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Nexus centered on the cerebral amygdala, emotions and learning

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Abstract

Neuroscience has advanced in the interactive understanding between emotions, the role of the amygdala and the learning mechanism, seeking to clarify the functions of the limbic system as the center of the emotional processor, since the brain also learns through emotions. The objective is to describe the amygdaloid body, emotions and their implications for learning. This scoping review was conducted according to the recommendations of *The Joanna Briggs Institute*, with a search for articles in the SciELO, PubMed, *Science Direct*, and *Research Gate* databases, within a four-year time window (2022-2025). The mnemonic combination PCC (Population, Context, Concept) was used to define the guiding question of the research. There were 24 articles were included, which contextualized the main structures of the limbic system and functions of the amygdala related to learning. It was possible to consider that the amygdala, a subcortical structure of the limbic system, modulates emotions, attention and memory, and the fear mechanism, with intense effects on learning. Emotionally charged experiences strengthen cognition and neural plasticity. This highlights the relevance of interdisciplinary approaches between cognition and learning physiology. Although this review provides evidence that the amygdala and positive emotions modulate memory consolidation with strong effects on learning, further research is desirable to clarify neurodidactic applications in the face of the new paradigms for education in the twenty-first century.

Keywords: learning, emotions, amygdala, education, neurodidactics.

Resumo

A neurociência tem avançado na compreensão interativa entre as emoções, o papel da amígdala e o mecanismo de aprendizagem, buscando esclarecer as funções do sistema límbico como centro do processador emocional, uma vez que o cérebro também aprende por meio das emoções. O objetivo é descrever o corpo amigdalóide, as emoções e suas implicações para a aprendizagem. Esta revisão de escopo foi conduzida de acordo com as recomendações do *The Joanna Briggs Institute*, com busca de artigos nas bases de dados SciELO, PubMed, *Science Direct* e *Research Gate*, em uma janela temporal de quatro anos (2022-2025). A combinação mnemônica PCC (População, Contexto, Conceito) foi utilizada para definir a questão norteadora da pesquisa. Foram incluídos 24 artigos que contextualizaram as principais estruturas do sistema límbico e funções da amígdala relacionadas à aprendizagem. Foi possível considerar que a amígdala, estrutura subcortical do sistema límbico, modula as emoções, a atenção e a memória, e o mecanismo do medo, com intensos efeitos na aprendizagem. Experiências carregadas de emoção fortalecem a cognição e a plasticidade neural. Isso destaca a relevância de abordagens interdisciplinares entre

cognição e fisiologia da aprendizagem. Embora esta revisão forneça evidências de que a amígdala e as emoções positivas modulam a consolidação da memória com fortes efeitos na aprendizagem, pesquisas adicionais são necessárias para esclarecer as aplicações neurodidáticas diante dos novos paradigmas da educação no século XXI.

Palavras-chave: aprendizagem, emoções, amígdalas, educação, neurodidática.

Resumem

La neurociencia ha avanzado en la comprensión de la interacción entre las emociones, el rol de la amígdala y el mecanismo de aprendizaje, buscando esclarecer las funciones del sistema límbico como centro del procesamiento emocional, ya que el cerebro también aprende a través de las emociones. El objetivo es describir la amígdala, las emociones y sus implicaciones para el aprendizaje. Esta revisión exploratoria se realizó según las recomendaciones del Instituto Joanna Briggs, buscando artículos en las bases de datos SciELO, PubMed, Science Direct y Research Gate durante un período de cuatro años (2022-2025). Se utilizó la combinación mnemotécnica PCC (Población, Contexto, Concepto) para definir la pregunta de investigación. Se incluyeron 24 artículos que contextualizaban las principales estructuras del sistema límbico y las funciones de la amígdala relacionadas con el aprendizaje. Se concluyó que la amígdala, una estructura subcortical del sistema límbico, modula las emociones, la atención, la memoria y el mecanismo del miedo, con profundos efectos en el aprendizaje. Las experiencias con carga emocional fortalecen la cognición y la plasticidad neuronal. Esto resalta la relevancia de los enfoques interdisciplinarios entre la cognición y la fisiología del aprendizaje. Si bien esta revisión proporciona evidencia de que la amígdala y las emociones positivas modulan la consolidación de la memoria con importantes efectos en el aprendizaje, se necesita más investigación para aclarar las aplicaciones neurodidáticas a la luz de los nuevos paradigmas educativos del siglo XXI.

Palabras clave: aprendizaje, emociones, amígdala, educación, neurodidáctica.

Introduction

The growing connection of neuroscience in education has boosted neurodidactics, which links cognitive science and pedagogy to improve learning. Neuroscientific advances in the limbic system and higher cognitive functions highlight the critical role that emotional engagement plays in learning and educational performance. Neurodidactics is an interdisciplinary approach that integrates knowledge linked to pedagogical *praxis*, emphasizes the importance of understanding how emotions influence cognitive functions in learning (Kämpf et al., 2023; Pradeep et al., 2024).

