EMP Educação Matemática Pesquisa
ISSN 1983-3156
Qualis A1
http://dx.doi.org/10.23925/1983-3156.2026.v28.e72191

Epistemological assumptions for learning mathematics: an analysis between Paulo Freire and cognitive neuroscience

Presupuestos epistemológicos para el aprendizaje de las matemáticas: un análisis entre Paulo Freire y la neurociencia cognitiva

Hypothèses épistémologiques pour l'apprentissage des mathématiques : une analyse entre Paulo Freire et les neurosciences cognitive

Pressupostos epistemológicos para aprender matemática: uma análise entre Paulo Freire e a neurociência cognitiva

Daniela Jéssica Veroneze[1]
Universidade Regional Integrada do Alto Uruguai e das Missões – URI Frederico Westphalen
Doctor in Education
https://orcid.org/0000-0002-5500-4733

Arnaldo Nogaro[2]
Universidade Regional Integrada do Alto Uruguai e das Missões – URI Frederico Erechim
Doctor in Education
https://orcid.org/0000-0003-0517-0511

Abstract

The article aims to highlight the fundamental assumptions for learning mathematics at any level by analyzing the epistemological assumptions of Freire and cognitive neuroscience. Its methodology is qualitative and bibliographical, drawing primarily on the works of Paulo Freire (1996, 2022, 2020, 2005, 2001, 1967, 2024a, 2024b), Dehaene (2016, 2022), and Cosenza and Guerra (2011). It is understood that the main epistemological assumptions are: thought-thinking, knowledge, language-communication, emotions-feelings, executive functions, motivation, praxis and consciousness. From the convergences, it is inferred that mathematics education is a complex field, characterized by the tension between innate, learned, technical and political knowledge.

Keywords: Epistemological assumptions, Cognitive neuroscience.

[1] E-mail: danielajessicav@gmail.com
[2] E-mail: narnaldo@uricer.edu.br

Submetido em:27/06/2025 *Aceite em: 06/10/2025* *Publicado em: 23/03/2026*

Resumen

El artículo pretende destacar los supuestos básicos para el aprendizaje de las matemáticas en cualquier nivel, analizando los presupuestos epistemológicos de Freire y la neurociencia cognitiva. Su metodología es cualitativa y bibliográfica, utilizando como autores principales a Paulo Freire (1996, 2022, 2020, 2005, 2001, 1967, 2024a, 2024b), Dehaene (2016, 2022) y Cosenza y Guerra (2011). Se interpreta que los principales supuestos epistemológicos son: pensamiento-pensamiento, conocimiento, lenguaje-comunicación, emociones-sentimientos, funciones ejecutivas, motivación y praxis, y conciencia. Se puede inferir de las convergencias que la educación matemática es un área compleja, que encuentra tensión entre el conocimiento innato, aprendido, técnico y político.

Palabras clave: Supuestos epistemológicos, Neurociencia cognitiva.

Résumé

Cet article vise à mettre en évidence les hypothèses fondamentales de l'apprentissage des mathématiques à tous les niveaux, en analysant les postulats épistémologiques de Freire et des neurosciences cognitives. Sa méthodologie est qualitative et bibliographique, avec comme auteurs principaux Paulo Freire (1996, 2022, 2020, 2005, 2001, 1967, 2024a, 2024b), Dehaene (2016, 2022) et Cosenza et Guerra (2011). Les principaux postulats épistémologiques sont : la pensée, la connaissance, le langage et la communication, les émotions et les sentiments, les fonctions exécutives, la motivation, la praxis et la conscience. Ces convergences permettent de déduire que l'enseignement des mathématiques est un domaine complexe, en tension entre les savoirs innés, acquis, techniques et politiques.

Mots-clés : Hypothèses épistémologiques, Neurosciences cognitives.

Resumo

O artigo tem como objetivo evidenciar os pressupostos basilares para aprender matemática em qualquer nível, analisando os pressupostos epistemológicos de Freire e da neurociência cognitiva. Sua metodologia é qualitativa e bibliográfica, usando como principais autores Paulo Freire (1996, 2022, 2020, 2005, 2001, 1967, 2024a, 2024b), Dehaene (2016, 2022) e Cosenza e Guerra (2011). Interpreta-se que os principais pressupostos epistemológicos são: pensar-pensamento, conhecimento, linguagem-comunicação, emoções-sentimentos, funções executivas, motivação e práxis e consciência. Depreende-se a partir das convergências que a educação matemática é uma área complexa, encontrando tensão entre o conhecimento inato, o aprendido, o técnico e o político.

Palavras-chave: Pressupostos epistemológicos, Neurociência cognitiva.

Epistemological assumptions for learning mathematics: an analysis between Paulo Freire and cognitive neuroscience

Introduction

Cultural issues are structured amid biological and physiological aspects, predisposing differences between humans and animals who, despite having similar brain structures, become distinct - especially regarding learning. According to Nicolelis (2020), humans, unlike animals, learn primarily through imitation, a process that is not limited to reproducing the final outcome but involves attention to the development and unfolding of imitation itself. Animals, on the other hand, learn through emulation, in which only the final reward-driven acts are emphasized.

In this sense, the human being is not merely a passive recipient of others' ideas and content, docilely adapting to situations and repeating exactly what their educator teaches. Rather, they are beings who, through analysis, must open themselves to critical processes and to understanding the purposes of imitation, with a focus on comprehension, creation, transformation, and curiosity (Freire, 2020, 2022). This occurs, according to Dehaene (2022), because humans, through their historicity, become cultural and social beings who learn in two distinct, though not dichotomous, ways: (1) through curiosity and discovery, actively testing their hypotheses; or (2) through the influence of other human beings, in a more receptive manner, based on trust in their knowledge and life experiences, which are shaped by social factors.

The processes of evolution of the body, brain and culture have produced cellular-level differences in brain regions that, in turn, have changed the way humans act and construct the world. It is considered that learning results from the changes occurring in the learning process itself - where learning is changed - implying a comparative reference between moments in time (Andrade & Silva, 2005). It is understood that it is through this search, amid a myriad of possible adjustments to the internal model projected in correspondence with the external world, and through the selection of simple models that data are combined and preserved (Dehaene, 2022). If what has been learned is retained by the organism, recursive mechanisms come into play and may link the learned behavior to memory for future preservation (Andrade & Silva, 2005).

Therefore, beyond neurophysiological consolidations, it is essential to understand that learning represents a biologically driven structural change between knowing and remembering, which can be expressed through behavioral outcomes such as this resulting change. Such changes establish the transformation of what has been apprehended into reinvention and application to concrete existential situations, stemming from the contradictions of one's own world—not merely to adapt to reality, but to intervene in it (Freire, 2022, 1996). This translates into different ways of reading and rereading the world and into the possibility of transforming it (Freire, 2001).

It is emphasized, based on readings of cognitive neuroscience and Freire, that learning occurs through different sensory pathways and is established according to preliminary configurations within recursive behaviors. Human learning, in particular, denotes the necessity of attention, memory, consciousness, perception, language, motivation and curiosity, and is influenced by emotions and feelings, which can be evoked and consolidated into intelligent and conscious behaviors.

Maturana and Varela (2001) state that learning can be innate and/or acquired. According to the authors, behavioral phenomena are relational, depending on what is perceived between the organism and its environment. Thus, certain structures do not depend on the specific historical particularities of interaction, being considered genetically determined, and behaviors such as the sucking reflex in newborns are instinctive. Conversely, as Maturana and Varela (2001) highlight, more complex structures must be learned for certain behaviors to develop, requiring interaction as a means of forming ontogenetic behaviors, such as running or speaking. Both types are regarded as behavioral qualities and are indistinguishable in terms of the nervous system's nature and functioning, being classifiable only in relation to their structural history.

They develop through recalibration, which works as a process of trial and error, comparing what was intended with what was inferred, decomposing the learning problem into a hierarchical model of levels, and identifying regularities on increasingly broader scales, that is, in the evaluation of results (Dehaene, 2022). To this end, it is necessary to make comparisons, doubt, experience uncertainty, accept and understand mistakes and contradictions, and make sense of the problematized situation, thereby paving the way for understanding the object or situation and analyzing it (Freire, 1996, 2022).

This process takes place in different brain regions, where hypotheses are formulated and sent to other areas, triggering an exchange of messages that convey them to interpret the external world (Dehaene, 2022). Furthermore, these messages interact with bottom-up signals coming from the external world, which are confronted with the brain's internal model of reality, calculating possible errors between what was intuited and what was observed (Dehaene, 2022). In the absence of error, it is understood that the model was correct, while in its presence, it ascends through the mental stream and adjusts parameters throughout its processing, converging toward a model that aligns with the external world (Dehaene, 2022).

Dehaene (2022) and Cosenza and Guerra (2011) exemplify that learning requires several key assumptions. Among them are the need for shared attention, engagement, curiosity and motivation, understanding of errors, and the ability to act upon them, as well as consolidation based on long-term memory. Obviously, other assumptions are also involved, such as the notions of consciousness and rationality, necessary stimuli, and congruent sensations, feelings, and emotions. For Dehaene (2022), these assumptions - occurring similarly in the brain - demonstrate that learning happens in all humans, differing only in terms of prior knowledge, curiosities, and individual motivations. In other words, what changes to make learning effective are the learner's preferences and meanings.

Learning is a form of self-criticism in an evaluative sense, seeking logics and hypotheses that conflict with reality, in a constant ability to predict rewards or punishments (Dehaene, 2022). When it comes to education and learning that are not grounded in direct experiential knowledge—such as in certain sciences and more rigorous abstractions—formal learning environments come into play. However, these do not exempt less formal spaces, such as families and society as a whole, from engaging in more critical education. In such spaces, as Freire (2022, 2020, 1996) emphasizes, the encounter and interaction among subjects give meaning to being and living through the relationships established between subject and object, oriented toward knowledge expressed through language and intervention in the world, where questioning, problematizing, and dialoguing about what is to be learned are essential. This reverberates and echoes within the neural electromagnetic storms previously traversed by other brains - brains that have become historical - manifesting in elaborated expressions of mental abstractions that were also, in some way, subjectivities (Nicolelis, 2020).

According to Dehaene (2022), it is through formal education that neural plasticity and recycling become readily developed. Plasticity is the ability to form and dissolve connections between neurons as a result of constant interactions with the body's external and internal environments (Cosenza & Guerra, 2011). Neural recycling is the process of reusing brain circuits to apply them to new functions, allowing details of what is innate to be refined and opened to the external world (Dehaene, 2022, 2016). These processes provoke changes in attitude, creativity, action, and participation within transitional parameters, fostering experiences of practice, critical thinking, and awareness (Freire, 1967).

