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Metacognition in mathematics teaching and learning: foundations, strategies and pedagogical possibilities

Metacognição no ensino e aprendizagem da matemática: fundamentos, estratégias e possibilidades pedagógicas

Metacognición en la enseñanza y el aprendizaje de las matemáticas: fundamentos, estrategias y posibilidades pedagógicas

Mariana Figueira Secafim [a]
Cuiabá, MT, Brasil
Federal University of Mato Grosso (UFMT), Institute of Education

Marta Maria Pontin Darsie[b]
Cuiabá, MT, Brasil
Federal University of Mato Grosso (UFMT), Institute of Education

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Abstract

Mathematics occupies a central place in the school curriculum and is, at the same time, identified as one of the disciplines with the highest rates of difficulty, failure and rejection among Basic Education students. This scenario highlights the need to understand the cognitive processes underlying mathematical learning beyond the execution of algorithms and the memorization of formulas. This article aims to analyze, from a theoretical and reflective perspective, the role of

[a] PhD Student in Education, email: marianasecafim@gmail.com
[b] PhD in Education, email: marponda@uol.com.br

metacognition in the teaching and learning of mathematics, exploring its conceptual foundations, strategies and the pedagogical possibilities arising from it. This is an analytical theoretical literature review, conducted through the selection and articulation of classical and contemporary works on metacognition, learning strategies and mathematics education. The analysis revealed that the historical difficulties in mathematics teaching reflect, to a large extent, the absence of a reflective dimension in learning processes — that is, students' lack of awareness of their own cognitive processes. The metacognitive strategies of planning, monitoring and evaluation demonstrated potential to transform this relationship, promoting autonomy and self-regulation. It is concluded that the intentional promotion of metacognitive practices in the classroom, by both teachers and students, constitutes a relevant pedagogical framework for overcoming the historical difficulties in mathematics teaching, making learning more conscious and autonomous.

Keywords: Metacognition. Mathematics Education. Metacognitive strategies. Self-regulation. Learning Autonomy.

Resumo

A matemática ocupa lugar central no currículo escolar e, ao mesmo tempo, é apontada como uma das disciplinas com maiores índices de dificuldade, insucesso e rejeição entre estudantes da Educação Básica. Esse cenário evidencia a necessidade de compreender os processos cognitivos subjacentes à aprendizagem matemática para além da execução de algoritmos e da memorização de fórmulas. Este artigo tem como objetivo analisar, de forma teórica e reflexiva, o papel da metacognição nos processos de ensino e aprendizagem da matemática, explorando seus fundamentos conceituais, suas estratégias e as possibilidades pedagógicas que dela decorrem. Trata-se de uma revisão teórica analítica da literatura, conduzida por meio da seleção e articulação de obras clássicas e contemporâneas sobre metacognição, estratégias de aprendizagem e Educação Matemática. A análise revelou que as dificuldades históricas no ensino de matemática refletem, em grande medida, a ausência de uma dimensão reflexiva nos processos de aprendizagem, ou seja, a falta de consciência dos estudantes sobre seus próprios processos cognitivos. As estratégias metacognitivas de planejamento, monitoramento e avaliação demonstraram potencial para transformar essa relação, promovendo autonomia e autorregulação. Conclui-se que a promoção intencional de práticas metacognitivas em sala de aula, tanto por professores quanto por estudantes, constitui um referencial pedagógico relevante para superar as dificuldades históricas no ensino de matemática, tornando a aprendizagem mais consciente e autônoma.

***Palavras-chave**: Metacognição. Educação Matemática. Estratégias metacognitivas. Autorregulação. Autonomia da aprendizagem.*

Resumen

Las matemáticas ocupan un lugar central en el currículo escolar y, al mismo tiempo, son señaladas como una de las disciplinas con mayores índices de dificultad, fracaso y rechazo entre los estudiantes de la Educación Básica. Este escenario evidencia la necesidad de comprender los procesos cognitivos subyacentes al aprendizaje matemático más allá de la ejecución de algoritmos y la memorización de fórmulas. Este artículo tiene como objetivo analizar, desde una perspectiva teórica y reflexiva, el papel de la metacognición en los procesos de enseñanza y aprendizaje de las matemáticas, explorando sus fundamentos conceptuales, sus estrategias y las posibilidades pedagógicas que de ella se derivan. Se trata de una revisión teórica analítica de la literatura, realizada mediante la selección y articulación de obras clásicas y contemporáneas sobre metacognición, estrategias de aprendizaje y educación matemática. El análisis reveló que las dificultades históricas en la enseñanza de las matemáticas reflejan, en gran medida, la ausencia de una dimensión reflexiva en los procesos de aprendizaje, es decir, la falta de conciencia de los estudiantes sobre sus propios procesos cognitivos. Las estrategias metacognitivas de planificación, monitoreo y evaluación demostraron potencial para transformar esta relación, promoviendo la autonomía y la autorregulación. Se concluye que la promoción intencional de prácticas metacognitivas en el aula, tanto por parte de los profesores como de los estudiantes, constituye un referencial pedagógico relevante para superar las dificultades históricas en la enseñanza de las matemáticas, haciendo el aprendizaje más consciente y autónomo.

