ESPAÇO PEDAGÓGICO
ISSN on-line: 2238-0302

Recebido: 29.09.2023 — Aprovado: 05.05.2024
https://doi.org/10.5335/rep.v30.15264

Metacognition and Computational Thinking in Vygotsky's Historical-Cultural Perspective[1]

A Metacognição e o Pensamento Computacional na Perspectiva Histórico-Cultural de Vygotsky

Metacognición y pensamiento computacional en la perspectiva histórico-cultural de Vygotsky

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Resumo

Em um contexto pós-pandêmico, onde práticas pedagógicas evoluem a partir de diversas bases epistemológicas, destacam-se o incentivo à autonomia e inovação de alunos e professores com protagonismo. Alinhada à Agenda 2030 da ONU, a pesquisa assume por base epistemológica a relação interdisciplinar entre educação e Ciência da Computação ao explorar o Pensamento Computacional associado à Metacognição. O texto aborda as características deste pensamento, identifica lacunas nas bases teóricas e apresenta um escopo que o entrelaça à teoria vigotskiana, Metacognição e Educabilidade Cognitiva. Resultados das reflexões teóricas e conceituais tecidas indicam que a metacognição, quando sistematicamente aplicada, promove o desenvolvimento do pensamento computacional. Para tanto, propomos uma arquitetura funcional ancorada em princípios vygotskianos, diferenciando conteúdos e habilidades, contribuindo para uma compreensão mais robusta deste pensamento com consequências potenciais para outras concepções e desenvolvimento de currículos, não apenas na computação, mas na formação de professores em todas as áreas.
Palavras-chave: Desenvolvimento de Currículo; Educabilidade Cognitiva; Sistema Conceitual.

Abstract

In a post-pandemic context, where pedagogical practices evolve based on different epistemological bases, the encouragement of autonomy and innovation among students and teachers stands out. Aligned with the UN 2030 Agenda, research assumes as an epistemological basis the interdisciplinary relationship between education and Computer Science by exploring Computational Thinking associated with Metacognition. The text addresses the characteristics of this thought, identifies gaps in the theoretical bases and presents a scope that intertwines it with Vygotskian theory, Metacognition and Cognitive Educability. Results of the theoretical and conceptual reflections indicate that metacognition, when applied systematically, promotes the development of computational thinking. To this end, we propose a functional architecture anchored in Vygotskian principles, differentiating content and skills, contributing to a more robust understanding of this thinking with potential consequences for other conceptions and development of curricula, not only in computing, but in teacher education in all areas.
Keywords*:* Curriculum Development; Cognitive Educability; Conceptual System.

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Resumen

En un contexto pospandemia, donde las prácticas pedagógicas evolucionan desde diferentes bases epistemológicas, destaca el fomento de la autonomía y la innovación entre estudiantes y docentes. Alineada con la Agenda 2030 de la ONU, la investigación asume como base epistemológica la relación interdisciplinaria entre educación y Ciencias de la Computación al explorar el Pensamiento Computacional asociado a la Metacognición. El texto aborda las características de este pensamiento, identifica vacíos en las bases teóricas y presenta un alcance que lo entrelaza con la teoría vygotskiana, la Metacognición y la Educabilidad Cognitiva. Los resultados de las reflexiones teóricas y conceptuales indican que la metacognición, cuando se aplica sistemáticamente, promueve el desarrollo del pensamiento computacional. Para ello, proponemos una arquitectura funcional anclada en los principios vigotskianos, diferenciando contenidos y habilidades, contribuyendo a una comprensión más robusta de este pensamiento con potenciales consecuencias para otras concepciones y desarrollos curriculares, no sólo en informática, sino en la formación docente en todos los ámbitos.

Palabras clave*:* Desarrollo curricular; Educabilidad Cognitiva; Sistema Conceptual.

Introduction

In a post-pandemic context, in which different pedagogical practices and concepts have been developed from a range of epistemological bases, one of the aspects that has been gaining notoriety and prominence in the academic sphere is the development of autonomy and innovation on the part of students and teachers (KURTZ; SILVA, 2023; KURTZ; SILVA; KRAJKA, 2021).

In this sense, it is important to consider the role attributed to Information and Communication Technologies (ICT), which, in some scenarios, went from being supporting actors to protagonists in the teaching and learning process, without, however, a deep construction or theoretical elaboration on the part of educators. In line with the UN 2030 agenda (ONU BR, 2015), we believe it is essential to situate the teaching and learning process, in favor of quality education (SDG 4), effectively associated with an educational context with, about and through ICT, from a Vygotskian perspective, that is, as mediational means constitutive of social and pedagogical practices (SILVA, 2020; KURTZ; MACHADO; JOHANN, 2022).

Thus, an interdisciplinary epistemological basis is fundamental. Within the scope of the studies we developed with the Mongaba: Educaction, Languages and Technologies research group, the educational field is closely linked to the area of Computer Science and it is from this perspective that projects and studies involving frameworks and theoretical bases emerge in an integrated manner. Computing, an academic area with its own body of knowledge, generally directs, in undergraduate courses, efforts to develop, together with academics, a set of skills and competencies structured based on fundamental concepts and practices in the area.

These skills and competencies, such as problem-solving, algorithmic thinking, abstrction, decomposition and evaluation, collectively constitute Computational Thinking (CT) (SILVA, 2020) which, according to Wing (2006), author who popularized the term, consists of an approach aimed at solving problems with techniques, tools, practices and concepts of computing, which considers a set of mental processes (mental tools). In 2014, the author added to the definition of CT the concept that such a thought process involves formulating problems and expressing their solutions in a way that humans or machines can carry them out.

Thus, individuals, even not directly involved in the computing area, can develop this thinking without machines. In this sense, characteristics of CT as proposed by Wing (2006) are:

1) Conceptualization - without programming: “thinking like” a computer scientist goes beyond the ability to program computers, as the area itself is not just about knowing how to program, but rather thinking, with multiple levels of abstraction.

2) Fundamental, non-mechanical skill: to act/interact fully in modern society, not just by memorization or repetition.

3) Human way of thinking, not machines: to solve complex problems, with intelligence and imagination, and improve computers.

4) Complementation and combination between mathematical and engineering thinking: computer scientists develop systems that interact with the real world and, due to the restrictions and limits of computing devices, subjects are led to think computationally, and not just mathematically.