Analogously, this demands a methodological shift in which educational environments seek ways of formation that go beyond performance and skill training, focusing instead on creating, recreating, and constructing history - making learning effective, joyful and scientifically capable of serving transformation or, regrettably, maintaining the status quo—thus diversifying learning experiences (Freire, 1996; Dehaene, 2022).

The concept of learning, both in Freire's perspective on mathematics education and in cognitive neuroscience, presents similar meanings. It is analyzed that, across these three fields, learning involves generating changes of state, whether internal or external, arising from attention and interaction with incoming information, through processes of adjustment, association, and reformulation according to the needs of knowledge. That is, it relates to creation or re-creation in the act of knowing and understanding reality, which is grounded in neural structures. Learning, therefore, is construction, interaction, investigation, (re)discovery, reflective thinking, deduction, intuition, action, comparison, abstraction, concreteness, language, communication and dialogue.

As the brain evolved toward functions that enhance survival, self-improving and adapting to diverse realities - and given the usefulness of mathematics for explaining the world, it came to process mathematics as fundamental, to the point of forming specialized neural networks for it, as highlighted by Dehaene (2022, 2016), Cosenza and Guerra (2011), and Nicolelis (2020). For this reason, counting abilities are present very early in some animal species, such as primates. According to Dehaene (2016), this ability, observed in animals and very young human infants, manifests in two ways: first, through an internal capacity to count whenever something external triggers it; and second, because this form of counting differs from that which is refined through schooling, being a simplified form lacking symbols for representing objects.

In the brain, mathematics emerges through the articulation of neurons that process to elaborate abstractions - results of combinations between the brain's refined structure and millions of years of selection of mathematical tools (Dehaene, 2022). It manifests in the human presence as an interaction with the world, which implies creating it, moving from the individual to the world and from the world to history (Freire, 1997). This refinement developed through the enormous flow of sensory information received, producing reactions in the human organism when facing a hostile and/or competitive environment (Dehaene, 2016).

However, it is essential to understand that mathematics develops from a pre-existing representation of quantities, refining its incorporation, or not, depending on the maturation of brains, cultures, and the forms of education provided (Dehaene, 2016; Nicolelis, 2020), thus suggesting a mathematical way of being in the world (Freire, 1997). It should be emphasized that mathematics is not expressed solely through counting and calculations, but also through the contributions of spatial sense and representations of the world, which ultimately guide humanity along different paths.

It is established in various brain regions from early childhood and is independent of sensory experiences (Dehaene, 2020). As shown by different experiments, Dehaene (2022, 2016) indicates that numerical processing is located specifically in the posterior part of the brain, bilaterally, in the parietal lobe, particularly in the horizontal part of the intraparietal sulcus. According to the author, the brain treats mathematics as a specific type of knowledge that requires its own neurological apparatus, interacting with other cortical areas to handle informational inputs.

Thus, learning mathematics could be considered the construction and reconstruction of mental (abstract) circuits which, through interaction with and within the world (concrete), allow it to be interpreted and transformed (concrete–abstract). It also involves building a field of knowledge that changes according to the ways one interacts with the world, becoming essential for both survival and transcendence - its expression conveyed through a unique language, constructed in an almost universal way. It is, as Freire (1997) argues, a form and condition of being in and with the world.

In this sense, the aim of this article, which employs a qualitative and bibliographical methodology, is to highlight the fundamental assumptions for learning mathematics at any level by analyzing Freire's epistemological assumptions and neuroscience, identifying their specialized congruences. To this end, the article is divided into two additional sections besides this introduction, namely: Fundamental Assumptions for Learning Mathematics and Final Considerations.

Fundamental Assumptions for Learning Mathematics

Learning mathematics requires foundational assumptions that are either intrinsically present within individuals or externally manifested. By analyzing Freire's assumptions, those of mathematics education, and those of cognitive neuroscience, it is possible to identify convergent foundational relationships that are essential for learning and teaching mathematics, aiming for an education that is both problem-posing and liberating. As Dehaene (2022) points out, learning is, in general, the ability to represent the world in its multiple dimensions.

In this sense, there are convergences that interact through praxis, resulting in a shared ideal of correlation, emerging from synthesized frameworks that are placed in dialogue with one another. Therefore, learning mathematics is grounded on the following assumptions: thought–thinking–reflection–criticality; knowledge–memory–attention–curiosity–creation; language–communication; emotions–feelings; and executive functions–motivation–planning–decision–praxis, all of which lead to the development of conscious awareness and the transcendence of mere dependence.

In concrete terms, thinking can be understood as the activation of neural circuits in response to information. From a deeper perspective, it is possible to distinguish different types of thinking that, systemically, may either result from lived experiences (often semi-conscious) or from more profound reflections on something - rooted in logical and abstract relations involving motives, aspirations, imagination, and creation.

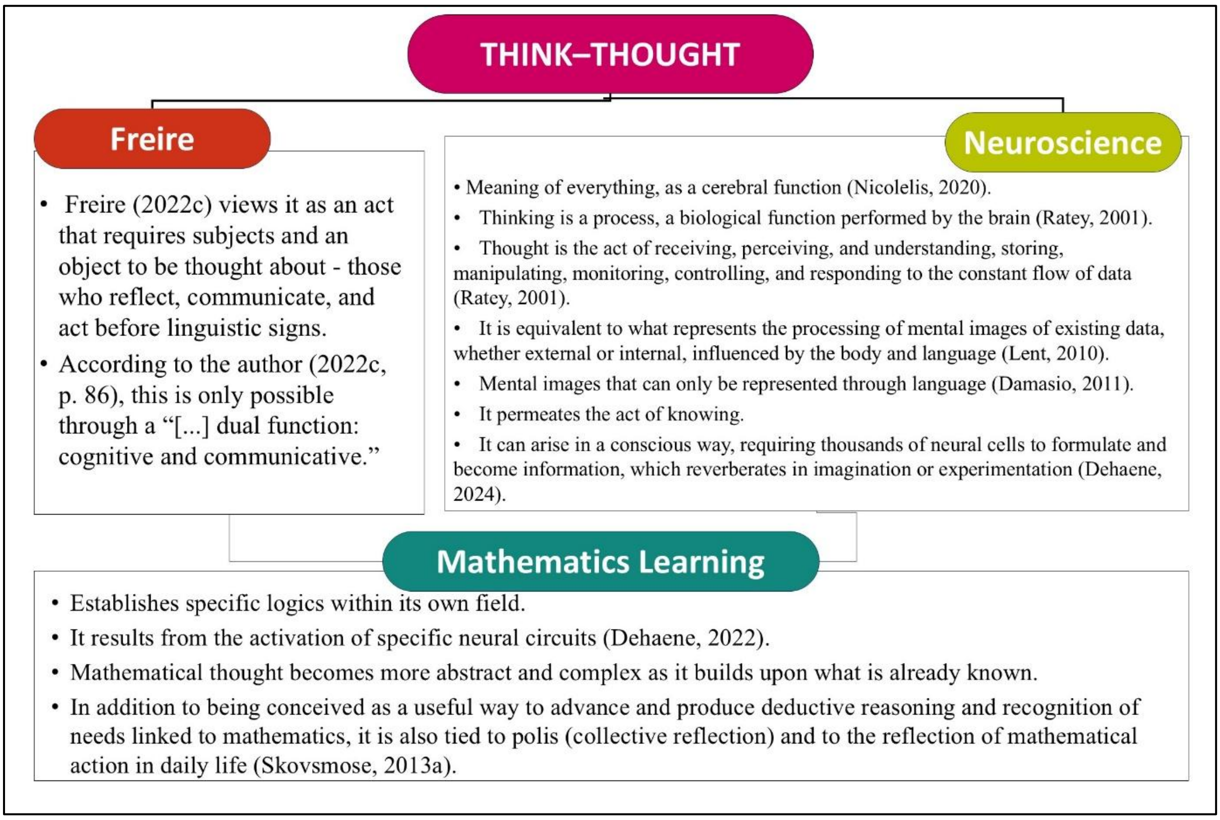
These types of thinking are influenced by the degree of attention given to internal, external, and concrete information, as well as by the formation or transformation of thought patterns. Likewise, thought influences behavior and language, shaping the development of criticality, which manifests in the act of thinking and thinking correctly, that is, through the internal verification of error, truth, and depth of interpretation. This process allows for comparison between what is already known and what is newly learned, enabling the association and reformulation of cognitive patterns.

In this way, thinking and thought are illuminated through practice and communication - the more one attends to, reflects upon, and focuses on one's motives, circumstances, and propositions, the closer one moves toward a critical mathematical understanding.

To deepen the comprehension of mathematical thought as supported by the works of Freire, cognitive neuroscience, and mathematics learning, Figure 1 was developed to illustrate their points of convergence.

Figure 1

Think - thought (Authors, 2025).



The thinking directed toward mathematical learning unfolds through a specific logic and reasoning that take shape in images and appropriate language, drawing support from prior knowledge and evolving learning experiences. It requires reflection and critical awareness for its deepening, recognizing not only the technical aspects but also the political and ethical dimensions that influence it. In education, thought must become increasingly methodical as it moves from common-sense concepts, students' experiences, and their curiosities (Freire, 2001), which enables the generation and nurturing of attention and motivation in the learning process, as well as the recycling of existing neural circuits to learn more deeply, since part of one's knowledge is innate while other parts are acquired to represent the world (Dehaene, 2016).

It is to understand that mathematical thinking tends to be formal, useful, deductive (Skovsmose, 2013a) and abstract, becoming a successful product of the human brain in scientifically describing the known universe (Nicolelis, 2020). Therefore, as age and education advance, such thinking becomes more complex, requiring not only memorization and automatization but also actions involving its formulations (Dehaene, 2016).

Thus, it becomes possible to organize mental images (Damasio, 1996) to explain or reflect, in a specifically mathematical way, on the concrete or physical world, which is abstracted or virtualized. It is the mathematical capacity - distinct from that of other animals - together with the creation of symbols, that allows the human brain to operate with abstract skills in the real world (Dehaene, 2022).

In education, this capacity is essential, since, according to Dehaene (2022), it is the key to learning, the ability to select informational parameters and to generalize what has been learned to new contexts. Thus, it is necessary to investigate the way of thinking of individuals engaged in educational processes, especially within formal education, so that learning truly occurs collectively, through the interaction between subjects, knowledge, and the world (Freire, 2005).

However, since thought can result in actions and behaviors, mathematics also needs to be approached critically, as it is neither neutral nor immutable (Freire, 1997; D'Ambrosio, 2014; Skovsmose, 2013a). Therefore, learning mathematics requires the presence of thought and, consequently, behavioral action, which, according to D'Ambrosio (2014), serves as a link between the reality that informs and the action that transforms reality, both grounded in reflection and criticality.