***Palabras clave**: Metacognición. Educación Matemática. Estrategias metacognitivas. Autorregulación. Autonomía del aprendizaje.*

1. Introduction

Mathematics has historically occupied a central place in the school curriculum, being simultaneously valued as fundamental knowledge and recognized for the difficulties it imposes on teachers and students. High failure rates, aversion to the subject (Brito, 1998), and the perception that mathematics is a field restricted to a few talented individuals, reflecting its historical function as an instrument of social selection (D'Ambrósio, 2001), compose a scenario that has persisted over the decades in Brazilian Basic Education. This paradox, a subject considered essential but widely feared, reveals not only gaps in content teaching but, above all, the absence of a deeper understanding of how students learn, think, and regulate their own cognitive processes in the face of mathematical challenges.

The increasing complexity of contemporary educational contexts demands that pedagogical practices transcend the logic of mere information transmission and memorization of procedures. In this scenario, metacognition emerges as a highly relevant theoretical and practical field, proposing that the learner should not be merely a passive recipient of content, but a reflective agent of their own thought processes. Defined in its classic formulation as cognition about cognition (Flavell, 1976), metacognition concerns the subject's ability to monitor, control, and evaluate what they know, what they do not know, and how they are learning.

In the specific field of mathematics, this reflective dimension acquires particular relevance. Solving a mathematical problem is not just applying an algorithm: it is a complex cognitive activity that involves understanding the problem statement, developing plans, monitoring the solution process, identifying errors, and evaluating the results. These processes largely require metacognitive skills that need to be intentionally developed. Costa (1984) argues that, to develop intelligent behaviors as a result of education, strategies intentionally aimed at developing metacognitive abilities need to be incorporated into teaching methods. Brojato and Portilho (2023) reinforce this perspective by highlighting that metacognition is not normally related to teacher and professional development, and that it is necessary to develop intervention programs aimed at the acquisition and development of metacognitive strategies in formative contexts.

Given this context, this article aims to analyze, in a theoretical and reflective way, the role of metacognition in the teaching and learning processes of mathematics, exploring its conceptual foundations, the available metacognitive strategies, and the pedagogical possibilities that arise from them. It is assumed that the intentional promotion of metacognition, both by teachers and students, constitutes a relevant path to address the historical difficulties in mathematics education. To this end, an analytical theoretical review of the literature was carried out, the methodological path of which is presented in the following section.

The article is organized into five sections, in addition to this introduction and the final considerations. The first section presents the methodological path of the research, including the nature of the study, the criteria for selecting the literature, and the databases consulted. The second section discusses the origins of the concept of metacognition from Flavell, as well as its dimensions and the main definitions consolidated in literature. The third section delves into the distinction between cognitive and metacognitive strategies, presenting their typology and the role of these strategies in the mathematics teaching process. The fourth section develops an analytical reflection on the implications of metacognition for the teaching and learning of mathematics, articulating the theoretical framework with the specificities of the discipline. Finally, the fifth section presents concrete pedagogical possibilities for promoting metacognition in mathematics classes, organized around the axes of planning, monitoring and evaluation.

2. Methodological approach

This study is characterized as an analytical theoretical review of a qualitative nature, developed through bibliographic research. According to Gil (2002), bibliographic research is based on already published material and aims to provide the researcher with contact with the theoretical contributions produced on a given topic, constituting a fundamental procedure for delimiting the problem and for grounding the analysis.

In this direction, the review carried out in this article does not assume a merely descriptive character, but an analytical-interpretative one, since it is guided by careful selection, critical reading, and articulation of classic and contemporary works on metacognition, learning strategies, and mathematics teaching. This methodological choice makes it possible to identify similarities, shifts, and tensions between the mobilized frameworks. Thus, the adoption of an analytical theoretical review proves pertinent to the field of research in Education, as it allows for the analysis of the phenomenon in its conceptual density and its pedagogical implications, without claiming exhaustiveness, but with an emphasis on the interpretative consistency and formative relevance of the selected literature.

The bibliographic survey was conducted in the Google Scholar, Scielo, CAPES Theses and Dissertations Database, and the Brazilian Digital Library of Theses and Dissertations (BDTD) databases, using the descriptors “metacognição”, “metacognition”, “metacognición”, “ensino de matemática”, “aprendizagem de matemática”, “estratégias metacognitivas”, and combinations thereof, with a time frame from 1976 to 2025, considering everything from Flavell's initial formulations to contemporary productions. Priority was given to scientific articles, theses, dissertations, and books of theoretical reference relevant to the field.

