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NEUROCREATIVITY: ANALYSIS AND EDUCATION OF CREATIVE THINKING

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Summary. The creative process is linked to brain activity. This process is understood as a "capacity to create" as opposed to the notion of innovation that focuses on the "action of creating". Thus, people are more creative when they detect cognitive stimuli linked to brain noradrenaline (neurotransmitter) levels, as it favors communication between networks. The frontal lobes are highlighted in emerging studies of creative thinking in relation to executive functions. Projected neural connections is a technique known as neuroimaging with the purpose of deriving information on brain restructuring and brain plasticity. Neuroimaging techniques make it possible to analyze the activity of the nervous system and to observe the development of learning skills. Throughout history, there has been talk of inspiration in sleep, or there has been talk of connectivity between the two hemispheres to favor creativity, or another agent of interest linked to the creative process, among others, is mental blocking. Different agents or perspectives of the creative process. And, finally, some activities that contribute to the use of creativity in their execution are proposed.

Keywords: creativity, brain, neuroscience, neuroimaging and neurotransmitters.

NEUROCREATIVIDAD: ANÁLISIS Y ENSEÑANZA DEL PENSAMIENTO CREATIVO

Resumen. El proceso creativo se encuentra ligado a la actividad cerebral. Dicho proceso se entiende como una "capacidad de crear" en contraposición a la noción de innovación que se centra en la "acción de crear". De este modo, las personas son más creativas cuando detectan estímulos cognitivos enlazados a los niveles de noradrenalina cerebral (neurotransmisor), ya que favorece la comunicación entre las redes. Los lóbulos frontales se ponen de relieve en los estudios emergentes del pensamiento creativo en relación a las funciones ejecutivas. Las conexiones neuronales proyectadas es una técnica que se conoce como neuroimagen con la finalidad de derivar información de la reestructuración cerebral y plasticidad cerebral. Las técnicas de neuroimagen permiten analizar la actividad del sistema nervioso y observar el desarrollo de habilidades en el aprendizaje. Asociadas a la creatividad, a lo largo de la historia, se ha hablado de la inspiración en el sueño, o bien se ha hablado de la conectividad entre los dos hemisferios para favorecer la creatividad, u otro agente de interés ligado al proceso creativo, entre otros, es el bloqueo mental. Agentes o perspectivas diversas del proceso creativo. Y, para finalizar, se plantean algunas actividades que contribuyen a emplear la creatividad en sus ejecuciones.

Palabras clave: creatividad, cerebro, neurociencia, neuroimagen y neurotransmisores.

Introduction

Throughout the centuries, creativity has been the focus of several studies. In Plato's *The Banquet (* 385-370 B.C.), the author defines the concept of "poiesis" as "the cause that converts anything we consider from non-being to being". Therefore, an approach to the notion of "creative process". Today, if we review the concept, we can see that it is defined as "the faculty to create" or as the "capacity to create" according to the Royal Spanish Academy. That is, as "the faculty of producing something": new and/or original ideas, new and/or original materials, and so on. A faculty and/or capacity that must be understood in the social and historical context in which they are developed, taking into account pre-existing knowledge. More recently, neuroscientific research is attempting to provide inputs that contribute to the understanding of the act we call creativity.

In today's society, it is important to be able to provide solutions to various problems, whether expected or not, and for which imagination, versatility and adaptation are tools for finding the most efficient and "elegant" solution to a given problem, the notion of "elegance" being understood as a simple and/or not excessively complex solution. Tools intertwined with critical thinking. In addition, we find another tool with emotional essence that influences in a notorious way, curiosity, facilitating learning.

In 1926, Wallas proposed four phases in the creative process from the perspective of information:

Phase 1: Preparation.

Regarding information: Basic knowledge and attitudes are established on which the foundations of the creative process will be built.

Regarding the problem: It is the moment when the mind is predisposed in a concrete approach to the problem in order to tackle it.