5) Ideas, not artifacts: computational concepts for approaching and solving problems, managing our lives, and interacting with others everywhere. They are important and transcend the software and hardware resources produced.

6) For everyone, everywhere: it will be a reality when it is fully integrated into human endeavors, ceasing to be an explicit “philosophy”.

Based on this conception, a substantial amount of work was published regarding experiences, course proposals, curricular reformulations, evaluation, teacher training, among others (BOWER; LISTER, 2015; CURZON *et al*., 2014; NATIONAL RESEARCH COUNCIL, 2011; WERNER; CAMPE; DENNER, 2012; RAMOS; ESPADEIRO, 2014). However, based on the investigation by Silva (2020), it was possible to verify that a significant part of these publications do not direct efforts to present assumptions and theoretical bases that support and guide a broader understanding of CT.

The integration of Vygotsky's cultural-historical theory with the concept of cognitive educability proposed by Fonseca (2018) offers a robust conceptual framework for understanding and fostering CT in the educational sphere. Vygotsky emphasizes the significance of sociocultural mediation in the formation of knowledge, highlighting the interaction between individuals as central to cognitive development (VYGOTSKY, 2007, 2008; IVIC, 2010; DANIELS, 2008).

This perspective echoes Fonseca's (2018) view of education as a mediated process, where metacognition plays a crucial role in the maturation of higher mental functions. By integrating these concepts, we recognize that computational thinking is influenced and enhanced by social and pedagogical interactions, reflecting the cultural values and contexts in which it is embedded (SILVA, 2020). Thus, by exploring these relationships, we aim not only to foster the development of computational thinking but also to strengthen educational practices, enabling educators to promote autonomy, innovation, and quality in student learning.

In this context, the objective of this report is to present a theoretical-conceptual scope that underlies and serves as an articulating axis between the CT, Vygotskian historical-cultural theory, the concepts of Metacognition and Cognitive Education/Educability. To this end, we deepen the understanding of the mental processes and dimensions linked to human development, which structure and support the development of CT in subjects, as well as the epistemological perspectives, which can enhance the teaching and learning process. We seek to expand understanding of CT development in higher education computing courses. The skills that support this particular form of thinking, such as abstraction, generalization, decomposition, algorithmic thinking and evaluation, are conceived as higher mental functions that need to be instituted consciously, both in students and teachers.

To achieve the outlined objective of this research, we adopted a methodological approach that integrates principles from Vygotsky's socio-cultural theory and concepts of metacognition within the context of computational thinking (CT) development. This methodology was chosen due to its capacity to provide a robust theoretical foundation for understanding the cognitive processes involved in CT, as well as to guide pedagogical practice in computer science education.

The research was conducted in several stages, beginning with a comprehensive literature review related to CT development, Vygotskian theory, and metacognition. This review served as the basis for formulating a conceptual model that integrates these elements cohesively and articulately. The conceptual model was then refined through discussions and critical analyses among the researchers involved, ensuring its relevance and applicability in the context of computer science and education in sciences.

In this context, we adopted a comprehensive literature review encompassing empirical, theoretical, and conceptual studies related to Computational Thinking, Metacognition, and Vygotskian theory. The literature review was conducted across academic databases such as Scopus, Web of Science, and Google Scholar, utilizing relevant search terms for each area of study. Inclusion and exclusion criteria were applied to select the most pertinent and significant articles for our investigation. Additionally, we considered the guidelines of the UN's Agenda 2030 and relevant literature on education, cognitive development, and information and communication technology (ICT). Data analysis followed an inductive approach, where emerging patterns and themes were identified and interpreted to inform our conclusions and recommendations.

Given this scenario, this report is organized in five dimensions regarding the association between CT and Metacognition: “Computational Thinking and the role of Abstraction”; “Conceptions of metacognition”; “Metacognition as a strategy for developing computational thinking”; “Metacognition in the context of Cognitive Educability”; and “A conceptual system for the development of Computational Thinking”, followed by some final remarks.

This theoretical and methodological approach allowed us to comprehensively and integratively explore the interconnections between CT, Metacognition, and Cognitive

Education/Educability, offering valuable insights into how these concepts can be applied and developed within the educational context. By providing a solid foundation of research and theory, we hope to contribute to the advancement of knowledge in this area and the improvement of pedagogical practices in basic and higher education.

Computational Thinking and the role of Abstraction

There is still no consensus in the international academic community on the definition of computational thinking (BRENNAN; RESNICK, 2012; GROVER; PEA, 2013; TEDRE; DENNING, 2016; AHO, 2012). However, Brackmann (2017, p. 29) proposes that the CT be recognized, effectively, as “a distinct human creative, critical and strategic capacity to know how to use the fundamentals of Computing, in the most diverse areas of knowledge, with the purpose of identify and solve problems, individually or collaboratively, through clear steps (...)”, reiterating what Wing (2014) points out, so that a person or a machine can execute them.

Cambraia and Araújo (2022) contribute to the discussion by proposing that health education, from the perspective of self-care, health promotion and disease prevention, can be increased with the construction of computational thinking, which enables the processing of essential information decision-making regarding access, understanding, evaluation and use of instruments, standards and guidelines for a quality life.

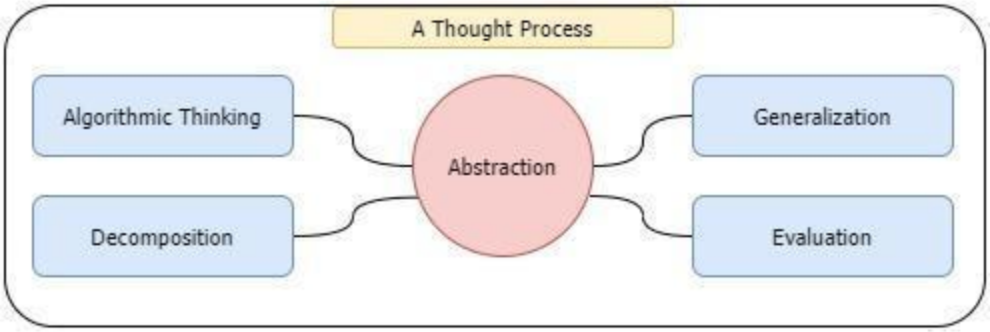
The idea that it is not necessary to use machines to develop the CT is also brought up in studies such as that of Shute, Sun e Asbell-Clarke (2017), which state that it is a “necessary conceptual basis to solve problems effectively and efficiently (i.e., algorithmically, with or without the assistance of computers) with reusable solutions in different contexts” (SHUTE; SUN; ASBELL-CLARKE, 2017, p. 150).