The integration of this knowledge represents a challenge to educators and school management, reinforcing the notion that effective learning is not a mere student effort, but an experience that involves the cognitive emotional of the student and also of the educator. In neurophysiological terms, the area called the Limbic System (SL) is the neural structure responsible for processing emotions, and is also involved in the formation of memories, fundamental in the formation of learning experiences, so Barco et al. (2024) emphasize that learning processes are certainly linked to affective factors.

For Pradeep et al. (2024), emotions influence and play a fundamental role in learning, with effects on educational outcomes. They explain that the positive emotional state expands the attentional focus and facilitates the consolidation of memory, while negative emotions, such as

anxiety and stress, can impair school performance. Despite the relevance of this theme, there is still a gap in published research that explores the emotional dimension linked to learning. All of this represents a challenge to contemporary educational management, which is still unaware of the role of the brain as a learning organ, the function of the amygdala and its tenuous boundary between emotions and memory, with effects on cognitive performance and learning.

Experimental studies throughout the twentieth century showed that the cerebral amygdala is linked to emotions, functions that have been difficult to confirm due to the rarity of selective conditions. However, recent clinical and neuroimaging studies have helped reveal the role of the amygdala in emotional processing and social behavior. Supporting neurodidactic studies that highlight the importance of emotional state and positive environment in the classroom to favor effective learning, engagement, student performance, and support for teacher planning (Inman et al., 2023; Mansueto et al., 2025; Saito et al., 2025).

In this context, the intersection between neurodidactics and knowledge about emotional function and effects, a multifaceted view of the physiology of learning emerges. The exploration of how emotional factors and other cognitive functions interact in educational contexts can enhance and deepen the understanding of more effective teaching strategies, support school curricula that promote emotional and cognitive balance during educational activities (Dubovi, 2023; Pardeep et al., 2024).

Recent studies corroborate that the amygdala, the structure of the SL, orchestrates emotional and cognitive behavior. They shape perceptions of the present, prioritize which memories last, inform new neural pathways, in the different threads that intertwine the learning experience. The amygdala manages the processing of information between the prefrontal-temporal association cortices and the hypothalamus, acts in the regulation of anxiety, fear conditioning, emotional memory and social cognition. These cognitive events are involved in learning (Attard & 2022; Johnson, 2024).

The amygdala receives stimuli from the sensory and visceral systems, which is why it is considered a very important brain structure in emotional learning. And, as mentioned earlier, when managing the processing of emotions, in pleasurable learning or not, it plays a fundamental role in memory processes. The main implication of the amygdala for the educational context is the importance of learning through emotional and collective experiences (Li et al., 2023; Johnson, 2024; Saito et al., 2025).

Thus, given its relevance to the educational context, the objective of this research is to describe the amygdaloid body as a subcortical structure in the processing of emotions and its implications in learning.

Methods

This is a scoping review, based on the following question: What is the interactive context between the function of the amygdala in the limbic system, emotions and learning? To elaborate the scientific question of the study, the mnemonic PCC (population, concept and context) was used: Where P: People in educational environments and functions of the amygdaloid body as a subcortical structure of the limbic system; C: Interventions of the emotional state in learning; and C: Educational environment conducive to emotional and social-cognitive learning of mutual influence.

This study adopted the methodological strategy of the *Jonna Briggs Institute* (JBI), whose objective is to map concepts of a given theme and identify knowledge gaps in the literature, advocating recent publications. The *Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews* (PRISMA-ScR) checklist was also used (Peters et al., 2020).

Original articles that met the scientific question of the present study, full text open access, meta-analyses, cross-sectional study, experimental or quasi-experimental, clinical trials, published in a 4-year time window (2022-2025), in the following languages: English, Spanish or Portuguese, were included. The time frame lasted until the month in which the search for articles was carried out, May 2025.

Articles on the theme, which did not fit the guiding question, dissertations and theses, conference articles, book chapters, conference reviews or gray literature, with restricted access, and articles outside the pre-established object of study were excluded. In total, 24 articles were included that supported the discussion of the present study.

Regarding data collection and organization, the search was carried out between April and May 2025 in the National Library of Medicine (PubMed), Scopus (Elsevier) and Science Direct and SciElo, ResearchGate-academic social network databases. In the first stage, the search was broader, using the Health Sciences Descriptors (DeCS), with structured and trilingual vocabulary, with indexing of articles from scientific journals. In Portuguese: learning, emotions, amygdalas, education; English: Learning; emotions; amygdala; education. The Boolean operators "and" and "or" were used. The State of the Art through Systematic Review (StArt) System was used to minimize excesses and duplication of searches, the zotero application for organizing references.