Through reflection and criticality, education enables the apprehension of objective data, analyzing and connecting them to one another to reformulate them more deeply (Freire, 1967). This occurs in an ethical and methodical manner to truly understand the object or situation under critique, surpassing mere exposure to facts (Freire, 2001, 2005) and fostering a transformation in thought and attitude. It is about testing what has been apprehended against what is already known, even if such knowledge operates unconsciously (Dehaene, 2022).

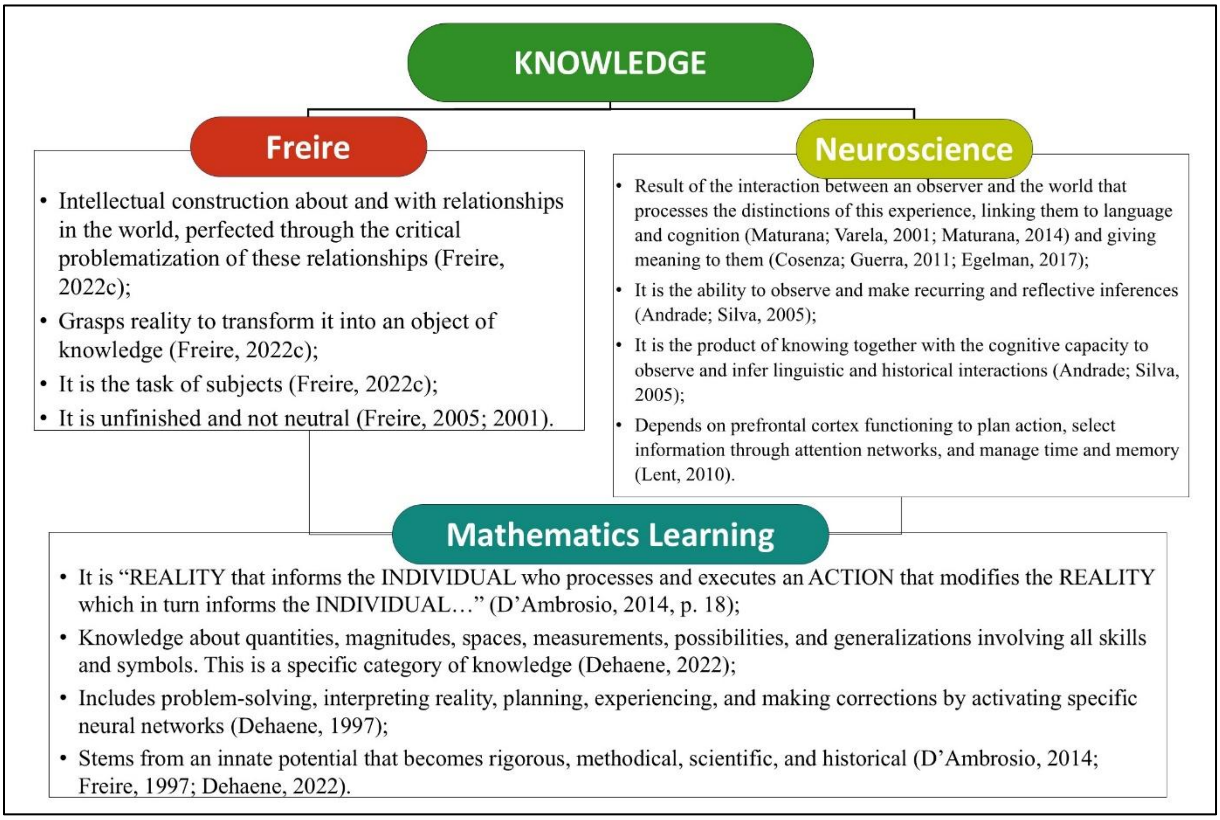
In this regard, Nicolelis (2020) clarifies that, as an efficient intellectual tool of humanity, mathematics can also become a double-edged sword capable of triggering great achievements or catastrophic tragedies. Therefore, in mathematics education, it is essential to maintain conditions for dialogue and discussion between knowledge and its uses, allowing comparison, analysis, and reflection not only through the internal and unconscious neural circuits [neuroscience] but also through the social, cultural, and individual actions that stem from its application. This is crucial, as relationships of survival and power are constantly at stake (Skovsmose, 2013a, 2013b; D'Ambrosio, 2014).

Therefore, in mathematics education, it is essential to develop right, critical and reflective thinking that acknowledges uncertainty and is methodical in interpreting facts, being open to revision, change and appreciation (Freire, 1996). It must build mental models that enable the development of skills, predictions and error analysis, as well as any other initiatives that enrich thought (Dehaene, 2022). In this way, mathematical learning and its generalization can dialectically construct both action and reflection, giving meaning to praxis in the pursuit of transformation and transcendence (D'Ambrosio, 1986; Freire, 1996, 2005).

Thus, knowledge provides the foundation for learning, as it results from the act of knowing and reflecting upon what is known. It compels attention to a fact or object, the curiosity it arouses, the methodical nature of thought, memory, and the resulting product - whether concrete or abstract - conscious or unconscious (Figure 2).

Figure 2

Knowledge (Authors, 2025).



It is granted upon the act of knowing knowledge itself, that is, the way one analyzes what is observed, informed, or experienced, processing it through actions of reflection, recursion, comparison, verification of situationality, and historical relation, in which lived experiences aimed at survival move toward transcending mere support. Mathematics relates to a specific field that, through its own deductive and distinctive language, seeks to clarify, propose and generalize what is in focus, becoming, through interaction and relationships with others and with/in the world, a specific area of the sciences. Therefore, it involves its own concepts and procedures, expressed through distinct and contextual attitudes and behaviors. It can stem both from knowledge generated by the concrete and immediate physical world and from creation - as understood by Skovsmose (2013b) as the potential of matheracy - and from the proposition of realities, blending into ways of being or, as Freire (1997) exemplifies, of conceiving oneself as mathematized bodies.

Since the world and reality exist only through human creation (Freire, 2022; Nicolelis, 2020), mathematics finds its scope within cultural development, which deepens and establishes it through other forms and languages to relate to and understand the world. As part of the process of creation, it is linked to authentic thought - one committed to personal and societal transformation - demanding curiosity that drives and positions individuals before the world (Freire, 2005, 1996), thereby reaching their potential as cyclical knowers of reality's informational processes (D'Ambrosio, 2014). This knowledge, considered powerful by Skovsmose (2013a, 2013b), becomes possible through the activation of neural networks that include problem-solving, interpreting actions, planning, experimenting, and correcting (Dehaene, 1997).

In the educational process, the interaction with and discovery of others and the world enable the creation of semantics to describe, invent algorithms, and recognize patterns, thus making coexistence possible (D'Ambrosio, 2014; Skovsmose, 2013b). In this pursuit, possibilities unfold for "being more," for overcoming and transforming given realities (Freire, 1996), leading - alongside mathematics - to the learning of hierarchical domains with implicit rules and specific inferences that emerge very early in life, serving to summarize a series of observations (forms of knowledge) (Dehaene, 2022).

In this sense, curiosity - recognized as a driving force of humanity and masterfully used in schools (Freire, 1996) - may arise early in life and stands as one of the key ingredients of learning. It directs attention toward knowledge, which, by returning to the undistinguished causes of phenomena, seeks to deduce their models, exposing observations to uncertainty and probability (Dehaene, 2022). However, within the reality of multiple subjectivities and interferences (Skovsmose, 2013a), knowledge becomes a process in continuous development and transformation, shaped by human motivations.

It thus makes sense to invest in restlessness and the incessant questioning that generate attention and awareness, aiming to refine methods and approach objects with greater precision - to move from naïve/spontaneous curiosity to epistemological curiosity, which is critical in - as to transform it into the production of knowledge (Freire, 2001, 1996). Accordingly, the teacher's role is to stimulate curiosity by understanding the context in which they work, adapting their tools, and challenging students (Dehaene, 2022). In this cycle between curiosity and knowledge, each transforms the other, since curiosity itself is already a form of knowledge (Freire, 1996, 2001).

The action that generates knowledge and gives meaning to mathematical understanding, when information (input) is processed as a result (output) of the strategies employed, produces the intelligence needed to survive and transcend (D'Ambrosio, 2014). Therefore, knowledge must be reflective, technological, and pragmatic, broadening horizons of application and responsibility by analyzing and predicting its outcomes, interpreting, understanding and conceiving its own action (Skovsmose, 2013b). In other words, it is delineated by praxis -whether individual or pedagogical - where acting, reflecting, creating, and recreating the world, language, thought, and knowledge make individuals consciously critical of their reality (Freire, 2005), leading to both knowing and doing (D'Ambrosio, 2014) within an ongoing process of incompleteness (Freire, 2005).

It is the role of mathematics education to investigate students' contexts, curiosities, prior knowledge, and common-sense understandings. Starting from what is already known, it should seek parameters for deepening through specific strategies and aim to transpose them as interrelated factors between Freirean theory and cognitive neuroscience. Furthermore, it is equally important across both fields to support learners in understanding what they know and what they do not, as well as to help them find balance in learning through discovery and mediation with others, thus giving meaning to knowledge that transcends mere memorization or automatization.

It is about exploring possibilities and randomness which, when thought of for learning purposes, allow the construction of ideas and the formation of subjects (Dehaene, 2022). This does not mean that all mathematics education is devoid of previously established objectives, with constant discoveries about elements already scientifically grounded and applied, or a juggling act of countless contents developing simultaneously because curiosities differ. On the contrary, as described by Skovsmose (2013b) and Freire (1996, 2005), it becomes necessary to consider the skills designed for formal education, including those related to reproduction and those used in traditional expository teaching - while ensuring that learners are not passive in their learning processes and that they engage in critical thinking about their relationships, viewing mathematics as both technological and social. In this light, it is imperative to establish short- and long-term knowledge objects and objectives to be taught and learned, proposing them not as donations or impositions but as an organized and systematized synthesis, returned to learners with identifiable elements from their own reality (Freire, 2001, 2005).

For this reason, thinking of education through thematic investigation, words and generative themes enhances the systematic construction of formal educational objects, fostering curiosity by composing and decomposing educational contexts so as to, as Freire (2005) states, transcend limits and worldviews as outcomes of critical, historical, and scientific knowledge. The more one investigates the ways learners think, the more education becomes a collective act (Freire, 2005), enabling the recognition of intentionalities and interactions.

