), 7-7. https://doi.org/10.31129/LUMAT.13.1.2696

Zhang, L., & Nouri, J. (2019). A systematic review of learning computational thinking through Scratch in K-9. *Computers & Education, 141*, Article 103607. https://doi.org/10.1016/j.compedu.2019.103607