The selection of works was guided by three criteria: (a) recognized theoretical relevance, prioritizing classic authors who laid the foundations for the field of metacognition (Flavell, Brown, González) and contemporary researchers who engage with Mathematics Education; (b) temporal scope, including productions from pioneering studies of the 1970s to recent research published in national and international scientific journals; and (c) relevance to mathematics teaching, considering works that articulate metacognition, learning strategies, and pedagogical practice. The organization and analysis of the material followed an analytical-integrative approach, identifying convergences, distinctions, and conceptual tensions between the different frameworks, which made it possible to construct a theoretical synthesis on the object investigated.

3. Metacognition: origins, concepts and dimensions

3.1 Concept origins

The term metacognition was introduced into the scientific literature by the American psychologist John Hurley Flavell, a specialist in Child Cognitive Psychology, in the early 1970s. His first investigations on the subject were linked to the study of metamemory, the knowledge that individuals have about the functioning of their own memory. According to González (1996), the pioneering studies of Tulving and Madigan (1969) already drew attention to how people know and regulate their own memory processes, laying the groundwork for what Flavell would systematize as metacognitions.

In 1976, Flavell Published his definition, according to which metacognition

> is related to the knowledge one has of one's own cognitive processes, their products, and everything they touch [...]. Metacognition relates to other things, to the active evaluation, regulation, and organization of these processes in relation to the cognitive objects or data to which they are applied, usually to serve a specific goal or object. (Flavell, 1976, p. 232)

This initial formulation already pointed to two central dimensions that would mark the development of the field: the knowledge that the subject has about their own cognitive processes and the active regulation of these

processes in relation to goals and objectives. In the following years, Flavell would deepen this model by articulating four classes of phenomena that correlate in a model of cognitive monitoring: metacognitive knowledge, metacognitive experience, goals or tasks, and actions or strategies (Flavell, 1979).

Metacognitive knowledge refers to the set of knowledge and beliefs accumulated by the subject about their own cognitive functioning or that of others. Flavell (1979) organizes this knowledge into three categories: i) personal factors (intraindividual, interindividual, and universal), ii) task characteristics, and iii) types of strategies. Personal factors encompass everything from what the subject knows about their own abilities to comparisons with others and universal beliefs about mental functioning. Task characteristics relate to how the nature of the information affects and limits the way it is handled. Finally, types of strategies refer to knowledge about the means and procedures that allow one to achieve cognitive goals effectively.

Metacognitive experience, in turn, encompasses any conscious cognitive and/or affective experiences related to the process of knowing, and can occur before, during, or after a cognitive activity (Flavell, 1979). A typical example is the sudden feeling of not having understood something, which signals to the subject the need to revisit and reorganize their understanding. This affective dimension of metacognition points to the inseparability between cognition and emotion in the learning process, an aspect widely recognized by contemporary (Cosenza; Guerra, 2011).

3.2 Evolution and plurality of the concept

Based on Flavell's formulations, the concept of metacognition expanded in the following decades, integrating contributions from different theoretical traditions. Baird and White (1984) proposed a particularly productive operational definition for the educational context, characterizing metacognition as an individual's knowledge of the nature of their learning, awareness of what they are doing and how they are doing it, and control over learning through informed decision-making with defined goals. This trilogy, knowledge, awareness, and control, offers a simple analytical framework for thinking about pedagogical practices, as it allows us to identify in which of these dimensions the student presents the greatest difficulties and where teacher intervention can be most productive.

Brown (1987) marked a milestone in this trajectory by characterizing metacognition in four categories: i) verbal communication as a cognitive process; ii) executive control within an information processing framework; iii) self-regulation and reflective abstraction, according to the Piagetian school; and iv) regulation by others, which focuses on the importance of social interactions in the internalization of processes, a central concept in Vygotsky's theory. This contribution by Brown (1987) therefore highlighted both the intra-individual dimension and the social and dialogical dimension of metacognition.

Mayor, Suengas, and González Marqués (1995, p. 51) define metacognition, a priori, as "cognition about cognition, knowledge about knowledge, and thought about thought." This definition, although synthetic, has relevant heuristic value: by emphasizing the recursiveness of thought, the act of thinking about one's own thinking, the authors situate metacognition as a second-order reflective capacity that operates on cognitive processes themselves and not merely through them.

González (1996) broadens the perspective by defining metacognition as a term that designates a series of operations, activities, and cognitive functions performed by a person through internalized intellectual mechanisms, which allow the individual to know, control, and self-regulate their own intellectual functioning. This formulation is relevant because it situates metacognition not as a fixed trait of the subject, but as a set of dynamic operations that can be stimulated, taught, and developed throughout the educational process.

The multiplicity of definitions, far from being a problem, reflects the richness and breadth of the metacognitive field. As Portilho (2011, p. 107) summarizes, metacognition is "knowledge about knowledge and knowing, including knowledge of the capabilities and limitations of human thought processes," and this knowledge has the ability to plan

and regulate the productive work of the subject's cognitive resources. Table 1 below synthesizes the main definitions of the concept throughout its history.