Initially, correspondence was sought by exploring titles, keywords, descriptors and abstracts of the studies and approximation with the object and question of the study. Subsequently, the selected studies were screened, first by reading the abstract and methodology, then by reading the full text. In the third stage, the articles selected for reading in full were explored in detail,

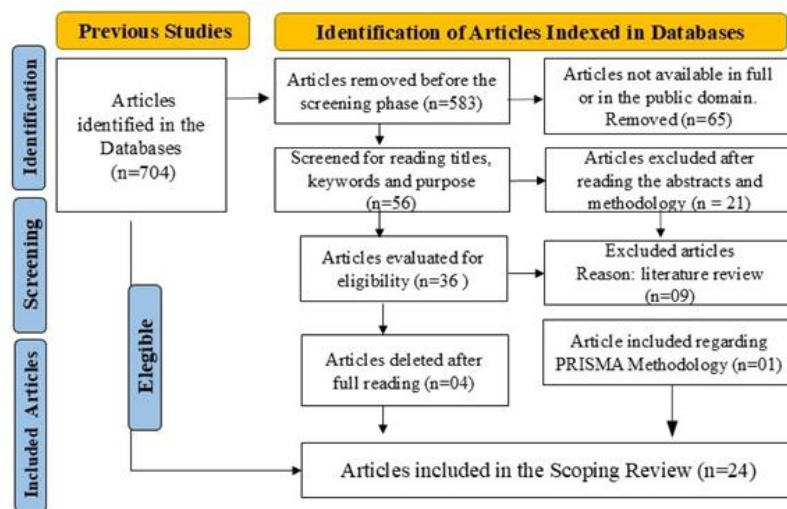
including their references, to identify more opportunities for discussion. The selection and screening process is described in the PRISMA-ScR flowchart (Figure 1). The methodological quality of the articles was not an eligible criterion for evaluation in the present study, since this is optional in the scoping review.

The typology of this research does not require submission to the Research Ethics Committee (REC), because it was carried out with secondary data in the public domain. The initial version of the protocol of this *Scoping Review* was registered in the *Open Science Framework* (OSF) with the identification number: DOI 10.17605/OSF.IO/6SDQN.

Findings

According to the stages, the articles selected for reading in full were included in this scoping review. The screening process is presented in the flowchart (Figure 1), based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR).

Figure 1: Flowchart of the selection of articles according to the PRISMA-ScR protocol.



Source: Created by the authors.

The Limbic System is the epicenter of emotional expression. The main structures of SL, its functions and relationship with learning, are described in Chart 1. It explains the connection of the hippocampus, for example, which is important for the formation of new memories in spatial learning. Establishing the relationship between the proposed method for conceptual discussion of this article.

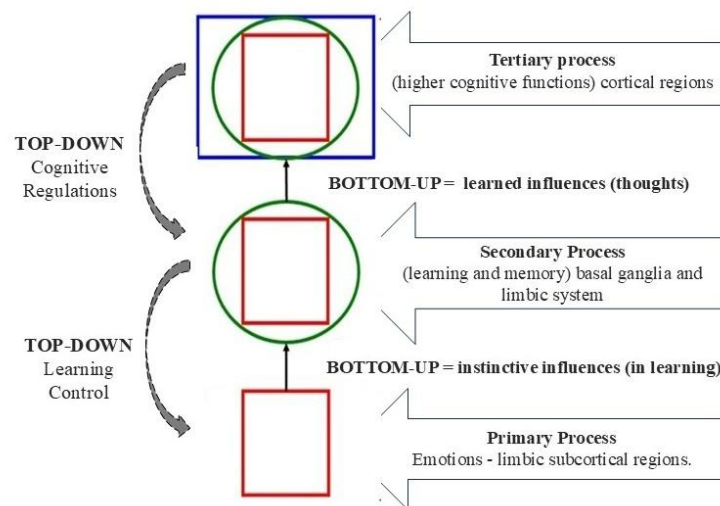
Chart 1: Main structures and functions of the limbic system involved in learning.

Structure	Main Functions	Relationship with Learning
Hippocampus	Formation and consolidation of declarative memories. Integrates contextual and temporal information	Acquisition of new memories, Consolidates and transfers to the neocortex lasting memories
Basolateral Tonsil	It processes emotions, fear and pleasure. Modulates emotions from memory	Modulates emotional memories. Intensifies emotional retention and interacts with the hippocampus
Entorhinal Cortex	Network from the hippocampus to the neocortex. Processes spatial information	Hippocampus-Cortex communication, consolidates spatial and contextual memories
Prefrontal cortex	Executive functions (planning, decision-making). Regulates attention and behavior	Participates in memory retrieval and integrates emotional learning information
Cingulate Cortex	It processes and regulates emotions, attention, and behavior.	Participates in the process through stimuli and experiences in affective memories

Source: prepared by the authors, based on the references of this review, in jun 2025.

The sublevels of emotional processing that occur in the Central Nervous System (CNS) and their "bottom-up" influences and "top-down" regulations and how the brain's emotional networks control learning, are synthetically represented in Figure 2.

Figure 2. Representation of the different emotional and cognitive influences and their interactions in the Nervous System (SN) with effects on learning.



Source: prepared by the authors, based on Tyng et al., Barco et al., Saito et al.

Discussion

This research synthesized the main concepts and evidence discussed in this scoping review, organized into categories that emerged from the analysis of the selected articles, including: a) functions of the amygdaloid system in the processing of emotions; b) interface of emotional

cognition and the learning mechanism; c) functional interactions of cognition for effective learning and brain structures, synthetically, in the educational context. The discussion follows a narrative approach, allowing a critical understanding of the findings.