Phase 2: Incubation.

Regarding information: The information is analyzed, processed and the focus is on the data of interest.

Regarding the problem: It gives the sensation of moving away from the problem, which is internalized in the right hemisphere.

Phase 3: Lighting.

Regarding information: Key data is found that transforms the first information into a second response.

Regarding the problem: The problem is restructured and inspiration occurs and the creative idea moves into the zone of consciousness.

Phase 4: Verification.

Regarding information: The information is contrasted with other information to elucidate the veracity and/or validity of the same, as well as the possibility of a more efficient one.

Regarding the problem: An assessment is made of the usefulness of the result in view of the problem posed.

On the other hand, Chávez (2001) distinguishes three phases from the perspective of the intervening subjects:

Phase 1: Association-Integration: The senders and receivers of information associate and become aware of it internally and externally.

Phase 2: Elaboration: The subjects involved use their talents to originate the creative idea or solution to the problem.

Phase 3: Communication: The idea and/or solution is shared.

Two perspectives of the same reality whose main focus is on the information or on the subjects of the problem posed, respectively. Two visions that respond to the same situation, and whose approaches may be of interest depending on the angle from which one wishes to highlight them. A situation that has as its epicenter the study of creativity, which is linked to various mental functions and components of each individual (Chávez *et al*., 2004). On the other hand, a consequence of this study is innovation, since it is understood as the "action of creating, modifying, and/or altering something by introducing novelties, according to the Royal Spanish Academy. That is to say, while creation refers to the capacity and/or faculty to create, innovation refers to the action of creating and/or modifying. An action whose ultimate purpose is to influence either the historical, social or scientific context, etc., at the time it arises.

Creativity and innovation are useful when establishing learning situations to meet the diversity of talents and abilities of students, and having as tools curiosity, emotions, imagination, versatility and adaptation when designing different activities.

This paper presents a review of several authors and studies based on neuroscience and creativity in order to deepen the understanding of the cognitive functions involved in cognitive development. Knowing these aspects can help to lead to practical results in the educational context, and therefore, to project a "path" to follow in order to establish the teaching of students. Within this broad framework, the study of cases with neuroimaging samples is also of interest, since it allows us to investigate the understanding of cognitive processes in creativity.

Neuroconcepts

In recent years, neuroscientific findings are not inconsistent with the methods of neuropsychology, but together they contribute to the study of the human nervous system. One of the main challenges is to circumvent reductionist perspectives based on the expression of cognitive constructs that define creative processes (Dietrich *et al*., 2015). The manifestation of creativity requires a theoretical synthesis through the conduit of neuroscience and its neuromethodologies in order to provide answers.

Through neurological development, the executive functions of brain activity linked to creativity can be observed. Knowledge of creativity is extensive, as it involves numerous brain structures and functions, as well as various neurotransmitters. Heilman's (2016) research pointed out that innovation requires divergent thinking and disconnection through frontal networks. He also mentions that creative people need to take risks and find novelties, attitudes that energize the "ventral striatal reward system". It also exposes the importance of associative and convergent thinking, operations that promote the annexation of neural networks. Thus, people are more creative when they detect cognitive stimuli linked to the levels of brain noradrenaline (neurotransmitter), since it favors communication between these networks.

Nowadays, the different brain areas can be connected, thus, the brain has a globalizing role. Fuster (2022) alludes that higher cognitive functions are located in the prefrontal cortex, where the neuronal bases are located. This same author mentions that this area is in charge of managing the complex information that circulates to the brain (formulating strategies, finding solutions, elaborating plans...), in order to provide a social response in relation to the context and to facilitate the execution of the actions of the motor cortex. However, it should be considered that the prefrontal cortex is the last part of the brain that does not finish developing until about the age of 20

Based on the latter assumptions, the generation of creative ideas occurs between the frontal and temporal lobes (Rodriguez, 2021). The frontal lobes come into contact with other regions of the brain according to the type of creativity being performed through different neurological pathways. For example, when semantic information is required, it is connected to the temporal lobes or if ideas are constructed, they are associated with the basal ganglia and the right angular gyrus, among other subcortical structures (González, 2018).