Deepening knowledge - which is always part of a set of a priori hypotheses projected onto received data and processed by systems that select the most suitable to circumstances (Dehaene, 2022) - contributes to the democratization of mathematical knowledge, which cannot be elitist, neutral, or purely technical/technological (Freire, 1997). It enables the development of citizenship, reinforced through rights, duties, and responsibilities, resulting in unique ways of being in the world (Freire, 1997). In other words, intentionality matters, something that has relevance from childhood onward (Dehaene, 2022).

This intentionality can operate at both micro and macro levels. It is micro when attention aligns with action for learning and doing; macro when the goal is to relate themes, contents and curricula to students' curiosities to ensure formal mathematical learning. In the first sense, when attention is given to new information, new strategies are designed or awareness of their connection emerges, while those already structured into routines and habits become automatic - at which point prefrontal cortex activation diminishes (Dehaene, 2016). In short, this occurs in mathematical learning when students' attention is engaged: as meanings and connections grow stronger, they become automated and require less conscious procedural application. This is the case with calculations - such as addition and multiplication - that sometimes draw on memory before the development of full reasoning (Dehaene, 2016). However, this decoding of the world, which in some cases is the educator's role, must be accompanied by meaning-making and the discovery of how to mathematize lived experience (Freire, 1997). It is about knowing why one acts and acting because one knows (Freire, 1996).

Beyond the fact that attention arises from curiosity and motivation, it is also a construct of execution, allowing focus and self-control by enabling the automatic selection of appropriate strategies and inhibition of inadequate ones to avoid distractions (Dehaene, 2022; Cosenza & Guerra, 2011). Emotions interfere in this process, with predominantly negative ones often affecting cognitive performance. Moreover, one cannot focus equally on two pieces of information traveling through the same sensory channel; it is more effective to process them one at a time (Cosenza & Guerra, 2011; Dehaene, 2022). These are results of mechanisms that develop during the first 20 years of life and deteriorate with age, yet can be trained through proper education. Such training is made possible by brain plasticity, allowing the development of tasks that - when intentionally varied - improve executive control, help avoid mistakes, and reduce susceptibility to distractions (whether environmental or not) (Dehaene, 2022; Cosenza & Guerra, 2011).

Regarding attention as it pertains to mathematics preparation on a more macro level, it is understood that reflections on school curricula and their objectives can contribute to the development of democratic and problem-posing education. This is facilitated by liberation - not by the production and use of immediate, reality-based resources merely to adapt rather than transform, as occurs in the "banking education" criticized by Freire (2005). Caution is therefore needed with information derived from neuroscientific fields. Since neuroscience focuses on understanding what enables learning and how it occurs across different teaching methods, it can risk adapting itself to knowledge through automatizing mechanisms before allowing a broad reflection on the conditioning factors and ideologies it entails. After all, repetition to achieve automatization is one form of learning, but one that may reduce awareness of content and inhibit questioning of what has been learned.

Thus, it is worth questioning: what do Brazil's education quality indicators truly propose to measure? What outcomes are expected from large-scale standardized testing? Toward which attitudes and behaviors do these results converge and transform? Overloading education for the sake of quantifiable indices - developed under the premise of procedural skills, of knowing or not knowing - may not be the most meaningful route to educational quality, as this approach often excludes critical thinking, interdisciplinarity and engagement with paradigms of uncertainty, nuance, and reflection beyond true/false binaries. Having clarity about the goals and intentions of mathematical knowledge is therefore crucial for educational practice, which must seek specific strategies to achieve and critically analyze them.

It is thus emphasized that educational practices that cause boredom - whether due to lack of stimuli, lack of meaning, or disconnection from students' knowledge levels - fail to motivate or engage learners, making it easier for attention to be lost and for long-term memories not to form. From this perspective, both educational theorists and neuroscientists cited here agree on the need to adapt and adjust methodologies in ways that engage students actively in learning, highlighting the importance of their participation in the process.

In this way, the ideal school practice, as argued by Dehaene (2022), is one that reduces the mechanical nature of stereotyped lessons that fail to align with students' prior knowledge and expectations, and that operate in a unidirectional and senseless way (solely from the teacher's perspective). For Freire (1996), making it ideal is possible when curiosity transforms into epistemological curiosity, through criticality and the construction of knowledge as a human, social, and historical capacity, within a creative and rich adventure that involves development, observation, reconstruction, and transformation of states, assuming risks and taking responsibility for unveiled freedom. Accordingly, mathematics education cannot be a simple transfer from teacher to student, but rather a process of problematization and dialogue mediated by content, through which knowledge is continually reconstructed (Freire, 2022).

Mathematics education that relies solely on problems with one correct answer, filled with descriptive exercises containing all necessary data for solution, reinforces the idea of non-human influence, projecting focal realities and leaving little room for generalization to other contexts (Skovsmose, 2013a). This approach, according to Skovsmose (2013b), kills curiosity by leading students to see problems found outside of school as ready-made, requiring no investigation, thus blocking transposition and promoting the belief that technological knowledge will always yield optimal solutions to real-world issues, without critical analysis or evolution.

Described by Skovsmose (2008) as the "exercise paradigm," this type of activity privileges teacher explanation and student resolution, turning error into punishment - a point of arrival - rather than a learning pathway for adjustment, association, and reformulation. It must be recognized that no one learns without making mistakes and that identifying errors and understanding how to correct them enables the construction of an internal "error catalog" (Dehaene, 2022) that results in meaningful learning - when reflected upon -and in reconnections. Often, a second error made when solving the same problem is not identical to the first, as it may reveal the development of new hypotheses and a different cognitive path. However, this entire process must be affective in order to restore self-confidence (Freire, 2024a), enriching information, producing meta-analytical actions to accept and rectify errors (Dehaene, 2022), and fostering proper argumentation to satisfy mathematical skills and lived experiences. In this way, as Freire (2024b) highlights, one overcomes self-depreciation through the courage to know and to go beyond, as an expression of human capacity.

Likewise, the excessive use of exercises in the form of commands - often disconnected from reasoning and reflective thought, expressed only through procedural or conceptual repetition devoid of dialogue - fosters absolutism not only of knowledge but also of resigned behaviors that extend beyond the classroom (Skovsmose, 2008; Arlø & Skovsmose, 2006), resulting in mere accommodation. Such practices hinder generalization and confine knowledge to focalist functions, making perception and transformation of scenarios more difficult (Freire, 2005).

Consequently, even though part of human knowledge is neurologically consolidated, mathematics, as Dehaene (2016) argues, is like a ladder climbed step by step through conceptual progress, depending on mastery of mathematical inventions. Many cultural tools expand the repertoire of cognitive strategies, enabling individuals to solve concrete problems. Age and education, however, are not intrinsic properties of the numerical system but rather instruments for its efficient use (Dehaene, 2022).

Enhanced through education and culture, mathematics education involves bidirectional causality: the earlier understanding is stimulated, the greater its developmental trajectory (Dehaene, 2022). Therefore, enriched and stimulating environments - employing diverse methods, methodologies, and materials (such as games and activities that promote interaction) - are interventions that strengthen mathematical capacities and their application across contexts (Cosenza & Guerra, 2011; Lent, 2019). Moreover, it is essential to transition from the concrete domain - for example, when a child counts on fingers - to the abstract or mental domain, performing the same calculation “in one’s head” (Cosenza & Guerra, 2011). That is, encoding and decoding knowledge (Freire, 2022).

Dehaene (2022, p. 181) emphasizes that “[…] in mathematics, sensory experiences do not count for much; it is ideas and concepts that do the heavy lifting.” In other words, handling materials, visualizing, or listening to narration cannot constitute the only learning elements without sufficient cognitive deepening; students must be guided to make inferences from what they perceive through these channels, conceptualizing and strategically manipulating their actions. Ensuring learning, therefore, ensures memory - since one depends on the other. Memory stores and can retrieve learned concepts and procedures. In mathematics, depending on the situation, one may need to think specifically about a problem or calculation, or merely recall relevant data spontaneously, as occurs when understanding multiplication and mentally constructing a table of results (the familiar "times table") (Dehaene, 2022). Once automated, these functions are stored in long-term memory and can be recalled when necessary, without extensive conscious reflection, as in the relation between concept and numerical symbol, which at some points were integrated but may still evoke curiosity, criticality and transformation.

Nevertheless, for mathematical learning, working memory is crucial. Its transitory nature allows the mind to retain objects of thought for a certain period through activation of stored brain records, making them accessible for manipulation in consciousness when needed, lasting hours or even days (Cosenza & Guerra, 2011). Simple calculations such as adding or subtracting two-digit numbers involve subprocesses of retrieving rules and facts from long-term memory, computing and storing intermediate results, and performing "carrying/borrowing" operations between units and tens, coordinated and executed by working memory (Corso & Dorneles, 2012). Within it, one identifies a sensory memory component lasting a few seconds, corresponding to the activation of related sensory systems, which is maintained only if relevant, alongside a repetition system and a mechanism for reactivating more permanent memory traces (Cosenza & Guerra, 2011).

This memory system implicitly encodes numbers at given moments (Dehaene, 2022), contributing to faster processing and fluent retrieval of facts from long-term memory (Corso & Dorneles, 2012). When an individual becomes proficient in mathematics - achieving automatization - working memory is freed up for other processes. However, when difficulty arises in retrieving facts, associated with weakened information, slow execution speed, and high error frequency, there is a greater likelihood of forgetting working-memory content and of failing to consolidate it in long-term memory (Corso & Dorneles, 2012). Hence, it is important to exercise control over the quantity and quality of information within working memory, ensuring proper processing (Cosenza & Guerra, 2011).