Table 1 – Synthesis of metacognition's main definitions

Author(s)	Year	Definition
Flavell	1976	Knowledge and regulation of one's own cognitive processes, their products, and everything that surrounds them; active evaluation, regulation, and organization of these processes in relation to cognitive goals.
Baird & White	1984	An individual's knowledge of the nature of their learning; awareness of what they are doing and how they are doing it; control over their learning through informed decision-making.
Brown	1987	Characterized in four categories: verbal communication, executive control, Piagetian self-regulation, and regulation by others (Vygotskyan perspective).
Mayor, Suengas and González Marqués	1995	Cognition about cognition, considering cognition or knowledge as the object of metacognitive activity.
González	1996	A series of cognitive operations that allow an individual to understand, control, and self-regulate their own intellectual functioning.
Portilho	2011	Knowledge about knowledge and know-how, including the capabilities and limitations of human thought processes, with the ability to plan and regulate cognitive resources.

Source: Prepared by the authors based on the reviewed literature (2026).

The analysis of the definitions gathered in Table 1 allows us to identify three transversal axes that run through the metacognitive field, regardless of conceptual variations among authors: the dimension of knowledge (knowing about one's own cognitive processes), the dimension of awareness (perceiving oneself as a learner in action), and the dimension of control or regulation (acting intentionally to adjust, plan, and evaluate cognitive processes). These three dimensions, articulated with each other, constitute the core of what is understood by metacognitive competence and offer the framework for thinking about pedagogical practices focused on mathematics.

Although all authors agree on these three axes, their emphases differ significantly: Flavell (1976) prioritizes the declarative aspect, what the subject knows about their cognitive processes, while Brown (1987) shifts the focus to executive functions and active regulation, articulating Piagetian and Vygotskian traditions. Baird and White (1984) operate from a more applied perspective, making the knowledge-consciousness-control triad directly usable in pedagogical practice. González (1996) and Mayor, Suengas, and González Marqués (1995) reinforce the dynamic and internalized character of these operations, while Portilho (2011) goes further by articulating metacognition with learning styles and strategies. This plurality enriches the field and indicates that metacognition can be mobilized both to understand individual cognitive functioning and to guide teaching practices intentionally promoting self-regulation.

In the Brazilian context, scientific production on metacognition in mathematics education, although growing, is still consolidating, according to the surveys carried out. Eduardo Neto (2025), in a state-of-the-art study that mapped Brazilian theses and dissertations defended between 1980 and 2023, identified only 13 works that investigate metacognition specifically in the training of teachers who teach mathematics. The study found that the contributions of metacognition identified in these studies encompass self-regulation, critical reflection, emotional management, and the strengthening of teacher autonomy, demonstrating that metacognition is not only a pedagogical tool, but a transformative axis in the training of those who teach mathematics.

Previous studies by Costa and Darsie (2018) already signaled this scarcity, indicating that of the total of 124 studies on metacognitive strategies mapped in Brazil, only 6.45%, equivalent to approximately 8 works, focused

specifically on the teaching and learning of mathematics. This panorama shows that the field, although consolidating, presents ample potential for growth and constitutes a relevant research agenda for Brazilian Mathematics Education.

4. Metacognitive strategies: distinction, typology, and role in teaching

4.1 Cognitive and metacognitive strategies: a necessary distinction

Understanding metacognitive strategies requires, as a starting point, distinguishing them from cognitive strategies, with which they are frequently confused. Although complementary, these two categories operate at different levels of mental processing and have distinct functions in the learning process. For the purposes of this article, the term "task" is used, following the guidelines of Stein, Smith, Henningsen, and Silver (2000), to designate any mathematical activity proposed to the student that mobilizes cognitive processes, from exercises of direct application to problem situations that require conceptual elaboration. Activity and task are treated as equivalents in this context, while the nature of the task refers to the level of cognitive demand it imposes.

Cognitive strategies are directly involved in performing cognitive tasks, such as understanding a text, solving a calculation, or memorizing information. Mayor, Suengas, and González Marqués (1995) define strategy as a set of procedures used with the intention of achieving any objective or goal, which may include practices of repetition, organization, and elaboration of new information. From this perspective, cognitive strategies are directly oriented toward the object of knowledge, that is, the content to be learned, without necessarily involving conscious reflection on the learning process itself.

Metacognitive strategies, in contrast, operate at a higher level: they are not directly involved in task execution, but rather in the evaluation, monitoring, and control of the cognitive strategies in use. According to O'Malley and Chamot (1990), metacognitive strategies differ from cognitive strategies in that they involve planning, monitoring, and evaluating the learning process itself, aiming to assess the effectiveness of cognitive strategies, regulate the use of knowledge, and decide when and how to use each strategy. Brojato and Portilho (2023) distinguish the two categories based on their function and level of awareness: cognitive strategies are directly involved in performing tasks, such as understanding a text, solving a calculation, or memorizing information, while metacognitive strategies operate at a higher level, focusing on the planning, monitoring, and regulation of learning itself. In both cases, the activity may be the same; what differs is the purpose and the degree of awareness that the subject exercises over it.

