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The logical-historical movement of the concept of computational thinking[1]

O movimento lógico-histórico do conceito de pensamento computacional

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ABSTRACT
This paper presents the logical-historical movement of the concept of computational thinking (CT) in mathematics education. The use of the term in mathematics education will be approached chronologically (historically) and logically. Based on this movement, the development of the concept of computational thinking for mathematics education will be explained, understanding that it is not just about programming languages or the use of computers (machines), but that the development of this thinking can contribute to the development of mathematical concepts related to algebraic thinking and algorithmic thinking.

Keywords: Logical-historical movement; Mathematical Education; Concept formation; Computational thinking.

RESUMO
Este trabalho apresenta o movimento lógico-histórico do conceito de pensamento computacional (PC) para a educação matemática. Abordar-se-á de forma cronológica (histórica) e lógica o uso do termo na educação matemática. A partir desse movimento, explicitar-se-á o desenvolvimento do conceito de pensamento computacional para a educação matemática, compreendendo que não se trata apenas de linguagem de programação ou uso do computador (máquina), mas que o desenvolvimento desse pensamento pode contribuir com o desenvolvimento de conceitos matemáticos relacionados ao pensamento algébrico e ao pensamento algorítmico.

Palavras-chave: Movimento lógico-histórico; Educação Matemática; Formação de conceitos; Pensamento Computacional.

1 Introduction

This work aimed to conceptualize computational thinking (CT) for mathematics education based on the logical-historical movement. To this end,

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we conducted a theoretical study of Brazilian productions in mathematics education that deal with the term "computational thinking" through state-of-knowledge research.

It was possible to verify that the term "computational thinking" was mentioned for the first time in mathematics education by Seymor Papert, one of the creators of the Logo language in the 1960s. When discussing geometric thinking, Papert stated that "the goal is to use computational thinking to forge more accessible and more powerful ideas" (PAPERT, 1994, sp).

In this context, the term was linked to the use of the computer for Logo programming. Over the years, the term and its language have been replaced by research and teaching practices focused on Internet use, different applications, and digital learning objects, among other technological resources, which made CT the study object of computer scientists mostly.

However, research in education and mathematics education is currently investing in the terminology. In 2006, computer scientist Jeannette Wing published an article addressing computational thinking in the educational context.

Wing's article did not provide a definition or a concept for computational thinking. However, it contributed to some researchers who approached the term in education and/or mathematics education, as well as other articles of hers, in which she improved the characteristics that she believed were part of the term.

It is worth mentioning that, in Brazil, in 2017 and 2018, we still did not have a developed concept or a consensus for what it meant to develop CT in the classroom. Nevertheless, even in this scenario, the National Common Curriculum Base (BNCC)[5] included the term.

In this way, we focused on carrying out a study based on the logical-historical movement of computational thinking in mathematical education, highlighting how and with what focus it is mentioned in the scientific research that involves it, and, from this, we developed a concept for the term.

[5] Available at: http://basenacionalcomum.mec.gov.br/abase/.

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Thus, we use the logical-historical perspective as a theoretical basis, assuming that mathematical education is constantly moving and undergoing social transformations, therefore being a historical category. We hope this study contributes to advancing academic and scientific research on computational thinking in mathematics education.

2 The importance of the logical-historical movement for this work

The logical-historical unit corresponds to the systematization produced by Kopnin (1978), who stated the non-existence of a logic devoid of objective/subjective human doing; that is, the historical and the logical are inseparable. For Kopnin (1978, p. 186), "the logical reflects not only the history of the object but the history of its knowledge."

In general terms, a logical-historical study can allow the construction of concrete and effective relationships of phenomena that make up the object under study, understanding that phenomena are singular and historically developed aspects that manifest themselves in varied possibilities of being of the essence of the object. From this perspective, understanding and relating phenomena, aiming to develop the concept, is precisely to reach the essence of the thing.

Thus, the historical (events, phenomena) and the logical (essence) are directly linked, forming a unit (a whole). The historical movement comprises the dialectical relationship between manifesting and hiding the essence (logical).

> Capturing the phenomenon of a specific thing means investigating and describing how the thing itself manifests itself in that phenomenon and how, at the same time, it hides in it. Understanding the phenomenon is reaching the essence. Without the phenomenon, without its manifestation and revelation, the essence would be unattainable (KOSIK, 2002, p. 16).