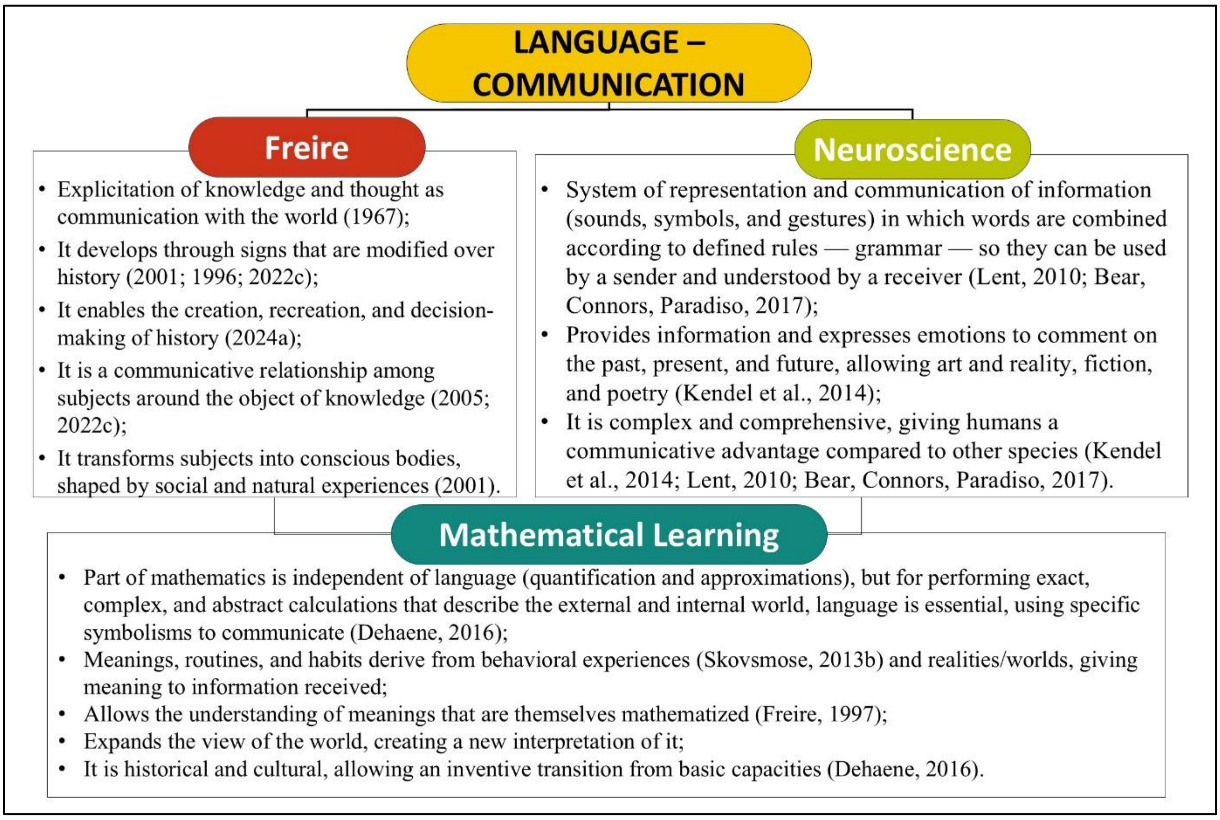
It becomes essential to pay close attention to the methods and methodologies employed when seeking to develop mathematical learning, as they enable the decoding of experiences and the derivation of abstract inferences. For this purpose, the time required to decode and execute a problem, as noted by Corso and Dorneles (2012), must not exceed the limits of working memory, in which processing speed and information retrieval are interconnected, both being crucial for the development and consolidation of intelligence. In this sense, it can be inferred that working memory influences the understanding of mathematics by providing the fundamental cognitive support necessary for task performance, coordinating and integrating other memory processes that impact learning.

This gives meaning to what the brain is willing to process, focusing attention on what is most significant and rewarding (Cosenza & Guerra, 2011). To be and to exist in and with the world is part of the cultural act, of language, and of thought - dimensions that go beyond the object being thought of - and become enriched through the act of communicating and being communicated, as a mathematical way of being and existing in the world (Freire, 1997). The naturalness of mathematical acts that accompany the human being from the moment of awakening - such as moving through space, telling time or planning activities - demonstrates the intrinsic relationship between mathematical activity and human becoming (Freire, 1997), thus revealing its innate and universal nature.

As the development of mathematics unfolds through its relationship with reality itself in constant construction and shaped by a slow process of investigation over thousands of years, during which many minds have collaborated and continue to collaborate to transform it into a language that, today, in most cultures, holds universality (Dehaene, 2022) - it becomes evident that its construction relies on its own linguistic signs, which, thus far, have responded meaningfully to human curiosity and projected reality. It manifests across all countries with shared symbolism, maintaining a deep connection to the survival of the species (D'Ambrosio, 1993), and part of it is structured transgenerationally in the brain, prior to formal education, enabling the understanding of the external world (Dehaene, 2016). Therefore, mathematical language (Figure 3) expands the language of each culture, allowing for generalization and the possibility of developing deeper knowledge about the world's phenomena.

Figure 3

Language (Authors, 2025).b



Since birth, the human being has had organizational qualities and information that lead to prediction for certain types of understanding, perceiving movements and speech since a very early age and finding innate conditioning for the learning of specific and unpredictable parameters (faces, colors, tones, preferences...) that vary according to the context (Dehaene, 2022). Freire (1996) emphasizes that the human being is born conditioned, not determined. Therefore, when deprived of contexts that allow this relationship to be perceived early on, formalized education - through its dialogical form of communication - must present these conditionings that do not determine, proposing scenarios of transformation and personal and social growth (Freire, 2005, 2024a).

Therefore, there is no pure learning; all its expression is given around conditionings that may derive either from one’s own essence or from the environment, assuming that they, in one way or another, present assumptions about a certain domain to be learned (Dehaene, 2022). From this perspective, it makes explicit knowledge and thought – a mathematical in this case -to communicate around the knowable object/fact (Freire, 1967), selecting, from a wide range of expressions, the one that best fits the data, to propose theories in which the brain is able to generate abstract formulas that combine the language of thought and wisely choose such formulas to confront plausible data (Dehaene, 2022). Thus, in this non-determination (Freire, 1996), the human being is allowed to modify oneself and to constitute oneself in the becoming that is historical and social.

While conditioned by one's own existence and by what the species carries in an evolutionary sense, mathematical knowledge becomes a construct of scientific facilitation, considering its innate and universal nature - rejected by no brain (Dehaene, 2016). In light of this, its linguistic labels, at first, are not important for mastering certain mathematical concepts such as quantity, greater or lesser relations, and some aspects of addition and subtraction within approximation conceptions - regardless of literacy - capturing reality and demonstrating that there is neither absolute ignorance nor absolute intelligence (Dehaene, 2016; Freire, 1967). However, when one intends to symbolize it as a system and surpass approximations toward more exact calculations, language becomes imperative and indispensable (Dehaene, 2016). It encompasses signs and meanings that change historically, as they require interpretation, observation, reading, listening and writing (Freire, 2001, 1996, 2022) to communicate the world, which, according to Dehaene (2016), expands the repertoire of available cognitive strategies, enabling the solving of concrete and general problems. It ceases to be a mere relation with the living system it inhabits, becoming existence itself. As Freire (1967) affirms, it becomes liberated from its support, socially organized, and open to change.

For this reason, humanity has developed - through inventive cultural transition over natural/biological basic capacities - a counting system using words that refer to numbers, represented by distinct symbols to demonstrate, compare, and generalize (Dehaene, 2016). It transforms the human being into a conscious body (here, a consciously mathematized body), through social and natural experiences, refining and deepening along with curiosity the experience of the species (Freire, 2001, 1997). Mathematical literacy (mathemacy/numeracy) finds in the incompleteness of life and knowledge itself the ground for a permanent and hopeful search (Freire, 1997), where semantics, algorithms, and routines are created to describe and express behaviors that relate to formal language (Skovsmose, 2013b) and to realities/the world, to give meaning to received information. It interacts in acting upon structures and within contextual organizations, allowing argumentation and relations to be established with actions of power/domination, as a way of doing science (Skovsmose, 2013a, 2013b; Borba & Skovsmose, 2013).

It is reiterated that the constitution and knowledge of mathematics are not neutral. When deeply analyzed, they relate to subjective ideals, and their language can be converted either to empower and enable autonomy or to restrict it. Thus, when placing mathematical education within the two fundamental levels proposed by Freire (2022) - operating between the emotional level and the level of admiration, and which offer, as cognoscible facts, linguistic expressions- one has, when analyzing Dehaene (2016), a mathematics that refers to changes surrounding basic capacities, developing into complex and abstract domains, and going beyond, as proposed by D'Ambrosio (2014) and Skovsmose (2013a, 2013b), the technical capabilities of science, to understand it in its most conditioning and critical relationships.

As a consequence, it becomes possible to develop new skills and competencies within mathematics itself, along with its interpretations and actions in political and social situations that, through their symbols and codes, are established to enable the construction of materacy as a human creation, thus contributing to democracy and citizenship through constructivist, sociocultural, and sociopolitical propositions of its uses (D'Ambrosio, 2004; Skovsmose, 2008, 2013b). In other words, it contributes to a reflective and critical literacy in mathematics, in which pedagogical practice transcends curricular determinants, questioning the why, what for, for whom, and against whom to teach (Skovsmose, 2013b; Freire, 2005).

By expanding the worldview and offering a rereading of it, mathematical language in formal education requires, as Dehaene (2022) argues, shared attention among linguistic interaction processes as a fundamental principle. It enables one to "speak the world" (Freire, 2001), in which mathematical knowledge both influences and is influenced by the development of everyday language (Dehaene, 2016, 2022). It is influenced because, since childhood, the ability to learn words refines the numerical sense by using a lens with a more precise focus, improving numerical acuity (Dehaene, 2016). At the same time, learning the words that refer to numbers affects the numerical sense, as children, through formal education over the years, come to recognize the possibilities by which the parameters of each native language - through combinations of phonemes and graphemes - create a combinatorial explosion, opening new spaces for mental representations (Dehaene, 2016, 2022).

This reveals the need for quality education because, as various studies in neuroscience across different fields show, the existence of sensitive periods for learning strongly influences these processes, given the anatomical development of the brain, in which considerable reorganizations occur due to intense cerebral plasticity (Dehaene, 2022). For reading and writing, according to Dehaene (2022), this sensitive period aligns well with basic education, particularly benefiting from the visual cortex, which is highly malleable at that stage. When such learning does not occur at the appropriate age, it becomes more complex, as certain brain regions are already occupied by other forms of recognition, such as faces and objects (Dehaene, 2022).

The same occurs with mathematics, as experiments conducted with adult individuals from the Amazonian Munduruku people revealed performance similar to that of preschool children, reflecting the impact of formal education on numerical acuity (Dehaene, 2016, 2022). Problems of political and educational nature once again interfere with issues of survival and transcendence. Therefore, educational quality in the most practical and everyday layers of the classroom, as well as in the political and ideological dimensions of education, becomes crucial to know their origins, to position oneself critically toward them, and to pursue teaching that aims for qualitatively broader goals than mere statistical performance.

Thus, formal education, following Freirean ideals, must guide, through critical and epistemological experimentation, the processes of reading and writing, building and rebuilding oneself as a subject engaged with mathematics, perceiving the social threads of the production of knowledge, language, and communication, moving from the simple to the complex, from the concrete to the abstract, while considering prior and common-sense knowledge (Freire, 1996, 2024a).