Furthermore, another widespread definition places CT in the dimensions Decomposition, Pattern Recognition, Abstraction and Algorithms - which represent the concepts and/or skills that support this thinking (BBC LEARNING, 2020; BRACKMANN, 2017; GROVER; PEA, 2013; DENNING, 2019).

In these terms, decomposition is associated with the fragmentation of the problem or system into smaller, more easily manageable parts. Pattern recognition makes it possible to identify similar characteristics and properties between and within problems. Abstraction refers to the ability to concentrate efforts only on important information and characteristics, ignoring non-relevant details. And, finally, algorithms involve the ability to develop a solution to a given problem through well-defined steps and rules.

Thus, the most recurrent key concepts of CT are anchored in the conceptions of Wing (2006, 2010, 2014) and Selby and Woollard (2013), which highlight five key concepts (Figure 1), which facilitate the development of curricula for computer science, ensure appropriate assessment methods to measure computational thinking skills and distance “practice” from “thinking skills”.

Figure 1. Key-concepts of Computational Thinking



Source: Silva (2020)

With the selected criteria, Selby and Woollard (2013) suggest that CT can be a cognitive process, which includes the skills of thinking in terms of: algorithm; decomposition; generalizations; evaluation and abstractions. Briefly, Algorithmic Thinking considers the ability to define the steps for solving problems and decomposition proposes looking at problems, algorithms, artifacts, processes and systems in terms of their parts for solving and projecting large-scale systems. Generalization is a process for solving new problems based on already established solutions, which involves the ability to verify structural and functional characteristics common to different domains and situations. The Assessment guarantees an algorithmic solution suitable for the established purposes. And, finally, Abstraction refers to the ability to select attributes and hide the complexity and implementation details in a problem-solving process (SELBY; WOOLLARD, 2013; CURZON *et al*., 2014).

Abstraction has always assumed a prominent role in the scope of Computer Science, reinforced in computing education (KRAMER, 2007; KRAMER, 2006; BLACKWELL; CHURCH*;* GREEN, 2008) because most of the products generated by the area result from computer programming activities: software, which are, naturally, abstractions of processes and data. According to Brookshear (2015), abstraction allows us to distinguish the external properties of a given component from the internal details of its construction. From a holistic perspective, it is important to emphasize that

> [...] Abstraction is not limited to science and technology. It is an important simplification technique through which our society has created a lifestyle that would otherwise be impossible. Few of us understand how the various conveniences of our daily lives are actually implemented. We eat food and wear clothes that we cannot produce ourselves. We use electrical devices and communication systems without understanding the underlying technology. We use the services of others without knowing the details of their professions. With each new advance, a small part of society chooses to specialize in its implementation, while the rest of us learn to use the results as abstract tools. In this way, society's portfolio of abstract tools expands, and society's ability to progress increases (BROOKSHEAR, 2015, p. 25).

In addition to Brookshear's perspective, Kramer (2007) also discusses this cognitive process, suggesting that the software itself is an abstraction. Therefore, based on the definitions of CT, we perceive a thematic and conceptual alignment from Vygotsky, with regard to the concepts of metacognition, metacognitive learning and cognitive educability, as we articulate below.

Conceptions of metacognition

Metacognition has been the subject of research for several years by “educational psychologists”, with a relevant role in the teaching and learning process at all levels of education (GETTING…, 2020). The American psychologist John H Flavell, a specialist in child cognitive development, is recognized for introducing the term in the 1970s as a result of research focused on children's knowledge and monitoring their memory processes. Furthermore, he was a pioneer in studies on developmental psychology theories and carried out an extensive study on Piaget's work (FLAVELL, 1975).

Regarding metacognition and monitoring, Flavell (1979) defines that “cognitive enterprises” in all their breadth and variety occur through actions and interactions between four classes of phenomena: (a) metacognitive knowledge, (b) metacognitive experiences, (c) objectives or tasks and (d) actions or strategies.

Metacognitive knowledge is that stored in a child or adult, which admits people as “cognitive creatures”, with their diverse tasks, objectives, actions and experiences. Metacognitive experiences are any conscious cognitive experiences that accompany and belong to any intellectual endeavor. Goals or tasks refer to the objectives of a cognitive enterprise. Actions or strategies refer to the cognitions or other behaviors employed to achieve goals. From this perspective, Dantas summarizes,

> If in Flavell's perspective, metacognition is related to knowledge of one's own knowledge and knowledge of the mechanisms of thought to learn, Piaget evokes these two movements when defining formal thinking as capable of understanding, interpreting and constructing abstract systems and theories. In this interrelationship with knowledge, which is no longer concrete or real, in which hypothetical-deductive thinking is necessary, the subject becomes capable of deducing conclusions through pure hypotheses, which involves much greater mental work (DANTAS; RODRIGUES, 2014, p. 227).

However, Flavell was not the first to study metacognitive processes. When analyzing socio-historical-cultural theory (VYGOTSKY, 2007), it is possible to recognize that its central assumptions and concepts are closely related to metacognitive principles. Even though the original elaborations are chronologically distant from the first explicit names on metacognition, several researchers have contributed to presenting, articulating and reflecting on the processes considered metacognitive (DANTAS; RODRIGUES, 2014; FONSECA, 2018; IVIC, 2010).

The idea of the Zone of Proximal Development (ZPD) (VYGOTSKY, 2007) as a region/space that lies between what a student can achieve alone and what they can achieve with specialized guidance, in which the specialist (teacher) assumes the responsibility for monitoring progress, set goals, plan activities and allocate attention. Soon after, gradually, responsibility for these cognitive processes is handed over to the student as they become more capable of regulating their own cognitive activities. This transition described by Vygotsky would currently be considered metacognitive development (GETTING…, 2020).