The existence of different brain areas leads to an exchange of information during the creative action. Jung and Haier (2007) formulate a list of all brain areas involved, supported by a sample of their functional and structural neuroimaging studies. Thus, neuroimaging or imaging is a technique that projects neuronal connections through an image in order to transmit information on brain restructuring and brain plasticity (Euroinnova Formación, 2022).

Consequently, brain regions become key pieces to understand the neurophysiology of the brain in the creative dimension. Likewise, neuroimaging techniques make it possible to analyze the activity of the nervous system and observe the development of learning skills, as well as to measure the characteristics of the brain and detect particularities. Consequently, neuroimaging becomes a new teaching neuromethodology to learn about the student's brain, learning style, creativity, among other aspects of interest (Sanz, 2022).

Creative brain

Creativity has a complex scheme integrated by different functions. Through these functions, the various brain areas can be determined. As mentioned in the previous point, the frontal and temporal lobes are closely linked to creativity, however, other areas may contribute in different processes (Gonen-Yaacovi *et al*., 2013). The promotion of higher cognitive skills (cognitive flexibility, spatial reasoning, verbal fluency...), including executive functions, provides a solid network of knowledge focused on the creative process. All these tasks are linked to the frontal lobes, however, the linkage that originates with other brain areas guarantees this creative process (Heilman, 2016).

It has been observed that the basis of the structure of cognitive ability encompasses frontal, parietal and occipital brain areas, as well as the relationship between cognitive functions and the creativity index of the individual (Zhu *et al*., 2022). Attention, memory, language and executive functions have an impact on the creative process, which is why the prefrontal area is one of the brain regions that is most activated (Tapia *et al*., 2017).

In relation to other brain areas, other authors such as Gómez (2020), Mora (2017) and Blanco (2014) affirm the importance of the corpus callosum as a bridge between the cerebral hemispheres and creative processes. Along these lines, the corpus callosum can be defined as a structure formed by nerve fibers that creates a link between the right and left hemisphere of the brain (Fernandez, 2022). This allows the interrelation between the different areas of both hemispheres, which is a distinctive element in the course of the creative processes. Being synchronized, it enables the unification of the information directed to the brain.

Creativity encompasses several stages that deal with various neural bases, including: preparation, critical capabilities, innovation, elaboration of creative resolutions, and creative productivity (Heilman, 2016). In order to enhance them, it is necessary to understand their aspects. In this line, creativity encompasses functional schemes formed by an *ad hoc*division:

- *Brain function*

In various studies, such as that of Chen *et al.* (2016), examined the link between cognitive flexibility and creative performance in which the immersed difference of the medial prefrontal cortex and frontal lobe fractions was observed, with a larger size disparity existing in relation to divergent creative cognition. Thus, the frontal lobes apparently occupy an important place in the axis of creativity.

Analogously, several studies have shown the existence of brain areas related to creativity. Burgess-Chamberlain (2016) noted increased gray matter in individuals with visual perception. Thus, it can be inferred that the decisive elements of creative innovation are the connections that influence thinking and image making. For its part, verbal creativity is closely related to the left parieto-temporal areas of the brain, located within Brodmann's area 39 and 40 (Brodmann, 2010). Areas linked to problem solving through creative cognitive processes

Similarly, Chávez-Eakle *et al*. (2012) found a connection between brain blood flow and the level of creativity in several areas such as: "left middle frontal gyrus, right inferior parietal lobe, right straight gyrus (...)". This indicates that the blood fluid connects with creativity, involving emotional and cognitive brain processes. The left superior temporal gyrus helps to establish ideas and, in addition, the limbic system directs physiological reactions in the emotional aspect (Hurtado *et al*., 2017).