Thus, the logical becomes the "reproduction of the essence of the object and the history of its development in the system of abstractions" (KOPNIN, 1978, p. 183). In short, the logical is human thought's very appropriation of history. Therefore, the logical-historical study of an object derives from the search for the phenomena of that object, establishing a unity between its essence and its theory.

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> The study of the history of the development of the object creates, in turn, the indispensable premises for a deeper understanding of its essence. That is why, enriched by that history, we must once again return to the definition of its essence, correct, complete, and develop the concepts that express it. In this way, the theory of the object provides the key to the study of its history, while the study of history enriches the theory, correcting, completing, and developing it (KOPNIN, 1978, p. 186).

The author above states that researching, studying, or trying to understand the history of an object means analyzing its evolution, movement, change process, emergence, and development. The study and understanding of the logical occurs through the search for generalization of the historical process of this object.

This generalization process is not linked to the fact that the subject must understand the object from a strictly chronological perspective of the facts. However, generalization encompasses the resignification of a given object under study, building the dialectic between logical and historical, giving meaning to the movement of the phenomena studied.

In this way, the logical-historical movement allows the subject to detach themselves from the global (real empirical) understanding of a given object and, through categories and abstractions, construct a critical (concrete) view of this object, as shown in Kosik (2002) and Kopnin (1978).

Understanding the logical-historical movement of the term computational thinking corresponded to studying the phenomena of the history of this object of knowledge, its production, and development. This study led us to recognize the non-existence of a concept of the term for mathematics education, and, therefore, we dedicated ourselves to developing it.

The logical-historical movement enabled us to understand reality as a social becoming since the conception of computational thinking in mathematical education changes over time, being in a constant movement of abstraction and generalization. This study movement aligns with Vigotski's assumptions and those of the cultural-historical theory, given that we are based on Vigostski's concepts of thought and language.

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3 The logical-historical movement of computational thinking in mathematics education

The logical-historical movement to understand the phenomena involving computational thinking in mathematics education occurred first by surveying works that had already mentioned the term.

This survey was carried out in a state-of-knowledge study[6], a research method implemented through a bibliographical review about the production of a particular theme in a specific area of knowledge.

> [...] This type of research is not just a review of previous studies. It seeks, above all, to identify convergences and divergences, relationships and biases, approximations and contradictions in research and present evidence and understandings of knowledge based on academic studies, such as theses and dissertations (MELO, 2006, p. 62).

The review of state-of-knowledge studies occurred after an investigation in the Capes Theses and Dissertations Catalog database[7], which contains articles from the Scielo[8] and Capes journal platforms[9]. The search selected research posted on the platforms between 2009 and 2019, and the descriptor used was "*pensamento computacional*" [computational thinking] (NAVARRO, 2021).

This search found 125 works, 15 doctoral theses, 68 master's dissertations, and 42 articles. After reading the titles and abstracts of these works, we selected 16 that covered mathematics education and read them entirely to understand how computational thinking was approached.

In short, this research brought the development of computational thinking closer to programming and problem solving. We could also realize that there is no

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[6] To access complete information about this survey and the quantitative and qualitative data, access the master's dissertation by one of the authors, found at the following link: https://repositorio.ufscar.br/handle/ufscar/15112.
[7] Capes. Coordenação de Aperfeiçoamento de Pessoal de Nível Superior. Catálogo de Teses e Dissertações. Disponível em: https://catalogodeteses.capes.gov.br/catalogo-teses/#!/.
[8] SCIELO - Scientific Electronic Library Online. Periódicos. Disponível em: http://www.scielo.br/.
[9] Capes. Coordenação de Aperfeiçoamento de Pessoal de Nível Superior. Portal de Periódicos Capes/MEC. Disponível em: http://www.periodicos.capes.gov.br/.

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consensus on the definition of computational thinking and how to develop it in mathematics education.

Chronologically, the term computational thinking was first mentioned in mathematics education with the Logo language around 1967 by Seymour Papert, Cynthia Solomon, and Wally Feurzeig. The expression was linked to computer programming through a robot, which was later nicknamed turtle. Papert (1972) argued that using programming language –and, consequently, computers– could benefit mathematics and other areas of knowledge.

Such ideals for using computers never ceased to exist. However, they lost momentum in research due to other technological resources that emerged and were improved for mathematics education.

The term computational thinking returned to circulation among research focused on mathematics education after over thirty years, with an article published by Jeanette Wing in 2006. In this article, the author did not bring a definition but explained the characteristics of computational thinking with a bias towards computer science.