This structure aims to expand the understanding of how the amygdala influences emotional and cognitive processes, addresses the limbic system with and brain networks involved in the process of emotions, with effects on learning. These are knowledge based on neurosciences, which fundamentals the principles of neurodidactics, as a set of interconnected knowledge applied to the learning process. Recognizing emotion as a preponderant cognition for more effective learning.

Neuroscience is an area of interdisciplinary studies on the nervous system (NS), its structure, functions, development, and alterations. The central nervous system (CNS) consists of the brain (brain, cerebellum, brainstem, and subareas) and spinal cord, which controls and coordinates all organic functions. The brain is a complex structure, formed by nervous tissue, whose functional unit is the neuron. This nerve cell is specialized in receiving, processing, and transmitting information, making up the synaptic circuitry (Qasim et al., 2023; Mansueto et al., 2025).

Neurons, excitable cells, are responsible for conducting nerve impulses, have dendritic extensions, which receive electrochemical signals, and axons that transmit signals to adjacent neurons. Glial cells in nervous tissue play a role in sustaining, nourishing, isolating, and defending the NS. The dynamic interaction of these support cells allows adaptive phenomena such as neuroplasticity that forms new synaptic connections, modulates neural networks through a variability of stimuli (Qasim et al., 2023).

Neuroplasticity occurs in several functional areas of the NS. Through the higher functions (tertiary) located in the cortical regions, which regulate high-level cognition, influenced from top to bottom (top-down). This involves (secondary) learning and memory processes located in basal regions of the ganglia and superior parietal lobe, influenced from the bottom up. And emotions that are essential for the formation of memories. (Primary) emotions in the limbic subcortical regions, such as the amygdala, influence learning by the bottom-up mechanism. (Qasim et al., 2023). The integration of the top-down and bottom-up levels, mediated by emotions, is fundamental for learning (acquisition, retention and retrieval), as shown in Figure 2.

It is important to clarify that emotions and feelings make up affective experiences. Cognitive processing brings emotions to consciousness, transforming them into feelings. The term "emotion" derives from the Latin "emovere", which means to move from the inside out, to come into contact. It is a way of communicating the most important inner states and needs of an individual. Emotions are classified into primary and secondary. The primaries are universal, innate

as fear, joy, repulsion/disgust, anger/wrath and sadness. Secondary ones are cultural, socially learned such as shame, guilt, jealousy, and anxiety (Saito et al., 2025).

Human emotions are complex, they are usually born from the dynamics of interrelationships. In addition to being intricate and multidimensional, they involve a combination of feelings, thoughts, and physiological responses. This means that the emotional process in the brain cannot be reduced to a simple correspondence of specific brain areas (Dubovi, 2023).

Different emotional influences and cognitions interact to unfold learning. In general, the CNS controls, coordinates the organism and processes information. The SL, recognized as the emotional brain, is a complex network of neurons in the center of the brain, with distinct interconnections and performs basic functions in emotions, memory. The SL is composed of different structures, including the amygdala, the hippocampus, the cingulate cortex, the olfactory bulb, the hypothalamus, and others. They are regions of gray matter, mainly responsible for emotions and social behavior (Wassum 2023; Dubinsky & Hamid, 2024).

In 1822, for the first time the term "cerebral amygdala" came to describe an almond-shaped structure, by Karl Friedrich Burdach. But it was in the 1930s that Kluver and Bucy, after studies of temporal lobe lesions in primates, evidenced changes in social and emotional behavior in animals. Subsequent research confirms that the emotional changes were related to damage to neurons in the amygdaloid area, which has come to be recognized as a key component of SL (Kämpf et al., 2023; Pahutat et al., 2024).

The tonsils are located in the temporal lobe, in the dorsomedial portion of the parahippocampal gyrus, anterior to the tail of the caudate nucleus. Its main function is to regulate emotions, such as fear, aggression, anger, pleasure and anxiety, it is also involved in the process of emotionally charged memories, rewards and decision-making. This structure processes emotional reactions and assigns emotional meaning to experiences. The relationship between the amygdala and fear is evidenced by functional neuroimaging, being, for example, activated when seeing facial expressions of fear (Qasim et al., 2023; Wassum, 2023; Mansueto et al., 2025).

The processing of emotions and the attribution of meaning relative to experiences are functions of the cerebral amygdala. It evaluates the emotional load of a stimulus and regulates, mainly, emotional responses such as fear, aggressiveness and happiness, influencing various aspects of behavior and cognition. It is involved in aggressive behavior, which is why it is considered a reliable predictor of aggressive attitudes. The amygdaloid body and hippocampus, responsible for consolidating short-term memory, are the gateway to the SL, which organizes emotions and behaviors, performing emotional memories. This explains why memories associated

with intense emotions (joy, fear, extreme, traumatic event) tend to be more vivid and long-lasting (Pahutat et al., 2024; Saito et al., 2025).