Oxford (1990) classifies metacognitive strategies as indirect, since they are not directly linked to the production of learning, while cognitive strategies are direct. This distinction reinforces that metacognitive strategies exert an executive and regulatory function over the entire learning process, making them especially relevant in contexts of high cognitive demand, a construct consolidated in Mathematics Education by Stein, Smith, Henningsen, and Silver (2000) to designate tasks that require students to engage in complex thinking, establish conceptual connections, and develop justifications, as opposed to low-demand tasks, limited to memorization or the application of procedures without conceptual understanding, as is the case in mathematics. Nobre, Queiroz, and Roazzi (2023) complement this perspective by highlighting that teaching and learning strategies based on metacognition can be intentionally determined and learned, reinforcing their pedagogical potential in contexts of greater cognitive.

4.2 Typology of metacognitive strategies

The literature in this field presents different typologies of metacognitive strategies, developed by various authors and from different theoretical perspectives. Although they vary in their organization, these typologies converge around three fundamental axes: planning, monitoring, and evaluation. This convergence is not accidental: it reflects the cyclical and interdependent nature of metacognitive processes, in which the subject anticipates, monitors, and judges

their own cognitive activity continuously. Understanding this triadic structure is fundamental for teachers and students to identify which strategies are being mobilized, or neglected, throughout learning situations.

Metacognitive planning involves the set of actions prior to undertaking a task: defining objectives, anticipating difficulties, selecting appropriate strategies, and mentally organizing the path to resolution. According to Costa (1984), the planning strategy consists of guiding the student to organize the task and encouraging the formulation of questions before and during its execution. This preliminary moment of metacognitive organization is fundamental, as it situates the learner in relation to what they know, what they don't know, and what they will need to mobilize to move forward.

Monitoring corresponds to the continuous tracking of the cognitive process during the performance of a task. According to Castro and Almeida (2023), monitoring consists of consciously tracking what is being learned, as well as identifying and correcting errors during the development of the activity. In empirical research with undergraduate mathematics students in Brazil, in mathematical modeling activities, Castro and Almeida (2023) showed that monitoring strategies manifested themselves when students verified the coherence of the approaches adopted and recognized the need to reformulate hypothesis or change strategies. In the mathematical context, this translates to verifying whether the operations performed make sense, whether the chosen path is producing coherent results, and whether it is necessary to backtrack and adopt an alternative strategy.

According to Castro and Almeida (2023), evaluation implies a reflection on the actions performed, comparing the results with the objectives defined in the planning, which allows the student to become aware of how, when, and under what conditions learning took place. The authors observe that this phase is frequently neglected in mathematics classes, which tend to end the process with the achievement of the correct result, without the student reflecting on the path that led them there.

In addition to these three fundamental dimensions, Carrasco (2004) presents a set of metacognitive strategies applicable to the school context, among which the following stand out: stimulating thinking aloud; focusing attention on understanding one's own way of thinking; asking not only about the results, but also about the procedures used; teaching strategies to overcome difficulties; showing the relevance of the subjects and establishing connections between them; stimulating questions before, during and after the task; analyzing one's own cognitive performance; selecting appropriate strategies for specific problems; maintaining attention and deciding when to resume an activity in the face of blockages.

It is important to emphasize, however, that the use of metacognitive strategies cannot be understood as a rigid algorithm to be followed mechanically. It is a flexible repertoire, whose effectiveness depends on the context, the nature of the task and, above all, the degree of awareness that the subject develops about their own cognitive processes. In this sense, the value of metacognitive strategies lies less in their systematic application and more in the reflective posture they cultivate, the student's willingness to observe, regulate and evaluate their own thinking as an integral part of the act of learning.

5. Metacognition and the teaching and learning of mathematics

Based on the metacognitive fundamentals and strategies discussed in previous sections, this section develops an analytical reflection on the implications of metacognition for the teaching and learning of mathematics, articulating the theoretical framework used with the challenges and possibilities of the educational context. It starts from the premise that mathematics, due to the nature of its tasks and the degree of abstraction it requires, constitutes a particularly fertile ground for the exercise of metacognition, both by the student and the teacher. In this direction, the section successively discusses mathematical learning as a complex cognitive activity, the cognitive and metacognitive

processes involved in problem-solving, and finally, the role of the teacher as a metacognitive subject, capable of modeling and mediating these processes with students.

5.1 Learning mathematics as a complex cognitive activity

Learning mathematics is much more than executing procedures and applying formulas. It is a complex cognitive process that involves the construction of concepts, the activation of prior knowledge, the development of abstraction skills, and, fundamentally, the ability to regulate one's own thinking when faced with mathematical tasks. As Cosenza and Guerra (2011) observe, learning involves brain processes that go beyond memorization, encompassing attention, working memory, and executive functions, all of which are directly related to the capacity for cognitive self-regulation.