According to Wing (2006), with computational thinking, one can "solve problems, design systems and understand human behavior, using concepts from computer science" (WING, 2006, p. 33). The author proposed that computer scientists' different ways of thinking about CT should be applied to solving computational problems and problems related to other disciplines and everyday life.

From there, Wing (2006) suggests that computational thinking should be developed in basic education through skills that involve abstractions, pattern recognition to represent problems in new ways, dividing problems into smaller parts, and algorithmic thinking.

Wing (2006) argued that computational thinking should be a skill for anyone, not just computer scientists. She says developing CT should be as important as developing reading, writing, and arithmetic, for example.

To complement her statements, Wing (2011) published another article stating: "Computational thinking is the thought processes involved in formulating

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problems and their solutions so that these are represented in a way that an agent of information processing can effectively execute them." Wing's (2011) new statement explains that the CT is segmented into several thought processes, the most important of which is the abstraction process.

Since then, some complementary research to Wing's (2006, 2011) has attempted to define the term computational thinking. In 2012, The Royal Society (2012, p. 29) stated that computational thinking is based on a "process of recognizing aspects of computing in the world around us and applying computer science tools and techniques to understand and analyze natural and artificial systems and processes."

Such definitions, even if operational, indicate that the understanding of computational thinking is closely linked to "[...] developing a computational thinking approach that is suitable for basic education students," according to the K-12 Computer Science Teachers Association (CSTA) report[10] (SEEHORN, 2011, p.10).

In the United States, England, and Italy, even though no concept is built on computational thinking, developing this thinking in education is already being researched. For example, several publications recognize the benefits and scope in teaching this type of thinking can offer (BARR; STEPHENSON, 2011; DENNING, 2009; HU, 2011; WING, 2006; WING, 2008; WING, 2011).

In those publications, sometimes the term computational thinking is totally linked to computer science, while at other times, as proposed by Wing (2006; 2011), the authors intend to remove computational thinking as only pertaining to computer science, providing the insertion of the development of this thought in education, which means that programming, an essential part of computational thinking, became no longer an essential feature, as it was with the Logo language.

Faced with this difficulty in defining and building a common concept of computational thinking, CSTA and the International Society for Technology in

[10] This is an organization created in 2004 that supports and promotes the teaching of computer science (http://www.csteachers.org/).

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Education[11] (ISTE) proposed nine essential characteristics of computational thinking: data collection, data analysis, data representation, problem decomposition, abstraction, algorithms and procedures, automation, parallelization, and simulation (ISTE/CSTA, 2011). Barr and Stephenson (2011) explain these characteristics, considering five different areas where computational thinking can be present.

Chart 1 – Main characteristics and capabilities of computational thinking

PC concepts, abilities	Computer science	Mathematics	Science	Social studies	Language arts
Data collection	Finding a data source for a problem area	Finding a data source for a problem area, for example, flipping coins or rolling dice	Collecting data from an experiment	Studying battle statistics or population data	Performing linguistic analysis of sentences
Data analysis	Writing a program to do basic statistical calculations on a set of data	Counting occurrences of plays, dice rolls, and analysis of results	Analyzing data from an experiment	Identifying trends in statistics data	Identifying patterns for different types of sentences
Data representation	Using data structures like an array, linked list, stack, queue, graph, hash table, etc.	Using sets, lists, graphs, etc. to represent data	Summarizing data from an experiment	Summarizing and representing trends	Representing patterns of different types of sentences
Problem decomposition	Defining objects and methods; main definition and functions	Applying order of operations to an expression	Creating a kind of classification		Writing an outline
Abstraction	Using procedures to encapsulate a set of	Using variables in algebra; identifying	Building a model of a physical entity	Summarizing facts; deducing conclusion	Using simile and metaphor; writing a

[11] ISTE is a global organization that serves educators and those interested in digital technologies in education (http://www.iste.org/).

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	frequently repeated commands to execute a function; using conditionals, loops, recursion, etc.	essential facts in a word problem; studying functions in algebra compared to functions in programming; using iteration to solve word problems		s from facts	branching story
Algorithms and procedures	Studying classical algorithms; implementin g an algorithm for a problematic area	Performing long division, factoring the problem; transforming into addition or subtraction	Carrying out an experimen tal procedure		Writing instructions
Automation		Using tools such as geometer sketch pad; star logo; python codesnippets	Using the probeware	Using Excel	Using a spell checker
Parallelization	Aligning, separating, and dividing data or tasks so that they can be processed in parallel	Solving linear systems; doing matrix multiplication	Simultaneo usly carrying out experiment s with different parameters		
Simulation	algorithm animation, sweeping parameters	Graphing a function on a Cartesian plane and modifying variable values	Simulatin g the solar system movement	Playing '*Age of Empires*' and '*The Oregon Trail*'	Reenact a story

Source: BARR; STEPHENSON (2011, our translation)

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In the sense presented in Chart 1, computational thinking is linked to computer use and thinking "with" technologies. Although these concepts can help develop activities that involve computational thinking, no studies indicate which and/or how many of these concepts must be used in teaching practice so that the teacher can provide students with opportunities to develop computational thinking.