Recognized as the "danger intensifier center," the amygdala is involved in the physiological response to fear and anxiety. It activates "fight or flight" reactions through its interaction with the hypothalamus and brain stem. In addition to influencing social behaviors and interpersonal relationships, due to its bidirectional connections with the hippocampus. It is a structure that is highly sensitive to acute and chronic stressors. Fear is a primary adaptive response to potential threats that triggers a cascade of physiological, cognitive, and behavioral changes. The basolateral amygdala (BLA) and medial prefrontal cortex (mPFC) are associated with adaptation, intense emotions, and decision-making. Having their neuronal activity and synaptic plasticity impacted by exposure to chronic stress (Inman et al., 2023).

Gellisch et al. (2024) analyzed the relationship between physiological markers of stress (heart rate, cortisol) and learning with health students. Exploring how these signals point to emotional and cognitive aspects and their relationship with learning performance.

Saito et al. (2025) based on experimental studies with rodents, found direct evidence that emotions intensify memory consolidation, highlighting the role of the amygdala-cortex circuit. Their findings shed light on mechanisms of prioritization of memory by emotional associations. Emotions capture attention and help memory, making them clearer and more relevant, whose somatic arousal generates connections that strengthen cognitive functions. This knowledge supports educational interventions and also in conditions of memory disorders, chemical dependency and post-traumatic stress disorder (PTSD).

The psychic function that evaluates affectivity in life experiences, permeates the SL, integrates the endocrine and immune system, and thus, organizes an adequate reaction processed by the amygdaloid body. Researchers corroborate that affectivity has motivating power, influenced by experiences linked to the learning environment and cultural conformation. The quality of synaptic connections is essential for meaningful learning and social behavior. Therefore, inefficient stimuli weaken neural connections related to learning (Attard, 2022).

When it comes to teaching and learning, the brain forms new memories by capturing specific stimuli from the experiences of "what," "where," "when," and "how." This is due to the activity of specific or conceptual neurons located in the medial temporal lobe. These are memory-connecting neurons, activated by stimuli related to ideas or people. Thus, during the transaction process, synaptic connections are strengthened, facilitating memory retention. In educational practice, this means that emotional and contextualized experiences favor learning. The amygdala, in turn, contains selective neurons (who/what) linked to emotional and semantic memories. It

reinforces the importance of the emotional connection to the pedagogical process, with content that is more stimulating and connected to the student's reality tending to be retained for long-lasting memory (Pahutat et al., 2024; Johnson, 2024).

Memorization is the process of acquiring and retaining information that varies according to the stimulus (visual, auditory, tactile, etc.). Their mechanisms travel through different neural pathways and can store data for seconds or years, such as short-term or long-term memory. Learning, in turn, involves the storage, consolidation, and retrieval of this information. This neurophysiological process is essential for shaping behavior and thoughts (Jácome & Campos 2023; Pahutat et al., 2024).

In the educational context, it is important to address neurodidactics, which integrates knowledge from neurosciences to pedagogy, to improve educational practices, student engagement and performance. Since learning is a physiological process dependent on the synaptic circuitry for the acquisition and realization of learning. In addition to emotional engagement in active environments, the important task of promoting social-emotional learning is highlighted. However, it is necessary for educators to create welcoming contexts that favor emotional and cognitive development, strengthen neural connections, promoting more effective and humanized learning (Jácome & Campos, 2023; Kämpf et al., 2023; Mansueto et al., 2025).

For Jácome & Campos (2023), traditional pedagogy partially considers the cognitive and prioritizes classificatory results. However, the neuroeducation approach values the emotional state as an important variable for quality learning, focusing on the brain's potential and the personalization of teaching. Neurodidactic strategies favor superior academic performance in relation to traditional methodologies. Mainly because they emphasize interactive tactics, relaxation, generation of positive emotions and environments, use of games in the classroom, promote learning as an active phenomenon. Labuschagne et al. (2024) add that research demonstrates that the amygdala plays a prominent role in detecting environmental stimuli, which are vital for emotional memory recall and survival.

According to Labuschagne et al. (2024) in neuroscientific studies with humans, the amygdala was associated with robust response to negative or threatening stimuli. The association between the amygdala and fear is supported by findings showing the link between mental health disorders, anxiety disorders, and discrepancies between student potential and levels of achievement in relation to student intellectual potential. This dysfunctional response of the amygdalas is notably related to fear.

In this sense, neurodidactic principles emphasize that learning experiences should be free of fear and be fun, spontaneous, creative, and respectful of sensitive periods and conditions of

development. It is essential to consider the role of positive emotions, whether in pedagogical practices or in the evaluative processes of learning. By aligning educational practices with these neuroscientific principles, educators support themselves to create environments that can stimulate engagement, confidence, and promote cognitive retention of learning, explain Jácome & Campos (2023) and Pradeep et al. (2024).

In learning, it is known that emotionally charged memories are intense and easily recovered by the action of the tonsilloid plot. The intensity of memory consolidation depends on the amount of emotion involved in the lived experience. The amygdala, the main structure of the emotional network, facilitates attention by processing emotions, influencing explicit memory, and activating other brain areas linked to learning, such as the hippocampus in the formation of new memories for consolidation and the prefrontal cortex involved in executive function (Pahutat et al., 2024; Kämpf et al., 2023).