For Vygotsky, human nature could only be understood by considering the context and sociocultural reality of individuals. Regarding the development process, especially that of children, he argues that it is related to concepts of transformation, conflict and overcoming, which are formed in the relationship between internal and external factors. Furthermore, he adds that human beings control their own behaviors, first through external means and, later, through internal, more general, abstract and complex operations. In this context, he mentions that external interventions promote internal mechanisms of self-reflection and self-control of behavior. In a prospective movement, learning enables and stimulates the development of typically human and culturally organized psychological characteristics (VIGOTSKY, 2007).

In this sense, Ivic (2010, p. 26) states that “even today, Vygotsky's theory is the only one that offers, at least in principle, the possibility of conceptualizing, in a scientific way, the metacognitive processes” that allow connecting this perspective of general cognitive development, as well as understanding the origin of the subject's ability to control their own inner processes, which describe the transition from external and interindividual control to individual intrapsychic.

Ivic (2010) points out that the metacognitive dimension of development proposed by Vygotsky is a result of his elaborations on the process of concept formation. Under these conditions, learners can acquire awareness of their knowledge processes, which are the core of metacognition. Furthermore, Vygotsky's contributions are evident because, instead of considering metacognitive processes as simple practical self-control techniques, a complete theoretical framework is proposed, in which the problems of metacognitive processes are inserted in the theory of the development of higher mental functions. From this perspective, metacognitive processes appear as a necessary step and, therefore, play an important role in the restructuring of cognition in general, with their function centered on understanding development as a process of transforming relationships between particular mental functions.

Metacognition as a strategy for developing computational thinking

The historical-cultural perspective constitutes a significant source of research on metacognitive processes in contemporary psychology (DANTAS; RODRIGUES, 2014; FONSECA, 2018; IVIC, 2010). The role of these processes in education is extremely important, as stated by Ivic (2010, p. 27) “[...] the absence of theoretical and empirical research, which could be conceived within the framework of this theory [...], is the only reason that explains why these processes have not yet been taken into account in education”.

In general, the process of metacognition and related concepts emerge as a strategic focus associated with the concepts of Cognitive Educability (CE) (FONSECA, 2018). In this context, metacognition can contribute to expanding understanding about CT as a means/instrument to guide teachers and academics in the process of developing this type of thinking.

Thus, metacognition, in cognitive educability, can enhance and qualify the teaching and learning process to the extent that it establishes a reflective view on the characteristics of CT and directs strategic actions to stimulate and produce meanings, facilitate (mediate) the process of meaning and contribute to conceptual elaboration. To this end, the process of conceptual elaboration occurs in terms of increasing generalization, psychic modifications, constant resignifications and, ultimately, awareness of what is known and practiced (ANDRADE, 2010). In these terms, metacognition, according to Silva (2020), is an essential condition for teachers and students to become aware of the cognitive processes used in the act of teaching and learning.

According to the report on metacognition and self-regulated learning published by the Education Endowment Foundation, an educational research and funding institution in England (QUIGLEY; MUIJS, 2018), there is a range of fundamental concepts and a set of strategies that can be used to encourage metacognitive and self-regulated learning in the classroom.

Considering that the evidence produced by research is often generic and difficult to interpret, the report compiled and systematized recommendations to facilitate understanding and use in formal educational spaces. Table 1 summarizes the seven recommendations proposed in the report.

Table 1 - Recommendations to encourage metacognitive and self-regulated learning

Recommendation	Synthesis
1. Teacher's understanding and professional skills to develop students' metacognitive knowledge	• Self-regulated learners, aware of their strengths, motivate and qualify themselves by developing metacognitive knowledge, while support from teachers is crucial for planning and evaluating learning.
2. Explicitly teach metacognitive strategies, including planning, monitoring, and evaluating learning	• Explicitly teaching cognitive and metacognitive strategies qualifies learning, being more effective when adopted together with specific content, following a sequence that goes from the activation of prior knowledge to structured reflection.
3. Model own thinking to help students develop their cognitive and metacognitive skills	• Modeling by the teacher, by revealing the thought processes of an experienced learner, is essential for developing metacognitive skills. Verbalizing metacognitive thinking during activities, along with "scaffolding" tasks such as worked examples, helps students develop their cognitive and metacognitive skills.
4. Set an appropriate level of challenge to develop students' metacognition and self-regulation	• The challenge is fundamental for the development of students, but it must be appropriate, motivating them to apply new strategies without overloading their cognitive processes.
5. Promote and develop metacognitive conversation/talk in the classroom	• In addition to explicit instruction and modeling, classroom dialogue is essential for developing metacognitive skills, with conversations between students and teachers building knowledge of cognitive strategies. Effective dialogue requires objectivity, with teachers orienting to challenges and building on prior knowledge.
6. Explicitly teach how to effectively organize and manage autonomous learning	• Teachers should explicitly support students to develop independent learning skills, using carefully designed practice with gradual withdrawal of support. Timely feedback and effective strategies are essential for accurate assessment, while supporting student motivation is critical for

	accomplishing learning tasks.
7. Support for teachers to develop their knowledge of such approaches and their adoption in schools	• Professional development and high-quality resources are essential to improving teachers' knowledge. Managers must provide time and support to ensure consistent implementation, while methods such as observation and structured interviews help assess self-regulated learning skills. Metacognition should be incorporated into teaching activities, not being an additional task for teachers.

Fonte: Adapted from Quigley and Muijs (2018)

It is possible to see that the recommendations have a strong relationship with several assumptions and principles of Vygotsky's theory. Reading highlights this approach, as the guidelines, even if of a practical and applied nature, are based in some way on concepts such as: scaffolding, higher mental functions ('higher order' thinking), zone of proximal development, consciousness, reflection, autonomy, among others.

Another experience reported in the international literature based on metacognition is the proposal from the University of Cambridge, with the “Cambridge Assessment International Education”, which can be consulted on a website with theoretical, practical and material information on the relevance of metacognition in education (GETTING…, 2020). This proposal provides for the description of the metacognitive process when students plan, monitor, evaluate and make changes to their own learning behaviors. It adds two dimensions: metacognitive knowledge, that is, what students know about learning, including knowledge about their own cognitive abilities, with different task strategies when appropriate; and metacognitive regulation, linked to what students do about learning, how they monitor and control their cognitive processes: when they deduce that, through a specific strategy, they are not obtaining the desired results, they decide to try a different one.