In Brazil, we can mention several initiatives to introduce computational thinking in recent years, involving researchers from schools and universities at different levels of school education (ANDRADE *et al.*, 2013; BARCELOS; SILVEIRA, 2012; FRANÇA; AMARAL, 2013; VIEL; RAABE; ZEFERINO, 2014).

Furthermore, computational thinking has been the focus of studies in postgraduate programs, as shown by Navarro and Sousa (2019) in the article entitled "O pensamento computacional na Educação Matemática: um olhar analítico para Teses e Dissertações produzidas no Brasil" [Computational thinking in mathematics education: An analytical look at theses and dissertations in Brazil], published in the proceedings of the 2019 XIII National Meeting of Mathematics Education (XIII ENEM)[12].

Although the theoretical and methodological scope of the term is not yet completely clear, it has already been included in the National Common Curriculum Base (BNCC) since 2017, where all mentions of the term are located in the Mathematics curriculum component. We note that, although there is no definition, the document relates it to the teaching of algebra without mentioning examples or educational possibilities.

Immersed in this logical-historical movement, we could develop the concept of computational thinking for mathematical education, realizing that, in this case, its development presupposes the development of mathematical concepts related to algebraic thinking and algorithmic thinking.

[12] Available at: https://www.sbembrasil.org.br/sbembrasil/index.php/anais/enem.

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4 What is the concept of computational thinking for mathematics education?

To develop the concept of computational thinking for mathematics education, we need to understand what thinking is. According to Vigotski (2000), thought and language are inseparable since language is a phenomenon of thought to the extent that it materializes in language.

Thought is structured in the link between the human being and the world (their reality); that is, it comes from the need of a subject to understand the dialectical concatenation between concrete and objective reality, from the need to communicate an idea and create tools to solve problems, using their psychic functions. According to Vigotski (2000), thought is composed of signs in their relationship with the "affection-intellect" unit (parts of the unit that is consciousness).

> [...] thought itself is generated by motivation, that is, our desires and needs, our interests and emotions. Behind every thought, there is an affective-volitional tendency, which brings within itself an answer to the ultimate why of our analysis of thought. [...] A full understanding of other people's thoughts is only possible when we understand their affective-volitional basis. To understand someone else's speech, it is not enough to understand their words. We must understand the thought, but even that is not enough -we also need to know their motivation (VIGOTSKI, 2000, p. 187-188).

In this way, developing thought is putting into motion higher psychic functions, such as sensations, imagination, logical memory, need, and language, and putting into practice the ability to abstract, generalize, and become aware of a given object.

Thus, starting from the logical-historical movement and considering that thought is intrinsic to the human being, related to the psychic functions that we activate to solve problems, we affirm that developing computational thinking is solving problems linked to the development of mathematical concepts related to algebraic and algorithmic thinking. Below, we will explain the meaning of problem solving, algebraic thinking, and algorithmic thinking.

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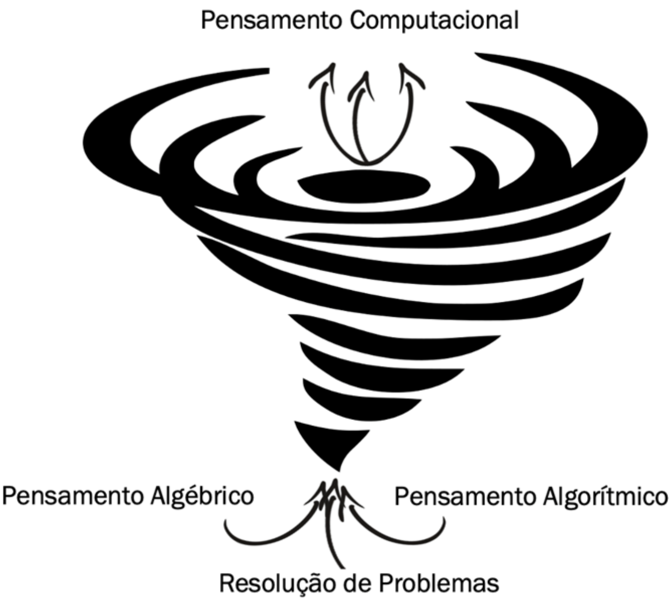
Figure 1- Concept of computational thinking



Source: Navarro (2023, p. 151)

Solving a problem means, to us, instilling in the individual the need to seek an unknown answer. In mathematics education, Onuchic and Allevato (2004, p. 221) state that a problem is “[...] everything that we do not know how to do, but that we are interested in doing.”