Piaget (1983) already indicated that cognitive development occurs through progressive processes in which the subject gradually constructs increasingly complex mental structures, being able to think hypothetically, formulate propositions, and develop the foundations of abstract thought. This development, however, does not occur spontaneously: it requires pedagogical environments that stimulate reflection, hypothesis formulation, and questioning, processes that are, in essence, metacognitive.

Ausubel (2003) contributed with the Theory of Meaningful Learning (TML), centered on the idea that new knowledge is consolidated when it is anchored in already existing cognitive structures, the so-called subsumers. As Moreira and Masini (1982) and Moreira (1999) explain, TML is an essentially cognitivist theory: meaningful learning is a cognitive process that, in its original formulation, does not require the student to have reflective awareness of their own state of knowledge. For it to occur, Ausubel establishes three conditions: i) that the material is potentially meaningful; ii) that the student has adequate subsumers; and iii) that there is a predisposition to learn (Moreira; Masini, 1982). However, Novak (1998) expanded upon this basis, demonstrating that metacognitive knowledge, including knowledge of how to learn meaningfully, is also crucial for the quality of meaningful learning.

In this sense, mathematics is configured as a privileged field for the development of metacognition, since mathematical tasks require the student to have precisely this ability to monitor, evaluate, and adjust their thought processes. As Polya (1973) points out, the act of solving mathematical tasks involves four fundamental phases: understanding the task, developing a plan, executing the plan, and evaluating the result. It should be noted that the term problem-solving is used here in a generic sense, referring to the act of solving mathematical tasks, and not to Problem Solving as a consolidated didactic-methodological trend in Mathematics Education. Each of these phases presupposes metacognitive skills, and without them, the student tends to act impulsively and in a fragmented way, without awareness of what they are doing and why.

5.2 Cognitive and metacognitive processes in problem solving

Mathematical problem-solving is recognized in the literature as one of the most productive contexts for the development of metacognition (González, 1998). González (1998) investigated the cognitive and metacognitive processes activated by university students during mathematical problem-solving, distinguishing two types of mental processes: cognitive processes, related to encoding, retention, organization, processing, and retrieval of information; and metacognitive processes, which concern the awareness and regulation that each person exerts over their own intellectual functioning.

The author proposes that mathematical competence is associated both with mastering the knowledge and procedures specific to the discipline and with activating processes that allow for the supervision, regulation, and control of this mastery. From this perspective, metacognition is conceived as a three-dimensional cognitive construct that involves the knowledge that the subject has about their own cognitive functioning, the internalized thought mechanisms they use to supervise and regulate this functioning, and the ability to regulate it concurrently with the

performance of intellectually demanding tasks (González, 1998), a category in which the resolution of mathematical problems paradigmatically fits.

González (1998) identifies a four-dimensional profile in the student, encompassing the affective, mathematical, cognitive, and metacognitive dimensions. The affective dimension concerns the student's attitudes, beliefs, and emotional dispositions towards mathematics and the learning process itself, elements that directly influence their willingness to engage in tasks. The mathematical dimension refers to the mastery of the concepts, procedures, and language specific to the discipline, that is, mathematical knowledge itself. The cognitive dimension concerns the ways in which the student approaches the search for a solution, the processes they activate to understand the task, organize the available information, and move towards the answer. The metacognitive dimension, in turn, refers to the level of awareness that the student develops around their own intellectual functioning: the ability to observe what they are doing, evaluate whether the chosen path is productive, and adjust the strategy when necessary.

This self-regulation capacity is especially relevant in the face of blockage situations, which are frequent in solving mathematical problems. González (1998) describes as a characteristic of the student with low metacognitive development the difficulty in perceiving and naming the moment when they are stuck, not knowing what to do and unable to move forward, which leads the student to mechanically repeat the same procedure without result or to abandon the task. The student who has developed metacognitive awareness, on the contrary, is able to recognize this state, interrupt the unproductive path and seek a new approach.

Leite (2011) shows, from empirical studies, that there is a significant relationship between the application of metacognitive activities and the improvement of student performance, particularly in mathematics in regular education. This relationship is not casual: when the student learns to reflect on their own thought process, they develop greater autonomy, a greater ability to identify and correct errors, and greater persistence in the face of challenges, qualities essential for mathematical learning.

5.3 The teacher's role as a metacognitive subject

Promoting metacognition in mathematics classes is not solely the student's responsibility: it requires the teacher to also position themselves as a metacognitive subject. This means that the teacher needs not only to master the mathematical content they teach, but also to be able to continuously reflect on their pedagogical actions, the strategies they employ, and the effects they produce on their students' learning. This dual requirement places the teacher in a unique position: while needing to develop their own metacognitive awareness, they also act as a mediator and model for students to develop theirs.