From this approach, creativity is not only about specific areas of the brain, but about the whole brain in its plenitude. Its functionality is supported by various developmental contexts, e.g., neurological conditions in infancy.

- *Neurotransmitters of the nervous system*

There are certain common contexts in which individuals experience fleeting ideas, for example, in states of recreation or drowsiness. Creativity is enhanced when different channels are activated and emerge in the most unexpected circumstances. This production of ideas is interconnected with the prefrontal cortex and the development of artistic ability (Bermeo and Urquina, 2021).

The activity involves *insight* (the phase of inspiration or illumination, the famous: "*Eureka*!"), creative schemes offer solution paths of a fleeting and automaton-like nature. Although it is true that this activity can also be carried out using analytical thinking with a more conscious and progressive method. Beaty, *et al*. (2015) conducted a study in which a task specific to divergent thinking was executed: Generate a second use for everyday instruments. In this activity, the uniqueness and fluency of the ideas provided was estimated, thus observing the coordination between neural networks linked to spontaneous thinking, cognitive control and functional recovery mechanisms. In the words of Estanislao Bachrach (2014): "It is the mental activity where a revelation or *insight* occurs in the brain and results in a new idea or action that has value."

The brain activates neurotransmitters to provide cognitive responses. As a result of the creative process, these biomolecules facilitate communication between neurons. This exchange of information is closely linked to dopamine (known as the "pleasure hormone"), a neurotransmitter linked to happiness and pleasure in the brain, emotions that affect motivation and creativity (Guillemin and Lemke, 2013). Likewise, the noradrenalinealso acts as a hormone and neurotransmitter, since it directs the tasks of the organs and cells of the nervous system, as well as influencing motivation and creativity.

Under this premise, it is possible to establish specific pedagogical strategies, delimiting affective and cognitive approaches during learning. Reyes *et al*. (2015) conducted a study in which it was observed that, by encouraging divergent thinking in activities, they increase the functions of abstract thinking, immediate memory and metaphorical sense.

Some aspects of executive functions and creativity are of interest. The production of ideas is a complex activity that interconnects with various regions of the brain. According to the context, creativity is directed towards different levels, for example, artistic talent, decision making, among other functions.

- *Executive functions*

As a result of the above, the frontal lobes become more important in emerging studies of creative thinking in relation to executive functions. According to Montenegro (2018), executive functions are defined as higher cognitive processes that favor the birth of ideas, mobility and the performance of simple operations, these are aimed at executing tasks with a higher level of complexity (decision making, writing, reading, etc.). These functions forge the tools "intermodal and intertemporal integration", which make it possible to conceive emotions and knowledge from the past to the future in order to find the key to different contexts (Verdejo-García and Bechara, 2010).

Additionally, if there is a higher gray matter index in some brain areas such as the right temporal lobe and left parietal lobe, it increases the percentage of creative cognitive competence (Chen et al., 2016). The activities with the highest ratio of creativity are articulated to the frontal lobe, specifically to the premotor cortex, since there is also a greater volume of gray matter, the latter lobe plays a fundamental role in creative behavior.

Finally, cognitive skills or tasks with a higher level of complexity are essential to ensure the quality and development of learning. Its function is supported by the regulation of behaviors that are not related to teaching; decision making and problem solving in the classroom; the objectives of school teaching; programming of tasks and activities; evaluation of knowledge for professional success.

- *Models of creative thinking*

Dietrich (2019) established four diverse processing models (cognitive, affective, intentional, and automatic), which together construct a graph divided into four areas: Intentional and cognitive; intentional and affective; automatic and cognitive; automatic and affective.

Table 1

Creative contingency table

	Cognitive	**Affective**
Intentional	Scientists and inventors	Writer
Automatic	A person and falling object (force of gravity)	Musicians and artists

Note. Source: Own authorship (2022) based on Dietrich's (2019) creative processing models.