Thus, the literature reported here illustrates the conceptual articulation that we have noticed in our studies, that the process of metacognition is closely associated with the development of CT as an approach to cognitive education that qualifies the teaching and learning process, as well as meaning and conceptual elaboration, whether as metacognitive knowledge or metacognitive regulation (what we know how to do about knowledge, monitoring and controlling it).

Metacognition in the context of Cognitive Educability

The concept of Cognitive Educability represents a different perspective to support teaching-learning processes and qualify formal education at its different levels (DALMINA; NOGARO; BATTESTIN, 2016; FONSECA, 2018; GONÇALVES, 2010; PEA; KURLAND, 1984). It places metacognition as a protagonist component in the systematized process of intentional interaction, enabling the maturation of higher mental functions. In the case of this investigation, such functions are identified as constituent and articulating skills of the CT.

Cognitive Educability must be contextualized, structured and carried out within the teaching and learning process. In this sense, contrary to what is traditionally accepted, in education, learning is not separated from teaching. Both teaching and learning establish a dialectical relationship and the terms shape each other in the process of cultural transmission (BERNI, 2008; DANIELS, 2008; FARIA; CAMARGO; VENÂNCIO, 2020; FONSECA, 2018; MARTINS; STOLTZ, 2020). From this perspective, subjects learn and develop through mediation activities (VYGOTSKY, 2008) or, as Fonseca (2018) proposes, mediatization[5]. In general, such activities involve dynamic interaction between human beings

> [...] in the dimension of mediatization, and in our pedagogical-ethical perspective, it is the essence of the teaching-learning process, it contains other more transcendent values of a non-material nature that are linked to the expansion and promotion of executive, conative and intersubjective cognitive benefits, that is, between co-creating subjects and co-authors of an interaction that influences the transmission and critical and creative assimilation of knowledge, and facilitates, expands, expands and promotes, concomitantly, the entire learning process, the true core of media coverage (FONSECA, 2018, p. 13).

In line with these assumptions, Roldão (2020) observes that, without appropriate mediation, the chances increase that students (mediatized) will continue using the signs that are familiar to them, without creations or transformations and, consequently, without forming other psychological links fundamental for cognitive development. Therefore, learning is characterized by modifiability, a process of recurring changes triggered by the teacher's mediatization and the student's intentional and motivational practice.

Cognitive Educability is made up of three components: critical thinking, creative thinking and metacognition with the intention of creating conditions for the development of cognitive functions in the process of intentional interaction, gradual enrichment of these functions, and not the pure, frontal and simple content, information or knowledge.

Fonseca (2018) highlights that the sooner we institute this type of cognitive intervention (based on scaffolding) in education, and in the training of individuals, the more positive results will be achieved. In this context, cognitive functions are requirements for critical, creative thinking and effective learning. In a traditional education system, characterized by complacency and demotivation, which delivers meaningless content that is not even cognitively integrated by students, these types of thinking do not develop.

From the systemic perspective of Cognitive Educability, the proposed tasks must involve the identification of elements that form part of a general knowledge system, formed by units and subunits, integrated in an interdependent manner and organized horizontally and vertically. The model of this system represents the totality of the contents, the various hierarchical units formed by components that interact with each other to reinforce and stabilize the knowledge itself in the students' cognitive structure. From this perspective, Fonseca (2018) highlights that:

[5] The author adopts the term “mediatization” instead of the term “mediation”. According to his understanding, mediatization is different because its relationship is centered on the interaction between two human beings with a focus on cultural transmission. Mediation means the relationship between two human beings in negotiation, commercialization or similar processes. In mediatization, the common pedagogical, cultural and interactive relationship is emphasized, considering the entire transcendental breadth of cultural learning and the acquisition of knowledge that passes between subjects and between generations. From a pedagogical, scientific and ethical perspective, mediatization differs from mediation because it is established in a dynamic process of promoting cognitive functions in learning beings.

> [...] The solution to each task requires access to strategies already learned in others, and vice versa, so that each one becomes a dynamic element of the knowledge system to be transmitted culturally. Solving tasks or implementing problems and projects is not a single purpose, the important thing is to discover the cognitive principles that are underlying and that connect the various components together (FONSECA, 2018, p. 182).

Based on these understandings, four cognitive principles are proposed by Fonseca (2018), for planning pedagogical actions within the scope of Cognitive Educability: 1) any task can have several solutions and not just a single one; 2) focusing more on the importance of the strategies and cognitive principles at play than on the operations and problem-solving procedures; 3) the strategies to be learned should, as much as possible, be applicable in various contexts; 4) cognitive functions must incorporate the conceptual structure of all disciplines in the training context under consideration. In this way, students inevitably develop autonomy and conditions for new and unexpected learning in future situations, problems, tasks or domains (DANIELS, 2008; FONSECA, 2018; IVIC, 2010).

In this conception of education, it is not the subject (learner) who has to adapt to the task. Cognitive Educability, for Fonseca (2018, p. 184) "shifts the focus from failure [...] to the modalities and processes of instruction, often without quality, without mediatizing effectiveness and without any connotation, but only loaded with didactic rigidity". The arguments presented reinforce the responsibility of the school and the media as a privileged space to employ mental tools that associate the individual's subjective knowledge with the collective cultural heritage (DANIELS, 2008; DEWEY, 2012; VIGOTSKY, 2008).

Thus, it is a process that permeates teaching and learning in all fields, as well as the development of the CT itself. But, specifically, in undergraduate courses in Computer Science, the development of this thinking is expected. Computers and their systems, whether in theoretical or practical conceptions, of use or creation, clearly assume the role of mental instruments or tools. Even though such computational resources, in their diversity and plenitude, often awaken very simplified visions and understandings with a strictly utilitarian scope, it is irrefutable that the social impact of these human creations conditions them as high-order symbolic tools or cognitive tools (JONASSEN, 2007).

In the context of Cognitive Educability, the teacher needs to know the process of internalization, because as Souza (2013) points out, "it is the first step in trying to understand the process of acquiring knowledge carried out by students in apprehending the object of study'' (SOUZA, 2013, p. 78). Even though Cognitive Educability has other paradigms and dimensions of analysis, metacognition naturally assumes centrality and protagonism in this social, educational and training environment full of meanings, whether of a theoretical and/or practical nature. This understanding is also evident in the literature consulted (DALMINA; NOGARO; BATTESTIN, 2016; FONSECA, 2018; GONÇALVES, 2010; IVIC, 2010). With this premise, definitions, conceptions, reflections and guidelines are presented, which designate the limits and contours of metacognition.

