

# Brain Mechanisms in the Learning Process

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## Abstract

This article introduces a brief literature review concerning brain mechanisms and their interplay with memory and learning. Its study lays an important basis not only for understanding learning processes but also for applying this knowledge into educational practice.

**Keywords:** Brain mechanisms, learning process, educational practice

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## 1. Brain generalities

The brain as integral to the nervous system is a very complex matter, as Gordon et al. (2013, p. 504) underline by quoting a pharmaceutical researcher in 1994: “If the human brain were simple enough for us to understand, we would be too simple to understand it”. This is mentioned in order to explain how after two decades of growing scientific progress in the disciplines of neuroscience, the exorbitant complexity of the nervous system is still hard to unravel completely.

One of the aims of the present section is to provide a glimpse of the process of information in human beings (specifically, in children) by referring to the elements of the nervous system and the role they play in the human information processing system.

According to Gordon et al. (2013), the two major regions in which the nervous system is divided are the central nervous system (CNS), containing the brain and the spinal cord; and the peripheral nervous system (PNS), containing the ganglia and nerves. In functional terms, the nervous system can be divided into regions that are responsible for sensation or sensory functions, which are involved in receiving information about the surrounding environment—known as stimulus—through the conscious perception of the five senses: smell, taste, sight, touch, and hearing; regions that are responsible for generating responses or motor functions, which generate responses to that information on the basis of the stimuli perceived by sensory structures; and regions that are responsible for integration, which combines sensory perceptions and higher cognitive functions such as learning, emotion or state of a person at a particular time, and memories of previous stimuli, to produce a response. Another division given to the nervous system is made on the basis of how it controls the body, presenting the somatic nervous system (SNS) as being responsible for functions that have the effect of moving skeletal muscles; and the autonomic nervous system (ANS) as being responsible for functions that cause glands to produce their secretions, or that affect cardiac or smooth muscle tissue. (p. 504-544)

In relation to the central nervous system, Molnar and Gair (2015) specify that the brain contains structurally and functionally defined regions that include the cortex (which can be broken down into four primary lobes), thalamus, hypothalamus, basal ganglia, limbic system, brainstem, and cerebellum. Molnar and Gair (2015, p.33) note that “while functions may be primarily localized to one structure in the brain, most complex functions, like language and sleep, involve neurons in multiple brain regions.”

Purnell (2020a) is more specific in the division of the brain’s regions and the tasks each region controls. He takes into consideration the explanation of Zuckerman (2009) about the four regions that the brain comprises:

1. Cerebrum: Controlling higher functions such as reasoning, learning, senses (sight and hearing) and speech.
2. Cerebellum: Coordinating muscle movements (body’s balance and posture)
3. Brain Stem: Collection of structures that include the Pons (a mass of nerve fibers that carries sensory information); the Midbrain (origin of fibers and structures that help control movement along with auditory and visual processing); and the Medulla Oblongata, which creates motor and sensory pathways between the midbrain, the pons, and the spinal cord. The brain Stem controls vital bodily functions such as cardiac activity, digestion, sleep, and respiration.
4. Diencephalon: Containing the thalamus, the hypothalamus, and pituitary gland that work together to produce and regulate neurochemicals. These structures regulate sensations, energy, control weight, and instinctual behaviors such as eating.

In regard to the spinal cord as integral to the CNS, Molnar and Gair (2015) argue that it is known as an information superhighway since it connects the brain with the rest of the body by means of its connections with peripheral nerves, transmitting sensory and motor input and controlling motor reflexes as well.

As for the peripheral nervous system, Molnar and Gair (2015) suggest that it contains the somatic and autonomic nervous systems whose main functions were explained earlier.

Generally speaking, the nervous system is made up of neurons and glia. Molnar and Gair (2015) note that

neurons are specialized cells that receive and transmit chemical or electrical signals. Specifically, between neurons, there are gaps known as synapses, where fibers from different neurons come close but do not touch and the chemicals released by the neurons, called neurotransmitters, cross over the gaps to communicate with other neurons. Gordon et al. (2013, p. 512) add that neurons are “responsible for the electrical signals that communicate information about sensations, and that produce movements in response to those stimuli, along with inducing thought processes within the brain”. On the other hand, Glia are non-neuronal cells that offer support functions to the neurons by playing an information processing role that is complementary to neurons, specifically, supporting neuronal development and signaling (Molnar & Gair, 2015).