These models of thinking pose different skills or complex cognitive tasks arbitrated by different neural circuits. Based on the above lines, people with the most developed intentional and cognitive areas possess a large amount of knowledge about a specific topic and combine it with their skills and abilities to put it into practice. They are usually professionals in the field of science and research. Next, people with the most developed intentional and affective domains let their professional activity be shaped by their emotions. They may prefer quiet moments for personal introspection or journaling, but they are equally logical and rational, coordinating reflective action with emotional creativity. On the other hand, people with the most developed automatic and cognitive areas tend to experience spontaneous cognitive creativity when they have the knowledge they need to get the job done, but may need some inspiration. This model of creativity can emerge in the most atypical moments, such as conceiving the latest idea for a book while doing household chores or imagining a solution to a problem while driving. This modality is observed in the basal nuclei of the brain (within the encephalon), in the development of cognition and emotion. Finally, people with more developed automatic and affective areas have a deeper emotional domain, although their functions are less structured, this can be reflected in musicians and artists.

This is why Dietrich (2019) hypothesized that these four models of creative thinking involve the dominance of different brain regions. Thus, creative thinking originates from two methods: Intentional and automatic. These lay out a neural roadmap that manages emotional information and cognitive processes.

Agents linked to creativity

Several agents to take into account related to creative thinking can be distinguished (Rodriguez, 2011; Mora, 2016):

Agent 1: The dream as inspiration.

Brain disinhibition has favored artistic production with its revelations (Bogousslavsky, 2002; Stickgold and Walker, 2005). Rest is a source of creative ideas (Dietrich, 2004).

Agent 2: Interhemispheric connectivity favoring the creative process.

There are different patterns according to sex according to (Razumnikova, 2004).

Agent 3º: Dichotomy between intelligence, giftedness, high abilities and creative talent.

High abilities and giftedness are related to creative talent (the latter to a greater extent in the figurative field). However, there is no correlation between intelligence and creativity (Rodriguez, 2021).

Agent 4º: Innovation and curiosity.

Innovation needs memory in terms of knowledge of previously raised solutions (Mora, 2016). A path that is influenced by emotions, curiosity in the face of the challenge posed and the abilities and actions to create.

Agent 5º: Frontal lobe dysfunction and creative block.

Depression is associated with this area and irregular functioning, linked to lack of motivation and cognitive flexibility (Rodriguez, 2011). Likewise, according to Flaherty (2004), lack of ideas can also lead to an incorrect functioning of the frontal lobe.

Some activities to develop creativity

According to neuroscience, anxiety is linked to creative inaction and, sometimes, to depression, leading to changes in frontal lobe functioning (Cannistraro and Rauch, 2003). Regarding creativity, the brain area indicated can be stimulated with creative tasks according to electromagnetic studies conducted by Carlsson, Wendt and Risberg in 2000. Following Ramón y Cajal (2013): "Every man can be, if he sets his mind to it, a sculptor of his own brain", so some activities are proposed in pursuit of such an end:

Activity 1. A dialogue with the canvas *Anxiety* (Munch, 1894).

- Analysis of the portraits and the environment.
- Question and analysis: does it convey tranquility or nervousness?
- Identify and express a basic emotion conveyed to you by the painting in accordance with Aguado (2018): "Fear, joy, sadness, anger, disgust, curiosity, admiration, surprise, guilt, and security."
- Respect and empathy are enhanced.

Activity 2. Recreational mathematics: We draw points and/or straight lines.

- Reflective activity on a sheet of paper.
- Question and analysis. Placed 4 or 5 dots on the paper, is it possible to draw straight lines without lifting the pencil from the paper and passing through each and every dot?
- Imagination, curiosity, the desire to excel and creativity are correlated.

Activity 3. Creative competence: Imaginative environments.