According to Bruner (1973 *apud* FONSECA, 2018), any individual, in principle, has the "virtuality" of thinking about their own thoughts, at the same time as they are mentally capable of correcting their ideas and elaborations through internalized reflection. Furthermore, you are effectively capable of "going beyond your thinking" (going meta). Meta, from Bruner's perspective, illustrates students' ability to reflect on their own knowledge and perspectives, that is, they are able to think about their thinking. In this sense, according to Dewey (2012), most individuals have the capacity for reflection, which allows them to develop more original and enlightened ideas, as long as they are explicitly and intentionally mediated (DANIELS, 2008).

In addition to this perspective, for Hartman (2001), metacognition refers to the knowledge and awareness of one's own cognitive process, or, equivalently, a cognition of cognition. Cognitive skills perform the intellectual work deliberated by metacognitive controls, which involve management, planning, monitoring and evaluation processes.

In the teaching and learning process, therefore, although cognitive skills are important, it is essential to emphasize metacognitive ones. Using metacognition, the individual is aware that their implicit cognitive processes can become explicit, that is, metacognition happens when we think about our own thoughts, reflect, understand knowledge, are learning or even making some mistake.

Thus, it is important to highlight that a dimension of metacognition is based on the Vygotskian principle that, in general, all teaching depends on the introduction of the word (VYGOTSKY, 2008), which allows the manifestation of thoughts, sensations and reflections. The word plays a central role in consciousness and, according to Ivic (2010), is the most direct expression of the historical nature of human consciousness. In this sense, once mobilized and put into operation, metacognition allows, in a flexible and reflective way, to face future problems, which may be posed by unprecedented and unpredictable circumstances. It stimulates the development of “generalizing perceptions” and abstractions, which, according to Vygotsky (2008), has a decisive role in the individual’s awareness of their own mental processes.

In the broad spectrum of definitions and understandings surrounding metacognition, Fonseca (2018) proposes its categorization into two distinct types of metacognition: cognitive and praxis. The first involves functions of monitoring and reflecting on current or recent knowledge, covering factual knowledge and knowledge of the problems to be solved, their objectives and their strategic approaches. Furthermore, you must know when and how to use sophisticated methods to resolve and conclude effectively. In the second, metacognition occurs when students consciously adapt and control their cognitive strategies during the solution and consolidation of a problem and during the elaboration of an intentional thought that advances, presupposes and surpasses any spontaneous action resulting from complex learning.

In this sense, we can verify that “metacognitive knowledge” and “metacognitive experiences” have a dialectical relationship, of mutual influence. Knowledge allows us to interpret experiences and operate on them, and experiences, in turn, contribute to the development and alteration of this knowledge.

In Vygotskian thought, metacognition presents itself as a way to increase students' ability to understand and apply, from its simplest concepts (spontaneous and everyday) to the highest conceptualization and abstraction, represented by scientific concepts (VYGOTSKY, 2008). In this sense, metacognition enables the student to produce generalizations on a recurring basis, which makes it possible to develop executive functions with greater capacity to implement and materialize the cognitive processes they elaborate (FONSECA, 2018).

Thus, awareness is a fundamental element for the teaching and learning process. Metacognition appears to be a viable way to mediate this process. Among the fundamental characteristics of metacognition is its dual vocation, which largely meets both the needs of teachers and students. In the case of the teacher (mediator), he/she can contribute to the planning of his/her pedagogical practices linked to the act of teaching and to the student as a strategic resource for autonomous learning. In both cases, the expected result is a gradual awareness of the processes used to teach and learn.

In terms of academic production on the topic, it is interesting to check works, both nationally and internationally. In the context of CT, several initiatives highlight the importance of metacognition to improve student learning. Basu (2017) proposes an open online learning environment, centered on the "Computational Thinking using Simulation and Modeling" (CTSiM) framework, which uses adaptive supports to stimulate computational thinking. The study reveals that students who received this support presented more accurate models and a better understanding of the fundamental concepts of the PC.

Educational robotics is explored as a pedagogical resource for the development of the PC, as highlighted by Atmatzidou (2016), regarding the positive influence of robotics on students' critical thinking, problem solving and metacognitive skills. Kalelioğlu (2015), similarly, relates educational robotics and programming as mediators for the development and application of metacognitive skills.

A third dimension, programming, had already been explored a long time ago by Pea (1984), in a critical analysis of programming learning, indicating that functional programming skills require metacognitive approaches, in addition to simple grammaticality. It highlights the importance of metacognitive strategies, particularly with adolescent students. This theme was recently the subject of the work of Romero (2017), who proposes the use of creative programming techniques to develop PC in higher education students, emphasizing the importance of creative and problem-solving skills.

More recently, in the article entitled “A reflection on knowledge already elaborated: metacognition and computational thinking in the use of robotics”, Batistela, Rosa e Teixeira (2022), present results of a systematic mapping that compiled and reflected on the relationships between metacognition, the CT and educational robotics. Overall, the study produces understanding that through metacognition, students can monitor and evaluate their own progress in learning computer programming and robotics, identifying their own strengths and weaknesses and developing more effective learning strategies.

Reiterating previous studies, they highlight that robotics can also be used as a pedagogical tool for learning metacognition, as it allows students to experiment and reflect on their own learning processes, monitoring and regulating their own thinking. An important issue recorded in the conclusions of the work is the need to carry out theoretical in-depth studies on CT and metacognition, especially with regard to establishing relationships between the terms.

Thus, throughout this epistemological chain, we seek to explain the conception of CT as the ability to transpose abstract meaning into concrete, considering a set of cognitive and metacognitive strategies related to computer science. The reviewed literature reveals two perspectives on the relationship between metacognition and CT: one highlights the need for mediating supports to stimulate metacognitive skills, while the other suggests that CT, in itself, is identified as metacognition. However, this discussion remains open in the context of professional training in higher education.

A conceptual system for the development of Computational Thinking

Among the goals of the research is the intention to understand the CT development process through consistent theoretical supports, which involve cognitive development, conceptual thinking and human learning.