Strategies such as games, manipulative materials, technologies and similar tools combined with horizontal, respectful dialogue that values what learners already know allow for the mediation of knowledge through content, reciprocity, and intelligibility, achieved through diverse channels (Freire, 1967, 2005, 2022). When integrated and refined, these give meaning to more accurate mathematical understanding (Dehaene, 2016). Once again, the intentionality of educational practices in teaching and dialogue fosters the development of knowledge, creating investigative scenarios and responsibility toward what one knows and how that knowledge is used, within the mutable nature of natural and historical reality, thus breaking accommodation and promoting transformation in ways of expression (Freire, 2024b; Skovsmose, 2008).

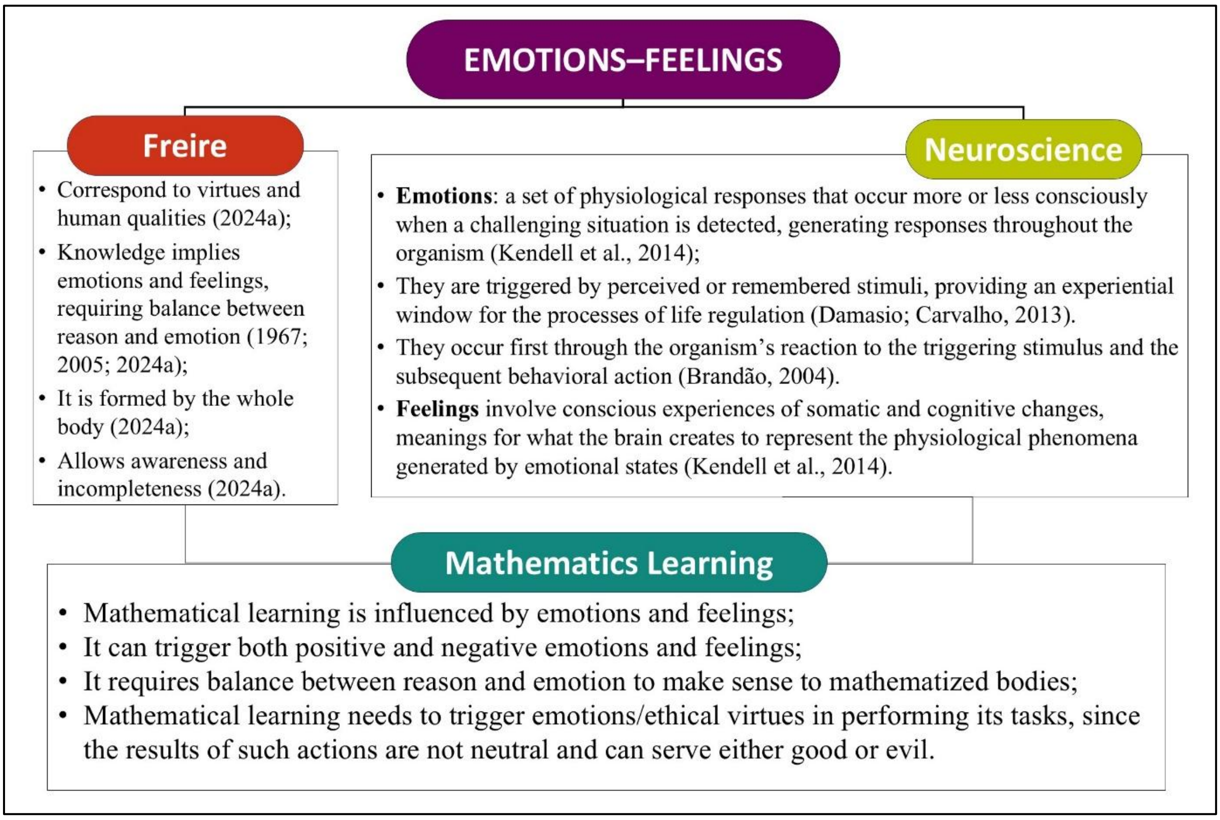
And it is also because learning takes place through mediation and interaction with the teacher that dialogue becomes important. Dialogue encounters the other, as proposed by Freire (2022, 2005). Not as a simple relationship between cognizant subjects and cognoscible objects, but as a communicative practice that subjects engage in concerning the act of knowing, grounded in gnosiological, logical, and historical constructivity that enables them to read the world. For this reason, deep and truthful knowledge becomes feasible through co-participation in the act of learning, bringing to the fore (consciously or not) a critical stance toward what is at play in the communicative field. It requires commitment to transformation and time for construction, while recognizing the relative history of dialogued knowledge (Freire, 2022, 2005).

From this perspective, overcoming learning barriers through adequate teaching methods - where individual differences lie in the motivations and pace of learning - allows the teacher to determine students' knowledge levels through necessary investigations, selecting the most relevant problems in order to acquire the foundations of language, literacy, and mathematics that every person needs (Dehaene, 2022). For this very reason, the better the communication, in general terms, the better the quality of mathematical learning, fostering exploration and the creation of arguments about the cognoscible objects/objectives, in which elements of the subjects' intellectual autonomy development are involved (Arlo; Skovsmose, 2006; Skovsmose, 2008). Thus, the concept of subjects mediated by the world expands, in the perspective of pronouncing it, contributing to its development, and taking responsibility for it, within its historical and social conception (Freire, 1996).

Throughout this process, the feelings that result from emotions become apparent (Figure 4), as factors that differentiate human beings from each other and from other species. They lead to the awareness of one's own existence, outlined through them, enabling the perception of shortcomings and incompleteness (Freire, 2024a).

Figure 4

Emotions e feelings (Authors, 2025).



Both the emotions and feelings brought by students and teachers from other contexts, as well as those created in the classroom during the development of knowledge, affect the structures of learning. Alro and Skovsmose (2006) remind us that positive and negative feelings naturally find their place in the mathematics classroom. As demonstrated by neuroscience, they affect memory and may generate rewards and gratifications or even disorders and traumas that lead to the avoidance of certain contexts. From the perspective of Cosenza and Guerra (2011), they are internal indicators of relevance, resulting from intragroup signaling in the face of communication and decision-making processes, taking place amid physical and physiological manifestations to mobilize corresponding cognitive resources.

Their recognition and emotional self-awareness guide behaviors, which may be more or less assertive and appropriate to the situation. Thus, emotions and feelings, as distinguishable in mathematics, often take on negative meanings due to the lack of sense attributed to complex knowledge, to immediate aspirations, and/or to the teaching approach employed - resulting in spiraling difficulties - since mathematical development occurs with greater acuity when supported by prior knowledge. Based on this, Brousseau (1967, as cited in Pinto, 1998) refers to three fundamental obstacles faced in mathematics: those of ontogenic origin, related to limitations in cognitive capacity; those of didactic origin, arising from instructional choices in its development; and those of epistemological origin, characterized by resistance to knowledge that is poorly adapted to current cognitive abilities.

As for the first obstacle, it is understood that limited cognitive capacities may result from various health issues, including malformations (microcephaly, syndromes, disabilities), personality-related problems, and emotional factors such as anxiety disorders. In mathematics, dyscalculia - a neurological disorder that affects the recognition and development of mathematical understanding more broadly - requires specific interventions for its handling and poses a challenge for teaching practice, which must specialize to better meet and develop these capacities. However, as Dehaene (2022; 2016) points out, some mathematical learning difficulties treated as dyscalculia actually stem from a lack of stimuli during sensitive developmental periods, failure to recognize prior knowledge, or poorly designed interventions.

Its dilution within the process of mathematical meaning-making leads to the creation of subjectivities and personal stances toward mathematical experiences, providing structures that influence both present and future educational contexts (Skovsmose, 2018). Thus, it is understood that some emotions and feelings can be controlled, while others cannot. Regarding the use of didactics in mathematics education, neuroscience is emphatic in emphasizing the development of positive feelings and emotions within formal education (Lent, 2010; Cosenza & Guerra, 2011; Dehaene, 2016, 2022). For this field, it is essential to create environments in which affectivity and security coexist in favor of education, avoiding stressors that cause the opposite, aversion and learning loss (Lent, 2010; Cosenza & Guerra, 2011; Dehaene, 2016, 2022).

The valuing of prior knowledge and of the knowledge yet to be developed - along with encouragement, safety, tolerance, humility, hope, solidarity, joy, “impatient patience,” and ethics - allows, according to Freire (1967, 1996, 2005, 2024a, 2024b), the creation of a space and time that stimulates learning to become increasingly open and conscious. This movement transcends pure memorization and technique, fostering the unveiling of meanings and purposes. Without permissiveness or authoritarianism, commitments and interactions emerge in relation to the cognitive object or fact, stimulating struggle and transformation (Freire, 2005, 2024a).

In this sense, emotions and feelings - whether positive or negative - cannot be removed from educational practice but must instead be understood to foster the development of safe and respectful environments in which uncertainty can be experienced (Alro & Skovsmose, 2006). When the environment generates negative effects, there is a tendency toward alienation and a loss of criticality, compromising mathematical creativity and giving rise to dependency, avoidance, and aversion (D'Ambrosio, 1986; Freire, 2005). Such contexts configure cyclical environments of negative emotions and feelings in which fear generates anxiety that, in turn, leads to errors, withdrawal, and stagnation. Ultimately, certain capacities are lost, which, as Freire (1997) interprets, fail to emerge due to inadequate development during schooling. As a result, these capacities no longer awaken openly and abstractly, transforming into stigmas and myths suggesting that mathematics is "for the few."