In the educational context, the interaction between emotions and other cognitions acts as a potentiator of selective attention, especially when faced with stimuli with significant emotional connotations. This favors the consolidation of lasting memory. A positive emotional state modulates the activity of the amygdala and hippocampus regions, improving the processing and retention of information. Furthermore, emotions reflect neurophysiological changes in response to environmental stimuli (Kämpf et al., 2023). The amygdala is not restricted to fear processing; its responses are complex, involving bilateral occipitotemporal connections and anterior brain areas (auditory and visual attention, emotional regulation), add Labuschagne et al. (2024).

Emotional stimuli can be understood as events, situations, words, images, or thoughts that provoke emotions. Internal emotions, such as memories, beliefs, and thoughts, or external emotions, such as gestures, words, and events. These emotional responses can be positive, such as joy, or negative, such as anger, fear, anxiety, and sadness. The term "emotional trigger" refers to stimuli that generate intense reactions, usually linked to traumatic experiences. Understanding triggers is critical for emotional and stress regulation. Negative emotions affect the body, mind, and behavior, activate the amygdala, and impair concentration, attention, and learning (Labuschagne et al., 2024; Gellisch et al., 2024; Mansueto et al., 2025).

Distinct brain circuits are involved in emotional responses. The amygdala-neocortical circuit shows the immediate awareness of the implicit process of emotions and the explicit process of thoughts, through the hippocampal-neocortical network. The right hemisphere of the brain is responsible for regulating negative emotions, while the left regulates positive ones. The amygdala, which is more involved in fear awareness, can trigger phobias by increasing its activity and

awareness. This shows that there is a direct connection between emotions, memory consolidation, and learning, state Johnson (2024) and Inman et al. (2023).

Emotions have effects on students' attention, motivation and behaviour in the context of learning. This modifies the prerogatives for choosing learning strategies that drive academic success. Due to the notorious relevance of emotions in the learning of students participating in a research, there was a noticeable increase in the emotional state and its effects on student performance, notably in variables related to the emotional state researched in the last two decades, according to Xie et al. (2025). The results of this meta-analysis found a significant relationship between positive emotions and performance ($k = 76$, $N = 43,551$, $r = 0.24$ [95%CI: 0.20-0.27]), the effects of negative emotions ($k = 78$, $N = 44,029$, $r = -0.25$ [95%CI: -0.28-0.21]) and the effect of emotions on motivation were significant and positive. They concluded that emotions are one of the core cognitions that modulates interpersonal interactions and interpersonal self-regulation.

Research that investigated how the divergent sub-regions of the amygdala process negative emotions such as fear examined 86 healthy adults by functional magnetic resonance imaging (fMRI) to analyze amygdala responses and brain connectivity networks related to facial stimuli of fear, anger, and happiness. They found that all sub-regions of the cortex responded to stimuli ($p < 0.05$), especially in the amygdala ($p < 0.001$). These findings suggest that the amygdala's specialization for fear is more supported by its connection network than on isolated activity (Labuschagne et al., 2024).

The amygdala's reactions to stimuli are rapid. Amygdala hijacking is an immediate reactive condition that is disproportionate to the stimulus, received as a threat to emotional stability. This is because the amygdala dominates the cortex and by the supply of neurotransmitters turns off rationality and affects the individual's behavior. This condition of amygdala activation can occur in the classroom, when a student receives public criticism and generates anxiety, shame, anger or crying, which overrides logical reasoning. Intense emotional reactions (severe feedback, discussion, or exclusion) compromise the activity of the prefrontal cortex, cause learning impairments, and alter student behavior (Labuschagne et al., 2024; Jácome & Campos, 2023).

Another relevant factor related to learning is sleep deprivation, resulting from the alteration of cortisol and melatonin, which affect neurocognitive functions such as abstract reasoning, mental flexibility and motor coordination. This is because the prefrontal cortex regulates the amygdala, which is directly impacted by the absence of adequate sleep. Memories encoded in wakefulness are consolidated during sleep. The amygdala participates in the consolidation of emotional memories and positive experiences in the *rapid eye movement* (REM) phase of sleep, the declarative memories during non-REM sleep. Sleep is essential for learning and emotional

regulation and its deprivation impairs memory processing, affects amygdaloid dendrites, and increases emotional activity (Saito et al., 2025).

The amygdaloid complex, a group of neuronal nuclei, processes and integrates information transmitted by neurotransmitters to organize emotions and influence behavior. For example, serotonin, known as the "feel-good hormone" participates in the process of emotional balance, synthesized mainly in the CNS, in the dorsal raphe nucleus, integrated into the SL, with serotonergic projections in the amygdala. This monoamine modulates perception, reaction and recovery in emotional experiences, regulates organic functions such as mood, sleep and appetite. At low levels, it can be associated with depression, anxiety, irritability, obsessive-compulsive disorder (OCD) (Taira & Sharpe, 2025; Johnson, 2024).