During the investigation, it was possible to recognize the approach, relationship and alignment of the concept of metacognition in various ways with the characteristics of the CT and its development with computing academics. From the perspective of metacognition, it is possible to expand the understanding of this process, as it presents conceptual and practical elements to explain, justify and guide, through reflection, significant actions, which qualify the teaching and learning process.

As discussed, metacognitive strategies are suitable for supporting both teachers (mediatizers) and students (mediatized). Furthermore, the concept of metacognition directly contributes to the understanding of several constituent elements of CT, such as abstraction, generalization, decomposition, evaluation and algorithmic thinking, presented previously.

Notoriously, throughout the study carried out, we expanded understanding and triggered many other challenges and investigative processes, in which the theoretical path adopted, based on Vygotsky, led to the constitution of differentiated teacher knowledge, for us, colleagues in the area and their colleagues. learners – regarding the role of PC and metacognition in their training. This, in turn, proved to be one of the great results of the study, in the sense of promoting the development of students if used systematically, as metacognition enables the student's engagement in their own training process, at a theoretical level, noting that the value of objects is not on the surface, but must be discovered.

Thus, the systematic presentation of a conceptual system, capable of being used in computing courses, serves as an element of dialogue with institutions and teachers. As the main purpose of this investigation was the identification of basic elements of a conceptual system to support the understanding and development of CT, the framework of this system was developed based on several assumptions and theoretical elements of Vygotsky's historical-cultural theory.

Thus, two main aspects support and outline the contours of this conceptual system:

a) The CT is conceptually idealized as a superior mental function and, within the scope of its development in computing courses, as a greater competence; It is

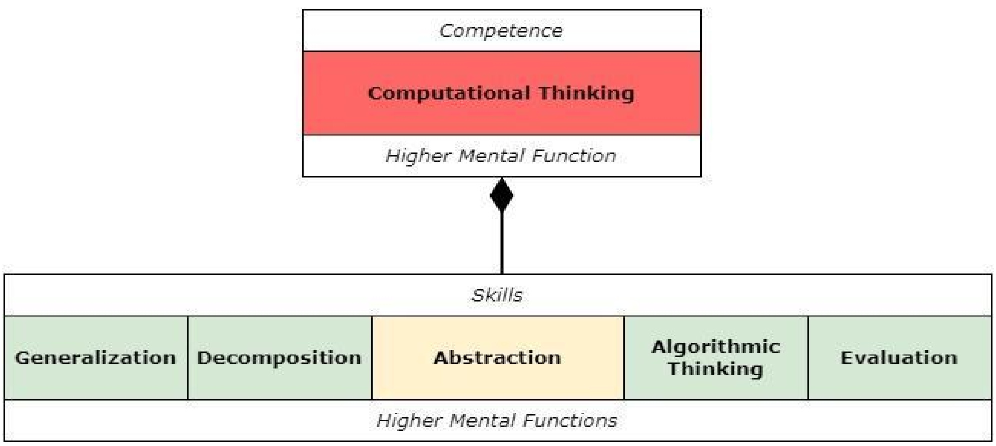
b) the other parts that support and make up the CT (generalization, abstraction decomposition, algorithmic thinking and evaluation) are higher mental functions.

From the perspective of planning pedagogical actions, understood as a set of skills, it is worth highlighting that, among the skills, abstraction plays the most important role. In this context, the CT is conceived as a competence, as it has a greater scope, as an objective to be achieved by computing professionals. To make this competence viable, several skills of a particular order, with a specific scope, are necessary, which must be developed to implement CT as a major competence.

Two important guiding documents such as the area's curricular guidelines (MEC, 2016) and the training references for undergraduate courses (ZORZO *et al*., 2017) do not list CT as a skill to be developed, they only indicate that the bachelor's degree courses in the area area of computing must provide professional training that reveals the skills and competencies to “recognize the importance of computational thinking in everyday life and its application in appropriate circumstances and in different domains” (MEC, 2016).

A visual representation of part of this conceptual system is presented in Figure 3.

Figure 3 - Computational thinking as a higher mental function



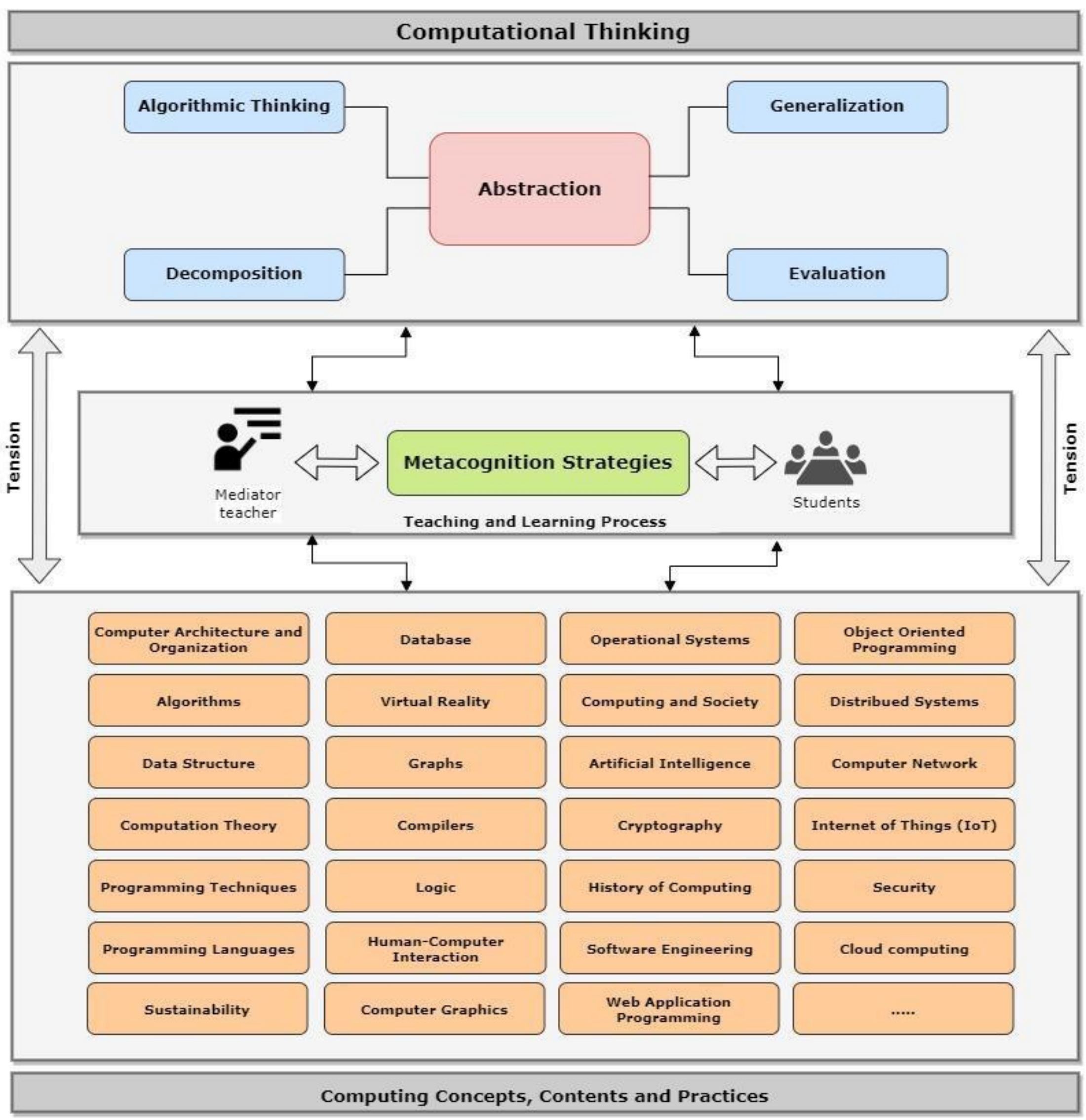
Source: Silva (2020)