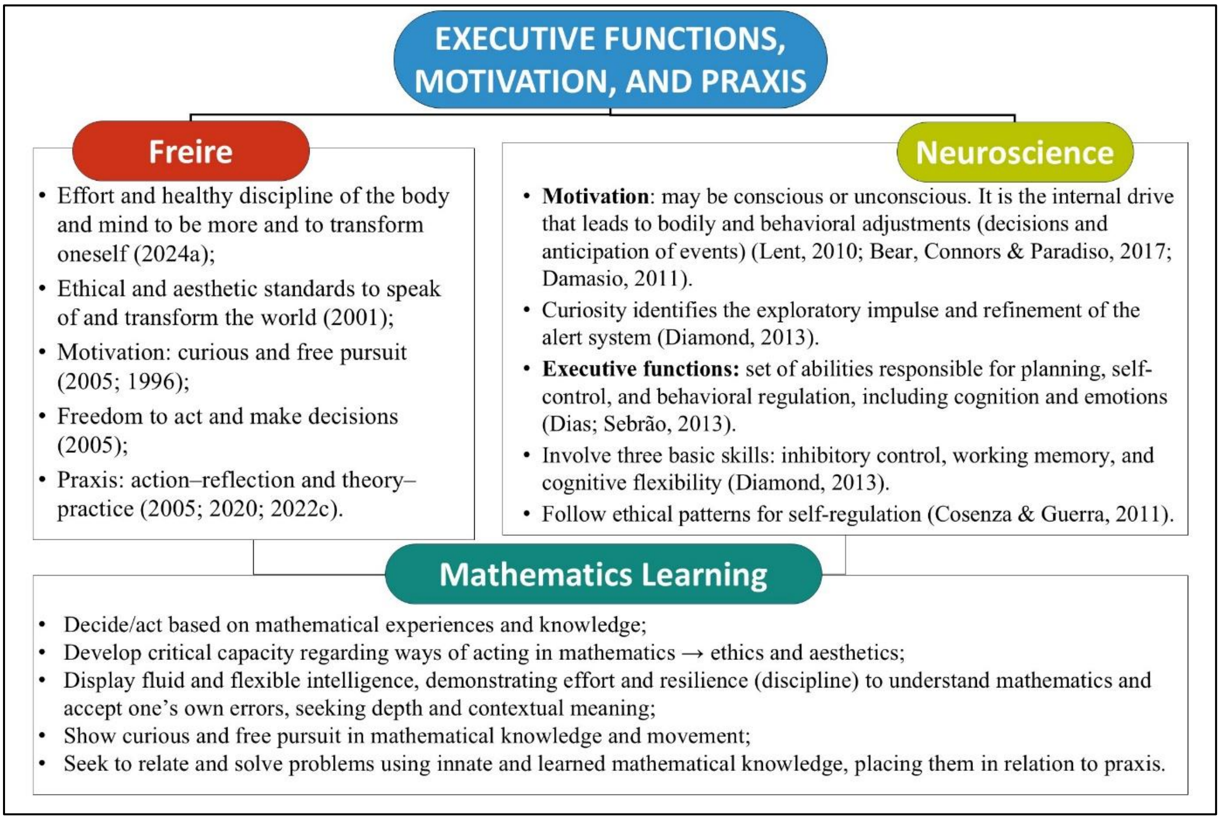
Thus, overcoming the obstacles of mathematics requires alternatives that recognize individuals as whole and integrated beings in the world - grounded in respect and collaboration to critically understand and confront universal situations (D'Ambrosio, 2014). It is, invariably, the transcendence of the strict dichotomy between true and false, right and wrong, and the punitive treatment of error, leading instead to a broader understanding of mathematics (Dehaene, 2016).

In this way, since human beings are programmed to learn and are mathematized bodies that move and transform themselves and the world, they are impelled by consciousness that desire, that express sensations and dreams, and that seek to know, to teach, and to intervene (Freire, 1996). These processes occur within citizenship and responsibility for knowledge -through decision and choice (Freire, 2005) - drawing upon emotions as a crucial factor in cognition, since through them individuals engage in curious pursuits (Freire, 2024a) and act toward transformation. For this to occur, freedom must be a fundamental element in development, considering the different aspects of life, criticality, possibilities and motivations that shape the course of humanity.

Curiosity, which implies knowledge, only becomes possible when motivated actions come into play. Motivational impulses, which refer to the exertion of effort upon the acts of knowing - and consequently of learning and making history - provoke planning, decision-making and the ability to inhibit, at times, immediate gratification in pursuit of deeper understanding. These processes produce cognitive flexibility in the face of challenges and states of overcoming. Therefore, in mathematics education, it is essential to move through the flexible aspects of theorizing and practicing within the constant back-and-forth of this relationship (see Figure 5): executive functions, motivation, and praxis.

Figure 5

Executive functions, motivation and praxis (Authors, 2025).



In a less direct yet correlational way, praxis finds coherence within executive functions and motivation, linking the act of knowing with the knowledge that acts. It situates itself in the tension of being beyond what is inherited, as Freire (2001) distinguishes. Faced with finitude, limits, and incompleteness, the conscious being perceives itself as a natural seeker. Through this curiosity, one explores mathematical knowledge of quantities and approximations, deepening concepts to formulate explanations about reality and its future.

In this sense, mathematical education requires more than technical and procedural capacities (D'Ambrosio, 2014); it also demands those aligned with criticality, involving other forms of inquiry, argumentation, and decision-making (Skovsmose, 2013a). These define ethical and aesthetic standards built through the effort to change and to improve, mediated by pedagogical practices that carry meaning, challenge established knowledge, and require complex cognitive abilities of self-control and discipline (Diamond, 2013).

It is important to value executive functions in mathematics, which are related to the construction and inhibition of synapses, discipline, effort, flexibility, self-control, and working memory. These functions guide planning, decision-making, motivation, and the actions that lead to awareness. This becomes possible when education allows freedom and problematization, contributing to mathematical doing that becomes critical through lived experiences and abstracted knowledge. Freire (2005, 2020, 2022) reminds us that every action or practice has an underlying theory that has been reflected upon and that must still be refined when returning from the practical field.

In this regard, Freire (1996, 2024a) emphasizes the teacher's understanding in accompanying the emotions, feelings, desires, intuitions, discoveries, and insecurities that arise in the classroom, allowing decisions about knowledge, the generation of autonomy, careful evaluation, planning and the willingness to take risks through knowledge and choice. According to Dehaene (2022), the lack of opportunities to choose and to go beyond the established, generating behaviors of mere compliance, is one of the main problems of teaching exclusively through textbooks and ready-made exercises. For the author, while most textbooks are well organized into chapters and specific topics - which can be beneficial - they also tend to include questions that relate only to the content presented, which is less favorable, as it prevents students from making connections with other areas of knowledge. This lack of relationship also leads to a lack of associative reasoning for making decisions beyond apparent perceptions and in broader contexts, as described by Skovsmose (2008) in his discussion of the exercise paradigm.

Dehaene (2022) highlights that this kind of educational organization - what Freire (2005) calls banking concept of education - still presents two negative consequences. First, questions are not revisited regularly nor examined from different perspectives, leading to intellectual stagnation by failing to engage students in selecting parameters of knowledge and in searching for strategies to solve problems. In other words, due to the limited stimuli prescribed by the statements of such exercises, students' ability to act upon broader contexts, requiring diverse knowledge linkages, selection, and decision-making, is hindered. Consequently, education becomes a practice of repetition with fewer possibilities for generalization.

This type of methodology may be relevant only when the exclusive goal is to develop proficiency skills limited to a specific type of knowledge assessment. Dehaene (2022) discusses these cases, establishing that spaced repetition of such content over a desired period - using strategies such as self-testing with exercises - ensures the automatized learning of certain knowledge, although these connections weaken if not revisited.

Furthermore, when analyzing the Program for International Student Assessment (PISA) exams, it is observed that Finland, a country with historically high scores in language, mathematics and science, has shown a decline in performance over the years, despite still maintaining relatively high achievement. Both local specialists and the country's Minister of Education, who have investigated the causes of this decline, propose similar hypotheses: the flexibilization of curricula that introduced interdisciplinary projects instead of the traditional division prioritizing specific disciplinary techniques; the increase in school digitalization, perceived as distracting, anxiety-inducing, and responsible for sleep alterations and reduced concentration capacity; demographic and economic changes placing part of the population and new immigrants in situations of vulnerability and inequality; the increase in bureaucratic demands on teachers; and budgetary crises that reduce education funding (Tenente, 2025).

To address this decline, the Finnish government intends to: ban the use of cell phones in classrooms; increase instructional hours in language and mathematics without abandoning project-based education; hire more special education teachers to ensure inclusion and support for classroom teachers; increase the number of physical education professionals to combat sedentary behavior and the intensive use of digital technologies; expand data collection on teaching practices in each school; and establish support programs for students with learning difficulties, especially for foreign students who lack proficiency in the local language (Tenente, 2025).

It is noteworthy that the different criteria determining the quality obtained in a proficiency test - although assuming specific knowledge from each area - must be observed, especially when there is no possibility of expanding into real-world contexts that demand more than one type of knowledge and more than one field of expertise.

When education becomes more complex and comprehensive, it becomes evident that certain proficiency assessments in a specific discipline are insufficient to express quality and the experiences involved, thus requiring broader interactions and diverse resources for problem-solving. Changing strategies to foster broader learning and to transform situations must be accompanied by changes in how assessments are conducted and how results are processed. Therefore, restricting learning to content that is almost identically tested obstructs creativity, limits the potential for change, hinders critical relationships, action, reflection, and the pursuit of knowledge (Freire, 2020, 2022).

It is interpreted that mathematics education also aims to foster flexible capacities to seek information beyond what has been proposed, identifying relevance, organizing critically, evaluating, generalizing and incorporating new concepts (Cosenza & Guerra, 2011) into its solutions. This highlights the importance of education as a liberating practice that recognizes the necessity of certain limits but does not confine itself to bureaucratic specificities of deposits and returns, instead valuing the healthy discipline of body and mind as essential for transformation and transcendence - without which intellectual work cannot take place (Freire, 2024a).

As an exploratory impulse of infinite curiosity and refinement of the alert system, where bodily and behavioral adjustments are pursued (Lent, 2010; Bear, Connors & Paradiso, 2017; Damásio, 2011; Diamond, 2013), mathematics education establishes scenarios of bodily and mental discipline, postponing certain rewards and regulating and acting upon oneself, both cognitively and emotionally (Dias & Seabra, 2013), while pursuing ethical standards (Cosenza & Guerra, 2011). Along with other fields of knowledge, mathematics education contributes not only to the development of skills but also to the promotion of consciousness about the world and the ways of acting within it.

Thus, it enables the resolution of complex problems through the cognitive flexibility triggered by praxis modulation - praxis that is exercised in and with the world. In this praxis, where language, thought, and reflection on one's own work operate, individuals can reflect on themselves and their activity, seeking to overcome limitations, interacting with others and with the world (Freire, 2022).