Serotonin is essential for emotional control in stressful situations, resilience and maintenance of adaptive responses. Taira and Sharpe (2025) report that serotonergic systems are associated with behavior and emotional control. Serotonin imbalance can condition anxious, depressive and aggressive behavior, naturally with effects on learning. Tryptophan depletion (serotonin precursor) reduces serotonin levels and has been associated with behavioral changes that are detrimental to the motivation-reward relationship, corroborate Saito et al. (2025).

Serotonergic neurotransmitters influence learning by regulating mood, motivation, and attention, as well as influencing the assimilation of content. It acts on neural circuits linked to memory and decision-making, processed by the cerebral amygdala. Serotonin regulates reinforcement learning, internal model formation, and favors adaptive actions by expecting reward from environmental dynamics. There is a correlation between learning and one of its main cognitive pillars, attention. The absence of attention compromises the absorption and apprehension of knowledge, in addition to hindering the dissemination of information through synaptic networks, which are essential in the formation of lasting memories (Taira & Sharpe, 2025; Li et al., 2023; Paré & Headley 2023).

The student's cognitive performance during activities depends on their emotional state, since attention, memory and reasoning are inseparable for effective learning. This performance involves the circuitry of the cerebral hemispheres connected by the corpus callosum in the subcortical area. The cerebral cortex is the *locus* of greatest neural integration in the CNS, where the plurality of sensory and motor information is processed and integrated, resulting in conscious perceptions. It plays a fundamental role in attention, thinking, memory, and language (Johnson, 2024; Taira & Sharpe, 2025), thus having an impact on learning.

The attentional state is the main cognitive mechanism of learning and widely requested in pedagogical activities and intensely involves neural function linked to perception, language,

writing, visuals and others (Taira & Sharpe 2025; Johnson, 2024). The neuronal theory of Emotion seeks to understand the mechanisms and effects on the structure of learning, through which the physiology of the amygdala linked to the emotion of fear is verified. The amygdala is the decoding structure of emotions, interpreting hormones such as serotonin, but also adrenaline, which is another neurotransmitter associated with fear. The physiology of fear activates the sympathetic nervous system that releases hormones such as adrenaline and cortisol, preparing the body for defense. However, it is the amygdala that identifies threats and triggers fight-or-flight responses (Dubovi, 2023; Pahutat et al., 2024; Taira & Sharpe, 2025).

Thus, the amygdaloid body detects situations of threats or stress and activates the sympathetic SN and adrenal glands, which release adrenaline into the bloodstream. It is understood that the student in an adrenergic condition may have greater difficulty in concentrating, as the brain enters a state of alert and impairs cognitive functions for successful learning. The brain is considered a "social organ", which seeks cooperation, relationships, a friendly and relaxed state that inspires confidence, and not fear and anxiety of failure or failures, since the state of confidence increases creativity (Inman et al., 2024; Taira & Sharpe, 2025).

Rewarding oneself and feeling like oneself belongs to the school environment is more relevant to student learning than being classified by evaluations involved in emotional tension. In this sense, neurodidactics values the brain in activities that produce lasting knowledge, mainly because neural architecture is influenced by the environment that drives interneuron connections through positive emotions (Barco et al., 2024). Brain plasticity is also mediated by mirror neurons, which reflect relationships with the environment. The feedback of the body state is registered in the somatic-sensory cortex, self-esteem and emotions in the Anterior Cingulate Gyrus that is part of the SL. And by seeing how these structures influence deep learning through emotions (Attard, 2022; Jácome & Campos, 2023).

For Attard (2022) the learner's brain develops quickly with reward stimuli, especially when the student's effort is valued. Positive emotions like empathy and security favor learning, while fear and stress hinder it. An environment with healthy emotions stimulates attention, memory and decision-making. Essential for effective teaching and learning and a positive environment for adequate performance at the base of the educational process, corroborate Gellisch et al. (2024).

Considering the structuring of pedagogical planning based on human cognition is crucial to enhance the teaching and learning process, for a personalized and efficient education. In this context, the emotional condition of the teacher and the student influences the quality, resourcefulness of their activities and the environment in the classroom. Positive emotions (confidence, hope) increase motivation, collaboration, enhance learning, and boost social skills.

This improves behavior, willingness to learn, and prepares students for professional challenges (Kämpf et al., 2023; Jácome & Yedra 2023).

Emotional states processed by the amygdala during learning strengthen connections with the frontal cortex, so emotionally charged memories tend to be more perennial. Balanced SL promotes greater security and better emotional regulation, while its dysfunction generates stress and anxiety. The influence of emotions on learning is recognized by neurodidactics to direct the creation of more interesting pedagogical strategies. This convergence is decisive for the engagement and retention of lasting information (Wassum, 2023).

This convergence of emotional awareness linked to education represents a contemporary challenge, essential to boost learning in this changing scenario. Teachers can model emotional regulation and encourage students' self-reflection to strengthen commitment, engagement, and emotional intelligence. Therefore, integrating neuroeducation into the curriculum, as a guide for school pedagogical management, is transformational and favors interdisciplinary and instructional practices with multisensory stimuli learning mindfulness (Camacho-Morles et al., 2022; Jácome & Campos 2023; Barco et al., 2024).