Therefore, if the CT and the skills that support it are superior mental functions, it is important to revisit some of Vygotsky's assumptions: i. All higher mental functions are sign-mediated processes; ii. The word as a sign plays an important role in the formation of concepts; iii. The concept has a social origin and its formation depends on the relationship with other subjects; iv. The development of higher mental functions occurs within social relationships, through the mediation of other person(s); v. Learning results from these assumptions; vi. Learning is decisive in the process of conceptual elaboration and in becoming aware of one's own mental processes (IVIC, 2010; VYGOTSKY, 2007, 2008).

Still within the scope of the proposal for a conceptual system, we propose a functional structure (architecture) to help guide the CT development process and contribute to the teaching and learning of computing. The scheme is supported by principles of Vygotsky's cultural historical theory, in particular metacognition, as a way of establishing awareness of knowledge and mental functions used in the learning process, and mediation (symbolic and instrumental), as an intentional process of meaning and initial responsibility of the teacher.

The elaborate architecture (Figure 4) seeks to explain the separation (distinction) between the contents and subjects in the area of computing knowledge that are part of the different disciplines present in higher education curricula, and the skills that condition and support the CT. This system indicates that the skills (generalization, decomposition, abstraction, algorithmic thinking and evaluation) must have a broad coverage of computing concepts, content and practices, that is, they must be explicitly considered and encouraged during the teaching process. Teachers need to understand the dialectical relationship between CT components and the concepts, content and practices of computing as an area of knowledge.

Figure 4 - Architecture for developing computational thinking



Source: Silva (2020)

In this sense, the concept of Cognitive Educability is an appropriate space to put this conceptual system into operation, as it aims to develop cognitive functions based on intentional interaction processes. In line with this conception, Fonseca (2018) indicates that Cognitive Educability enables the gradual and evolutionary enrichment of these functions and not the pure, frontal and simple transmission of information, content, or knowledge.

Thus, the proposal for this conceptual framework considers some premises indicated by Vygotsky's approach to support cognitive development and the teaching and learning process: i. concept is not learned through mechanical training, nor transmitted by the teacher to the student; ii. direct teaching of (computing) concepts is impossible and fruitless; and, iii. innatist conceptions, which lead to spontaneous and unchallenging pedagogical practices, underestimate the individual's intellectual capacity (FARIA; CAMARGO; VENÂNCIO, 2020; VYGOTSKY, 2007, 2008).

Final considerations

At the end of this research, an in-depth understanding of the CT development process emerges through the revised theoretical scope, focusing on cognitive development, conceptual thinking and human learning. The articulation of metacognition with the characteristics of the CT proves to be fundamental, offering conceptual and practical elements to qualify the teaching and learning process.

In this sense, metacognitive strategies are relevant both for teachers as mediators and for students as mediatized, providing a more comprehensive understanding of CT, addressing elements such as abstraction, generalization, decomposition, evaluation and algorithmic thinking. The study expanded understanding, provoked challenges and instigated investigative processes, consolidating differentiated knowledge for teachers and apprentices in the area of computing.

We realized that metacognition, as a central result, stands out for promoting the development of students when applied systematically, actively involving them in their own training process. The systematic presentation of a conceptual system, based on Vygotsky's historical-cultural theory, provides an effective dialogue with institutions and teachers, offering a framework for understanding and developing CT.

Furthermore, the proposal for a functional architecture, supported by Vygotskian principles, differentiates the specific contents of the computing area from the fundamental skills of the CT. We also highlight the importance of abstraction as a central skill, conceiving the CT not only as a set of particular skills, but as a broad competence to be developed by computing professionals. Current curricular guidelines and training references fail to explain CT as a competency, which highlights the need for an approach that recognizes it as a superior mental function in our view.

In this way, this research sought to contribute to a more robust and integrated understanding of the CT, establishing solid theoretical foundations and practical guidelines for teaching and learning computing. The proposed architecture sought to guide the development of this thinking, emphasizing the interrelationship between skills and content.

Cognitive Educability emerges as an appropriate space to operationalize this conceptual system, allowing the gradual enrichment of cognitive functions through intentional interactions. By adopting Vygotskian premises, we recognize that CT learning does not occur through mechanical training, but through challenging interactions that respect the individual's intellectual capacity and metacognition, which can represent significant changes in the design and development of curricula not only in the field of computing, but also in teacher training in all areas.

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Como citar este documento:

SILVA, Denilson Rodrigues da; KURTZ, Fabiana Diniz; ARAÚJO, Maria Cristina Pansera. Metacognition and Computational Thinking in Vygotsky's Historical-Cultural Perspective. *Revista Espaço Pedagógico*, Passo Fundo, v. 30, e15264, 2023. Disponível em: https://doi.org/10.5335/rep.v30.15264.