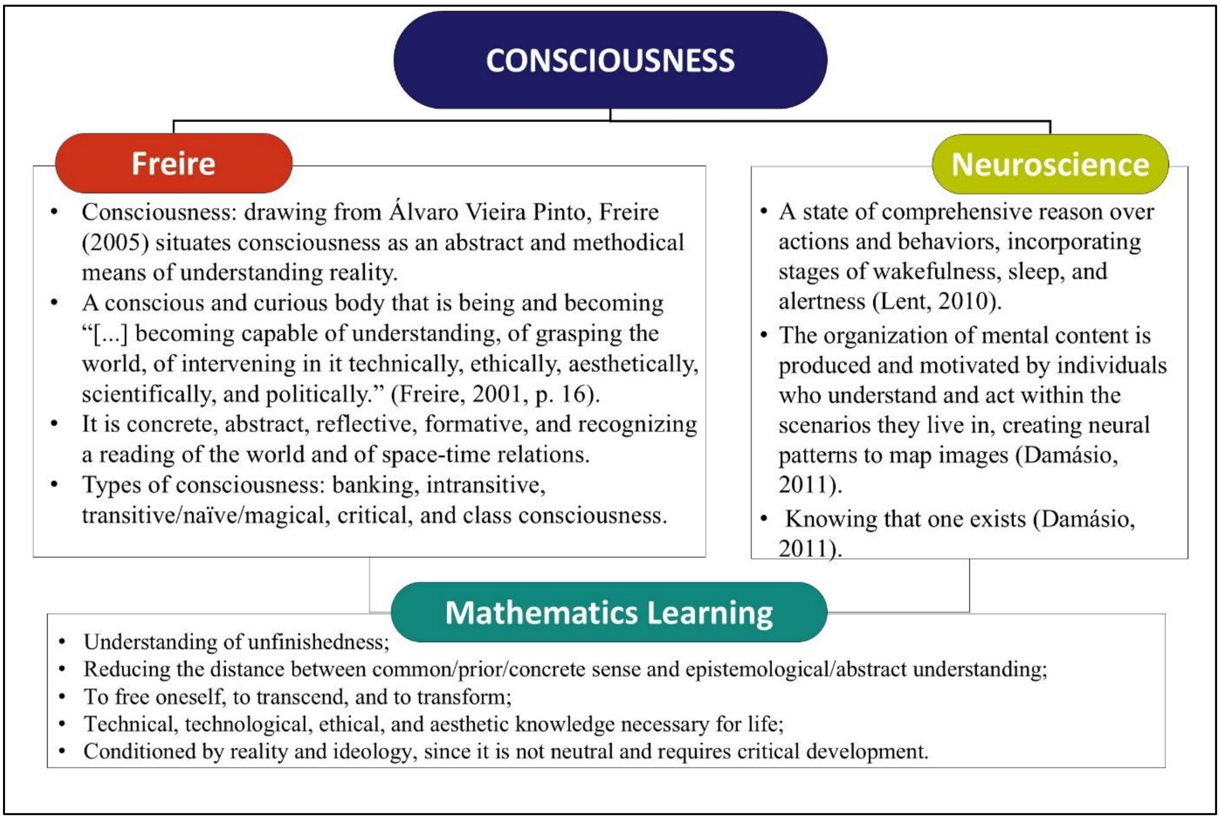
Through the problematization of reality and teaching practice - where concrete conditions are connected to intellectual ones - education can lead to more transformative and questioning practices, enlightened by theories that engage in dialogue and dialectics of doing, allowing for the creation and recreation of the world and of oneself (Freire, 2005, 2022), thereby making cognition more flexible by expanding knowledge boundaries and granting them conscious meaning.

Mathematics teaching practices must, therefore, focus on issues related to these broader levels of awareness. The lack of development in areas such as planning, working memory, decision-making, discipline, and flexibility within formal basic education prevents the maturation of the prefrontal cortex - the region responsible for these actions - thus contributing to the formation of inattentive, impulsive individuals with difficulties in planning, completing tasks, and engaging in complex behaviors, which in turn affects overall emotional and sentimental regulation (Dias & Seabra, 2013). Consequently, educational practice must provide structure for teaching and learning processes based on discovery and creativity, allowing students to realize that there is always much more to uncover (Dehaene, 2022).

In light of Freire’s thought, learning and liberation constitute a dialectical unity - one learns in order to be free, and becomes free in order to learn. Such a process emerges through acts of problematization and the pursuit of critical understanding, wherein the acknowledgment of failures and errors serves as a path toward transcendence. Through this movement, the layers of knowledge are unveiled and interwoven with critical consciousness, as represented in Figure 6.

Figure 6

Consciousness (Authors, 2025).



From the perspective of mathematical knowledge, consciousness - which gradually diminishes ignorance - emerges through the formulation of theories about the external world, derived from observation and analysis, inferring and reasoning through probabilities, and returning to observation until plausibility is reached (Dehaene, 2022). This process demands a reflective mathematics education, in which the involvement of its subjects (students, teachers, staff, management, and the school community) and the intentionality of knowledge, as both mental and physical behaviors, contribute to the construction of citizenship, whereby knowledge adjusts itself to the very process of learning (Skovsmose, 2008; D'Ambrosio, 2014; Freire, 2001).

Learning, therefore, is a transformation of what has been learned into reinvention and application, constituting a mental challenge to go beyond mere adaptation, encompassing intervention and re-creation - whether of reality itself or of knowledge (Freire, 1996, 2022; Dehaene, 2022).

It is the building of autonomy and the maturation of the self in order to become amid a transforming world (Freire, 1996). Hence, it is a state of attentiveness and a process of self-liberation, allowing one to act and become a subject of oneself, for oneself, and for the world.

Final Considerations

For the purposes of mathematics education to be fulfilled, it is necessary to go beyond the mere architecture of mathematics itself, which means demonstrate and formalize its knowledge; serve as a strategy to reach one's own potential and contribute to the common good; represent reality partially or holistically; be part of technological and decision-making development; reason; construct hypothetical situations; investigate to reach abstract levels; liberate; assume responsibility; complexify knowledge; foster thought and ideas; and contribute to planning and the development of society (Arlo & Skovsmose, 2006; D'Ambrosio, 1986, 2014; Skovsmose, 2013a).

The analysis and correlation of the writings of Freire, mathematics education and cognitive neuroscience reveal the urgent need to create scenarios that encourage students to take ownership and responsibility for their learning; to reflect upon knowledge and its applications; to align educational practices with students' contexts; to promote equity and social justice; to propose methodologies of intervention, intentional discovery, curiosity, and surprise; to pursue disciplined effort within welcoming and respectful environments that value the whole person; and to generate shared attention, dedication, metacognition, and expanded praxis.

In this light, it can be inferred that mathematics education - like all other areas of education - is inherently complex, situated within the tension between innate, learned, technical, and political knowledge. Therefore, integrating it deeply within basic education is essential, investing in the development of critical consciousness to interpret and transform reality, where interaction among subjects exemplifies them as biological, historical, and cultural beings.

References

Alro, H.; Skovsmose, O. (2006). *Diálogo e Aprendizagem em Educação Matemática.* Belo Horizonte: Autêntica.

Andrade, L. A. B.; Silva, E. P. (2005). O conhecer e o conhecimento: comentários sobre o viver e o tempo. *Ciências & Cognição,* (4), 35-41. http://www.cienciasecognicao.org/.

Bear, M. F.; Connors, B. W.; Paradiso, M. A. (2017). *Neurociências:* desvendando o sistema nervoso. 4. ed. Porto Alegre: Artmed.

Corso, L. V.; Dorneles, B. V. (2012). Qual o papel que a memória de trabalho exerce na aprendizagem da matemática? *Bolema,* v. 26, n. 42b, abr. https://doi.org/10.1590/S0103-636X2012000200011.

Cosenza, R; Guerra, L. (2011). *Neurociência e educação.* Artmed Editora.

D'Ambrosio, U. (1986). *Da realidade à ação:* reflexões sobre educação matemática e educação matemática. 6. ed. São Paulo: Summus editora.

D'Ambrosio, U. (2014). *Educação Matemática:* da teoria à prática. 23. ed. 2. reimp. Campinas, SP: Papirus.

Damásio, A. (1996). *O Erro de Descartes:* emoção, razão e o cérebro humano**.** São Paulo: Companhia das Letras.

Dehaene, S. (2016). *El cerebro matemático:* Cómo nacen, viven y a veces mueren los números en nuestra mente. 1. ed. Buenos Aires: Siglo Veintiuno Editores.

Dehaene, S. (2022). *É assim que aprendemos:* por que o cérebro funciona melhor do que qualquer máquina (ainda…). São Paulo: Editora Contexto, 2022.

Diamond, A. (2013). Executive functions. *Annual review of psychology***,** (*64)*, 135-168. https://shre.ink/bHkV.

Dias, N. M.; Seabra, A. G. (2015). Funções executivas: desenvolvimento e intervenção. *Estudos Interdisciplinares em Psicologia,* (1) 80-95. https://shre.ink/b2z4

Freire, P. (1967). *Educação como prática da liberdade.* Rio de Janeiro: Paz e Terra.

Freire, P. (1996). *Pedagogia da autonomia:* saberes necessários à prática educativa. Paz e Terra, Rio de Janeiro.

Freire, P. (2001). *Política e educação:* ensaios. 5. ed. São Paulo: Cortez.

Freire, P. (2005). *Pedagogia do oprimido.* Rio de Janeiro: Paz e Terra.

Freire, P. (2020). *Educação e mudança.* 41. ed. Rio de Janeiro: Paz e Terra.

Freire, P. (2022). *Extensão ou comunicação?* 25. ed. Rio de Janeiro: Paz e Terra.

Freire, P. (2024a). *Professora sim, tia não:* cartas a quem ousa ensinar. Rio de Janeiro: Paz e Terra.

Freire, P. (2024b). *Pedagogia da indignação.* Rio de Janeiro: Paz e Terra.

Freire, P.; D'Ambrosio, U.; Mendonça, M. (1997). A Conversation with Paulo Freire. *For the Learning of Mathematics,* Canadá, v. 17, n. 3, p. 7-10, nov. 1997. Disponível em: http://www.jstor.org/stable/40248246. Acesso em: 13 jun. 2024.

Lent, R. (2010). *Cem bilhões de neurônios.* Rio de Janeiro: Atheneu.

Maturana, H.; Varela, F. J. (2001). *A árvore do conhecimento:* as bases biológicas da compreensão humana. São Paulo: Palas Athena.

Nicolelis, M. (2020). *O verdadeiro criador de tudo:* como o cérebro humano moldou o universo tal como o conhecemos. São Paulo: Editora Crítica.

Pinto, N. B. (1998). O erro como estratégia didática no ensino da matemática elementar. *Tese* (Doutorado em Didática) Faculdade de Educação, Universidade de São Paulo, São Paulo, 1998. DOI:10.11606/T.48.1998.tde-12022015-151819.

Skovsmose, O. (2008). *Desafios da reflexão em educação matemática crítica.* Campinas/SP: Papirus.

Skovsmose, O. (2013a). *Educação Crítica:* Incerteza, Matemática e Responsabilidade. Ed. Cortez, São Paulo.

Skovsmose, O. (2013a). *Educação Matemática Crítica:* a questão da democracia. 6. ed. Campinas/SP: Papirus.

Tenente, L. (2025). *Antes 'melhor do mundo', Finlândia vê desempenho dos alunos cair e tenta encontrar erro; modelo inspirou Brasil.* Jornal G1. https://shre.ink/bHTb.