- The magic of thinking and creating with objects.
- Question and analysis: what can we do with a stick? can anything be invented or researched thanks to the sticks?
- To encourage creativity, examples can be shown from the discovery of the center of gravity with the fingers, the discovery of the fulcrum to lift an object or reproduction of the experience of Eratosthenes, with the demonstration that the Earth is round thanks to the shadow of two sticks (it can be exemplified with a cardboard representing the world and two toothpicks). See: Ministry of Science, Innovation and Universities. [FECYT ciencia] (2012). *One thousand schoolchildren measure the Earth like Eratosthenes* [Video]. Youtube. &lthttps://www.youtube.com/watch?v=S56r8lDHqDk> or by reproducing the following experiment in which collaboration is needed with other people in another country who have carried out the same experience and under the same conditions: IES Itaca. [itacaies] (2015). Project: Eratosthenes. Autumn Equinox. Searching for solar noon [Video]. Youtube. &lthttps://www.youtube.com/watch?v=b3XYjwGQOQ8>.

Activity 4: Design of a creative routine activity.

- Creativity and thinking routines.

- Question and analysis. We focus on a daily activity or action. is there an alternative way to be realized? which is the most effective? which is the most efficient? is one of the ways to be realized both the most effective and the most efficient?

Creative potential is associated with various stimuli. Tasks and activities are the drivers of creativity. Creating contexts as a method of expression is key to stimulating creative thinking. Experimenting, manipulating and inquiring with resources allows them to develop their skills. From this approach, experiential learning is very practical to turn the classroom into a "laboratory" where creative stimulation strategies can be promoted as a vehicle for the teaching-learning process.

Discussion and conclusions

The creative process is defined as the creative capacity as opposed to innovation which focuses on the action of creating. Two notions or "paths" that intertwine and become evident in the face of a challenge and/or problem. This process can be observed either from the perspective of the information, distinguishing four phases (preparation, incubation, illumination and verification) or from the perspective of the subjects involved, with three phases (association-integration, elaboration and communication). One of today's challenges is to avoid relegating the process only to the expression of cognitive constructs that define creative processes the expression of cognitive constructs that define creative processes.

Creativity arises when there is a need, this process involves an initial phase of fixing and searching for information. It could be called a "product" of a consistent search and the context. This information can be associated with images and feelings in order to reach an idea. Creative people need to take risks and find novelties. Higher cognitive functions are located in the prefrontal cortex, where the neural bases are located. The frontal lobes apparently occupy an important place in the axis of creativity. The generation of creative ideas occurs between the frontal and temporal lobes. The frontal lobes are becoming more important in emerging studies of creative thinking in relation to executive functions. An exchange of information occurs during the creative action in different areas of the brain. The interrelation between the different areas of both hemispheres, which constitutes a distinctive element in the course of the creative processes.

Throughout the creative process, the interrelationship between the temporal and frontal lobes of the brain is essential. Dopamine and noradrenaline as neurotransmitters that favor tasks related to motivation and creativity. While it is true that individual elements and social contexts that interfere must be taken into account in order to value this faculty. From another point of view, it is also interesting to note the different research that interconnects intelligence with creativity.

Brain regions become key pieces to understand the neurophysiology of the brain in the creative dimension. It seems that creativity is not only in specific areas of the brain, but in the whole brain as a whole. Its functionality is supported by the various developmental contexts. A new teaching neuromethodology to learn about students' brains is neuroimaging. Thus, it is of interest to infer in possible studies supported by neuroimaging techniques to investigate the relationships established between cognitive

processing and brain creativity, as well as to establish these neuromethodologies in their development. Neuroimaging can contribute to the early seeds of learning.

New horizons are opening up through neuroscience, with various neuromethodologies such as neuroimaging for the study of the brain and other capacities such as creativity. It can be inferred in future research that will delve deeper into the cognitive process, showing the connections and effects on information processing in the brain. These future advances may fuel knowledge and curiosity about the nature of the brain and behavior in relation to creativity. In the words of Francisco Mora (2017): "Without curiosity there is no attention and no knowledge."

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