Furthermore, within the scope of mathematical education, problem solving can be seen as a means of involving individuals in problem situations, stimulating the development of mathematical thinking, enabling thinking about mathematics in movement (dialectics), considering its relationship with daily life. It assumes that the dialectical unit of learning to solve problems is directly related to learning mathematics by solving problems (GÓMEZ-LÓPEZ, 1997; KRAVTSOV, 2019; MOYSÉS, 1999; MARCO, 2004).

Therefore, problem solving applied in the classroom is the proposition of a set of situations pedagogically directed by the teacher. It encompasses using mathematical concepts by students to develop possible solutions, logical-mathematical reasoning, techniques, and skills, as well as reading and

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interpreting information, mobilizing relevant concepts and knowledge, and planning and verifying resolution strategies.

Developing algebraic thinking in the classroom presupposes the production and use of algebraic models (representations), algebraic procedures (algorithms, rules, symbols, unknowns, measurements, numbers, sequence, among others), algebraic operationalizations (algebraic expressions, written records, schemes, pattern recognition, among others).

According to Kaput (2007) and Radford (2014), developing algebraic thinking is a way of working with abstraction and generalization in formalizing patterns through algebraic language in its materialized form.

Algebraic thinking can be understood as a way of understanding reality, which materializes in the representation, generalization, and formalization of patterns and regularities. Now, "[...] algebra frees the child's thinking from the prison of concrete numerical dependencies and elevates it to a more generalized level of thinking" (VIGOTSKI, 2000, p. 267).

The development of algorithmic thinking occurs through the resolution of a problem that uses decomposition and the execution of actions to find a solution. In other words, it involves decision-making about specific actions, establishing a logical and ordered sequence of facts to be studied and generalized.

We demonstrate here that developing algorithmic thinking does not mean focusing on developing programming. Furthermore, algorithmic thinking involves a logical procedure organized in stages to solve complex problems, carry out everyday tasks, and/or generalize.

Therefore, we emphasize that developing computational thinking in mathematics education requires problem solving that involves concepts related to algebraic and algorithmic thinking.

However, more than conjecturing "what" computational thinking is, we must reflect on "how we can use it in everyday life" and "how we can develop it to interpret information and solve problems." This change in questioning represents the logical-historical movement of computational thinking since we are dealing with the objectification of this type of thinking at the heart of

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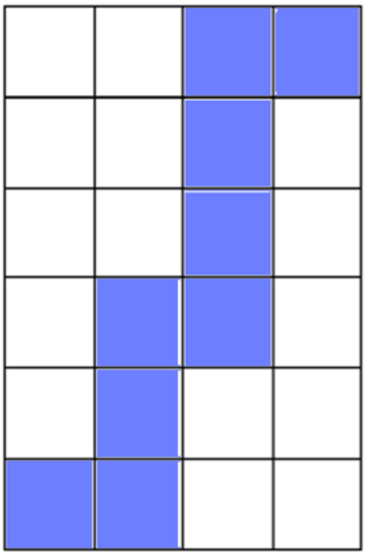
mathematical education; therefore, its connection with students' appropriation and use. Thus, we intend that its concrete content dialectically guarantees the formation of scientific thinking, the production of knowledge, critical reflection, and awareness.

That said, to develop computational thinking, the student must, from a given problem situation, study four movements:

a. interpret data, classifying and ordering them for subsequent analysis and synthesis;
b. raise and systematize hypotheses using different languages and building models;
c. seek regularities;
d. appropriate abstractions that appear in some types of generalization.

Navarro (2021) created an illustrative situation called "Which way to go," proposed in stages. In the first stage, the subjects involved must describe a path, as in the image below.

Figure 2- Which way to go?



Source: Navarro (2021)

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The next step consists of following a route on a 4x6 grid (different from the route shown). Students must also draw a 4x6 grid on a blank sheet of paper and describe the route drawn previously. The only rule at this stage is not to draw inside the grid.