In this context, a study conducted by Dubovi (2023), analyzed emotional involvement during learning through facial expressions and students' self-reports, and found that joy was the predominant emotion in enthusiastic and engaged activities ($p < 0.001$) while other emotions such as fear and sadness were less frequent. Emotional self-report proved to be an important predictor of performance, and it was possible to associate that the format of the activity influenced the emotions of the students participating in the study.

It is worth noting that academic performance is the most salient result associated with emotions, influenced by motivational and cognitive processes (Dubovi, 2023). An integration of meta-analysis results found that satisfaction linked to learning activities is associated with better performance, while the boring state was associated with basic performance. Effects of anxiety, it can cause distraction in the performance of tasks, on the other hand, it can work as a defense and motivate external regulation to avoid failure, involving a whirlwind of emotions in learners, explains Camacho-Morles et al. (2022) e Mansueto et al. (2025).

Self-regulation develops essential skills for student success, in school and, in practice, professional learning environments. Li et al. (2023) found that cognitive and emotional factors influence the intention of future teachers to use active methodologies, such as the flipped classroom. This contributes to strengthening the student's conviction of their ability to develop a specific task, known as self-efficacy. While self-efficacy improves perception and facilitates

activity, anxiety reduces it. It is linked to cognitive and technological factors that favor the use of dynamic models (Barco et al., 2024).

For Daugirdiene et al. (2024), emotional learning is strengthened with intelligent and positive pedagogical practices that promote student protagonism and thus trained teachers can apply the principles of neurodidactics safely and innovatively in the curriculum. Barco et al. (2024) reiterate that self-efficacy is a predictor of student success, resulting from students' trust in a favorable environment to perform their tasks. The attitude of the teacher has important effects on the academic objectives of his students, considering the affective and cognitive dimensions during classes and also during the training of prospective teachers.

It is in this sense that the authors emphasize the importance of understanding the function of the amygdala in learning. From this set of neurons in the medial temporal lobe of the brain, the process of storing emotional memories occurs, mainly. It also plays a central role in the response to fear and anxiety, modulating emotional reactions to stimuli that are sometimes threatening. Teachers can identify the student's behavioral signals, such as tone of voice and non-verbal expressions related to fear or discomfort, and thus adjust planning to favor well-being and engagement through dynamic activities (Inman et al., 2023; Pradeep et al., 2024; Daugirdiene et al., 2024; Xie et al., 2025).

Recognizing the integrative role of emotions is essential to encourage self-reflection, metacognition, and emotion regulation through structured activities and ongoing formative feedback. This in a welcoming environment, valuing participatory contributions in order to promote the student's autonomy and sense of belonging. Provide choices on how to demonstrate the content learned, provide interpersonal connections in a culture of trust and collaboration. Emotions are biologically determined, but also influenced by each individual's environment in relation to the other. Culture also affects how the emotional state is experienced and expressed (Attard, 2022; Xie et al., 2025).

Recognizing the integrative role of emotions in learning is key to promoting self-reflection, metacognition, and emotional regulation. Structured pedagogical activities, feedback-based evaluations and welcoming environments strengthen the student's autonomy and sense of belonging. Enabling choices and encouraging interpersonal connections favors collaborative culture. Emotions, although biologically determined, are modulated by environment, experiences, and culture. This influences experiences and expressions in the educational context (Paré and Headley, 2023; Barco et al., 2024).

Thus, the results of the present study provide an overview of the convergence between emotional, cognitive, and main functions of the amygdala tangent to learning. The interface of

these cognitive knowledges has been evidenced by new imaging technologies, on the learning organ and its interactivity connectomes. This study offers a compiled exploration of these factors, contributes to the dissemination of knowledge and possible hypotheses in future neuroscientific research applied to education.

Despite the contributions, this study has some limitations, such as the search restricted to three databases and a specific time window, which may have reduced the scope. Selection based on predefined criteria may also have excluded relevant studies. It is suggested that future research include further experimental and empirical studies.

Final considerations

Emotions constitute a complex neurocognitive construct linked to student learning and performance. This study highlighted the role of the cerebral amygdala, and the influence of emotive cognition on the process and retention of information and, consequently, on learning. Emotions are automatic and unconscious responses to stimuli, manifested in physiological and behavioral reactions, which directly modulate brain systems involved in learning, such as the hippocampus, limbic system, and cortex mainly. Negative emotions compromise cognitive performance, highlighting the importance of emotional regulation in the learning environment.

In this sense, teachers aware of these interactions can improve the pedagogical experience, promoting strategies that favor affective balance and synaptic plasticity, which are conditions that facilitate learning. In the face of the unusual demands for the twenty-first century, the ability to learn continuously – mediated by positive environments and balanced emotional states – becomes essential for human and professional development, based on a comprehensive and quality education.

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Autor 1 – idealização do projeto, delineamento do método, coleta e análise dos dados, escrita do texto.

Autor 2 - organização e edição do manuscrito, análise dos dados e revisão final do manuscrito.

DECLARAÇÃO DE CONFLITO DE INTERESSE

Os autores declaram que não existe conflito de interesse com o presente artigo.

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