Brojato and Portilho (2023) highlight that metacognition is not normally associated with teacher development, which makes addressing it in training processes even more urgent. The authors argue that knowing what teachers know about their own teaching process can be a starting point for change in the training of these professionals, and that continuing education programs from a metacognitive perspective place the teacher at the center of their own learning, promoting reflection on what, how, when, and where they learn. This movement leads the teacher to equip themselves to meet the learning differences of their students.

Lafortune, Jacob, and Hébert (2003) emphasize how fundamental teacher intervention supported by the use of metacognitive strategies is, as this allows students not only to know which strategies to use, but also why, when, and how to use them. According to the aforementioned authors, without this intentional mediation, students tend to employ strategies in an isolated and unconscious way, without being able to transfer them to new learning situations. This pedagogical intentionality is what distinguishes a practice that promotes metacognition from a practice that leaves it to chance.

The teacher as a metacognitive model is one of the dimensions most emphasized in literature. Costa (1984) states that, of all available instructional strategies, the one most likely to influence students is modeling by the teacher.

Since students learn by imitating the adults around them, a teacher who publicly demonstrates metacognition tends to produce students who are equally reflective about their own thought processes. The author points to some indicators of this public metacognitive behavior: sharing lesson plans by describing objectives and justifying actions; making mistakes and demonstrating how to recover from them; admitting that one does not know an answer and creating ways to find it; seeking feedback and evaluation of one's actions; and demonstrating understanding and empathy by listening to and accurately describing the ideas and feelings of others.

According to Costa (1984), the central component of metacognition is developing a plan of action and keeping it in mind over time. Planning a strategy before embarking on a course of action helps to keep track of the steps in the planned sequence, facilitates temporal and comparative judgments, assesses readiness for different activities, and monitors interpretations, perceptions, decisions, and behaviors. A direct example of this is what good teachers do daily: they develop a teaching strategy for a class, keep that strategy in mind throughout the instruction, and then reflect on it to evaluate its effectiveness in producing the desired results.

Brojato and Portilho (2023) reinforce this perspective by investigating school educators in a continuing education program, in which formative meetings structured under a metacognitive perspective favored the awareness, self-control, and autopoiesis of the participants, dimensions that, when developed in the teacher, expand their ability to promote them in their students as well. The study results suggest that teacher training intentionally structured around metacognition not only benefits isolated pedagogical practice but also transforms the way teachers themselves relate to their learning and teaching process, creating a formative cycle that naturally extends to the classroom.

This perspective of the teacher as a metacognitive subject reinforces the understanding that metacognition is not just a student skill, but a pedagogical culture that needs to be built collectively by teachers and students in the daily routine of mathematics classes. When teachers and students share an environment where reflecting on one's own thinking is valued and practiced, the conditions for deeper and more autonomous mathematical learning become much more favorable.

6. Pedagogical possibilities: how to promote metacognition in mathematics classes

This section builds upon the analytical reflection developed earlier, presenting a set of pedagogical possibilities aimed at promoting metacognition in mathematics classes. It connects the theoretical framework used with guidelines for teaching practice. It is based on the premise that metacognition does not emerge spontaneously in the school context; it needs to be intentionally and systematically cultivated, both through the selection of appropriate tasks and through the teacher's pedagogical mediation.

A fundamental assumption for promoting metacognition in the classroom is pedagogical intentionality. As Costa (1984) warns, to develop intelligent behaviors as a relevant outcome of education, instructional strategies intentionally aimed at developing metacognitive abilities need to be incorporated into teaching methods. This means that the teacher cannot expect students to spontaneously develop the ability to reflect on their cognitive processes; it is necessary to create pedagogical situations that make this reflection necessary, possible, and valued.

In the context of metacognition, pedagogical intentionality implies that teachers plan their lessons considering not only the content to be taught, but also the cognitive processes that students will need to mobilize to learn it and the ways in which they can become aware of these processes. This involves selecting mathematical tasks that demand reasoning, planning, and evaluation; formulating questions that go beyond the correct answer; and creating spaces for students to verbalize, share, and reflect on their ways of thinking.

Carrasco (2004, p. 38) proposes that the development of metacognition requires that the student learn to "learn how to learn," a perspective also present in Novak (1998), for whom metacognitive knowledge, including knowing how to learn, is fundamental to the quality of learning, which involves: having the necessary physical, psychological,

and planning conditions to learn; clearly defining what to learn; selecting the necessary information; understanding and storing this information through attention and organization; and self-monitoring one's learning by thinking reflectively and critically. These steps constitute, in essence, a metacognitive roadmap that can be taught and practiced in mathematics classes.

Specialized literature offers a wide repertoire of pedagogical practices for this purpose, organized around three fundamental axes: planning, monitoring and evaluation. These strategies do not operate in isolation but are articulated in a complementary and interdependent way throughout the mathematical learning process, composing a continuous cycle in which the student anticipates, monitors and judges their own cognitive activity. Structuring teaching around these three axes means offering the student not just specific techniques, but a way of relating to mathematical knowledge in a more conscious and autonomous way.