Then, students exchange descriptions and try to draw someone else's route on the grid. After that, we return the sheet to the author of the description to check it.

Then, they socialize their ideas, asking questions such as: Was it possible to draw the path with the description you received? Did you understand the description? Was the person who took the description able to repeat the same path taken in the draft? How could we standardize our language? What mathematics content can be explored in this activity?

Therefore, depending on how it is explored, this situation can enable students to experience the four movements above to develop computational thinking. For example, ideas of syncopated and symbolic algebra, Cartesian plane, and matrix, among other mathematical concepts, can be explored.

On this basis, we defend a dialectical perspective of computational thinking under the aegis of the logical-historical movement (KOPNIN, 1978; KOSIK, 2002), which demands intertwining some psychic functions responsible for organization, discovery, and generalization.

Developing computational thinking in mathematics education is exercising the function of generalizing thinking, which means acting consciously when solving a problem, acting in the ordering and conceptual categorization of reality into sets of objects, data, information, hypotheses, situations, and phenomena.

In this sense, computational thinking is a problem-solving process, with plugged and/or unplugged situations (whether using digital technology or not), which encompasses the interpretation and organization of data, analysis and synthesis, generalization, the abstraction and concretization of concepts related to algebraic and algorithmic thinking (NAVARRO, 2021).

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Finally, from a logical-historical perspective, computational thinking in mathematics education helps students produce mathematical knowledge (algebraic and algorithmic thinking) and develop research and problem-solving skills, which favors students' development and expands their reading of the world by thinking dialectically, i.e., by understanding reality in its entirety.

5 Final considerations

This work aimed to argue and reflect on the concept of computational thinking for mathematical education based on the logical-historical movement. To this end, we conducted a theoretical study of Brazilian productions in mathematics education that deal with the term "computational thinking" through state-of-knowledge research.

The logical-historical movement was fundamental to the development of this concept, as it gave rise to studies on the conditions under which the term has been used in research and everyday school life within the scope of mathematics education.

This study showed that computational thinking was still closely linked to computers and digital technologies. The concept we unfolded shows that we do not necessarily need these technologies to develop this type of thinking in the classroom for teaching mathematics. Problem situations can be applied with plugged and unplugged activities, such as the one exemplified (Which way to go?).

Given all that has been elucidated, investigating the logical-historical movement of the term computational thinking meant recognizing that this type of thinking is in constant movement, adaptation, and social transformation, therefore becoming a historical and dynamic category, as, from the perspective of logical-historical unity, there is an inherence between the historical and the logical, since a logic devoid of the objective/subjective actions of the human being would be impractical.

Thus, we argue that computational thinking, within mathematical education, can help students produce mathematical knowledge (algebraic and

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algorithmic thinking), develop research and problem-solving skills, and broaden their understanding of the world and critical thinking.

Thus, computational thinking cannot be considered isolated, fragmented, and mechanized knowledge based on specific procedures and stagnant rules, tending solely to training skills or developing a programming language.

In this sense, we conceive that CT in mathematics education means solving problems involving the development of algebraic and algorithmic thinking. Therefore, computational thinking is a dialectical movement of thought that aims to guide students in the actions of interpreting, analyzing, questioning, exploring, investigating, decomposing, reflecting, observing regularities, and producing syntheses, tending to the construction of systematizations, resolutions, and /or strategies through mathematical language, resulting in abstraction and generalization. In turn, computational thinking can be a fruitful way to break with the empirical-discursive, technicist, and mechanistic paradigm that aims to train skills and techniques, memorize formulas, and reproduce proofs and axioms through work focused on programming language as a product.

El movimiento lógico-histórico del concepto de pensamiento computacional

RESUMEN
Este artículo presenta el movimiento lógico-histórico del término pensamiento computacional (PC) en educación matemática. El uso del término en educación matemática será abordado cronológica (histórica) y lógicamente. A partir de este movimiento, se explicará el desarrollo del concepto de pensamiento computacional para la educación matemática, entendiendo que no se trata sólo de lenguajes de programación o del uso de computadoras (máquinas), sino que se enfatiza que el desarrollo de este pensamiento puede contribuir al desarrollo de conceptos matemáticos relacionados con el pensamiento algebraico y el pensamiento algorítmico.

Palabras clave: Movimiento lógico-histórico; Educación matemática; Formación de conceptos; Pensamiento computacional.

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