In the planning axis, the use of metacognitive questions before the start of a task stands out. Castro and Almeida (2023) highlight that planning in mathematical activities is marked by anticipatory thinking, including decisions about what to do, how to do it, and when to do it, which characterizes it as a structuring metacognitive strategy of the problem-solving process. In the context of solving mathematical problems, this translates into questions such as "What is this problem asking?", "What do I already know that can help me?", and "What strategy will I use?", which promote intentional planning and avoid the tendency to start solving impulsively.

In the monitoring axis, González (1998) highlights that metacognitive processes perform specific functions during problem-solving, among which are monitoring calculations to ensure that they continue to be applied correctly to the problem, noticing the emergence of blocking situations and making this perception explicit, enabling a change of strategy, and critically analyzing reasoning to detect gaps or logical errors. Costa (1984) adds that monitoring involves both looking ahead, learning the structure of a sequence of operations, identifying areas where errors are likely and choosing strategies that reduce this possibility, and looking back, detecting errors already made and evaluating the reasonableness of the results obtained.

In the context of assessment, working with error as an element of learning deserves special attention. Luckesi (2012) highlights that error in learning is a starting point for progress and should not be seen as an obstacle, but as a valuable resource for reviewing and advancing with reflective and conscious learning, providing moments of reflection. When the teacher invites the student to analyze where and why they made a mistake, they are promoting a metacognitive exercise of great value. This process requires the student to mentally reconstruct the path taken, identify the point of deviation, and understand the logic underlying the mistake made, thus developing a deeper understanding of the mathematical content.

The Learning Journal is another metacognitive tool with great potential for mathematics classes. Costa (1984) recommends writing and illustrating a personal journal throughout an experience, as this leads students to synthesize thoughts and actions and translate them into symbolic form. In the mathematical context, this instrument can include a description of the strategies used, the identification of difficulties encountered, and the evaluation of one's own performance, supporting more individualized pedagogical interventions.

Finally, Brojato and Portilho (2023) observe that continuing education programs that prioritize reflexivity and the articulation between knowledge and lived reality can contribute to the promotion of metacognitive awareness strategies, and that this contribution can be extended to how teachers and students deal with their learning. The more aware the teacher is of the use of metacognitive strategies, the greater the chances that metacognitive development will be incorporated into daily life as support for learning and learning assessment, transforming the relationship of individuals with mathematical knowledge in a progressive and sustained way.

7. Final considerations

This article sought to analyze, through an analytical theoretical review, the role of metacognition in the teaching and learning processes of mathematics, discussing its origins, dimensions, and strategies, as well as its pedagogical implications. The analysis of metacognitive origins, dimensions, and strategies revealed that this field is not merely a theoretical abstraction, but a set of concrete educational practices capable of transforming the relationship of individuals with mathematical knowledge.

The literature review revealed that historical difficulties in mathematics education are not limited to deficits in content or procedural skills. They primarily reflect the absence of a reflective dimension in the learning process, students' lack of awareness of their own thought processes, and the absence of pedagogical practices that intentionally cultivate this awareness. Metacognition, by proposing that the learner should also be the subject who reflects on how they learn, offers a robust response to this challenge, constituting an important framework for understanding these processes, without disregarding, however, that the field of Mathematics Education has other equally relevant theoretical perspectives for this understanding.

The metacognitive strategies discussed throughout the article, prior planning, continuous monitoring, critical evaluation, thinking aloud, working with errors, learning journals, and the teacher as an explicit model of reasoning, are not isolated resources, but integrated parts of a shared pedagogical culture, built day by day by teachers and students in mathematics classes. This culture presupposes, first and foremost, that the teacher is himself a metacognitive subject, capable of reflecting on his practice, identifying his gaps, and explicitly modeling the thought processes he wishes to promote in his students.

The article also indicated that metacognition in mathematics education is linked to other emerging theoretical fields, such as educational neuroscience, which offers a scientific basis for understanding the brain mechanisms that support cognitive and emotional self-regulation. This articulation, still incipient in the Brazilian literature, points to a fertile horizon for research and pedagogical innovation, suggesting that mathematics education can be significantly enhanced when based on the integration between metacognitive awareness and understanding of the neural processes that support it.

In short, promoting metacognition in mathematics classes means investing in an education that is not limited to the transmission of content, but that forms subjects capable of thinking about their own thinking, regulating their cognitive processes, and progressively building intellectual autonomy. This is a pedagogical perspective that repositions the student's role in the learning process: from a passive receiver to a reflective agent of their own cognition. In this sense, metacognition is not merely a teaching tool, but a guiding principle for educational practice, with transformative potential for both mathematics learning and the broader development of critical and autonomous individuals. Deepening this perspective, both theoretically and through empirical research, represents a relevant agenda for research in Mathematics Education in Brazil.

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