In this line, Meece (1997) contends that neurons are programmed to receive certain stimulation during the period in which the formation of synapses are at a peak. She mentions that certain environmental stimulation is expected by neurons, as Greenough, Black, and Wallace (1987) put it, the reception of environmental stimulation in neurons will form new connections; meanwhile, those neurons that fail to receive the appropriate stimulation will fade and die off. Moreover, Molnar and Gair (2015) reported that the human brain contains around 86 billion neurons, and most of them share the same cellular components but are also highly specialized. They point out that each day about one thousand new neurons develop in the hippocampus—that is, the brain structure involved in learning and memory.

## 2. Learning and the brain

Hart (1983, p. 10) described the brain as the organ for learning. Coch, 2018, p. 309) posed the importance of including learning about the brain in teacher education. In this regard, Hart (1999) mentioned that “designing an educational experience without an understanding of the brain is like designing a glove without an understanding of the hand”. Similarly, Coch (2018) mentions that as “learning occurs in the brain in context” it would be reasonable the study of the brain as a component of teacher training programs.

According to Howard and Jay (2019), performance in most everyday tasks, including learning, requires many regions of the left and right hemispheres of the brain to work together in a very sophisticated parallel fashion. Some of these everyday tasks engage more one side of the cortex than the other. For instance, language tends to activate the left hemisphere more than the right. However, both hemispheres are connected by the corpus callosum, which is considered as an information super highway that integrates processing across the right and left side of the brain. (Cozolino, 2013a) remarks that “in general, the left hemisphere has taken the lead on language processing, linear thinking, and pro-social functioning while the right hemisphere specializes in visual-spatial processing, strong emotions, and private experience.”

Molnar and Gair (2015) remark that each hemisphere of the cerebral cortex can be broken down into four “functionally and spatially defined lobes”, namely frontal, parietal, occipital and temporal. Additionally, Howard and Jay (2019) mention that from the four lobes located in each hemisphere of the cortex, there are some associated more with some mental processes than others. Examples include the frontal lobes, which are extremely involved with our conscious thinking and reasoning. Neurons in these frontal lobes control cognitive functions like speech, maintaining attention, and decision-making. The parietal lobes are more involved with automatic unconscious processing. Neurons in these parietal lobes are involved in speech and reading. The occipital lobes are involved with processing our vision, that is, seeing, recognizing, and identifying the visual world. And the temporal lobes are involved with processing and interpreting auditory information, which also contains the hippocampus—a structure that processes memory formation.

Despite that each lobe has a specific function, the brain is multi-sensory and it is highly interconnected, meaning for example, that just seeing a picture of a bell will produce activity not only in the visual cortex but in the auditory cortex as well, due to the association created of the picture of a bell with the sound of a bell. Here, Howard remarks that the learning process benefits from being able to represent information in a variety of ways using different modalities such as sight, sound, touch, etc. Consequently, he suggests that in the teaching process, all the senses should be stimulated to learn because evidence has shown that making links between those different forms of information, certainly help individuals understand and learn.

Furthermore, underneath the cortex, there are some subcortical structures that are very important for learning as well. One example is the hippocampus, which is crucial for laying down memory in the cortex. And the amygdala is also found there, which is involved with an individual’s emotional response. According to Howard and Jay (2019), these subcortical structures interact and communicate with the cortex in different ways and are essential for our experience of emotions which are very intertwined with our reasoning and learning. These structures are within the limbic system. Neuroimaging studies of the limbic system during the learning process, along with the measurement of brain chemical transmitters including dopamine, reveal that “students’ comfort level has a critical impact on information transmission and storage in the brain” (Willis, 2016). Willis highlights some factors that affect this comfort level, for instance, trust and positive feelings for teachers, self-confidence, school communities, and supportive classrooms. These factors are “directly related to the state of mind compatible with the most successful learning, remembering, and higher-order thinking.”

Cox (2018) mentions how the amygdala plays a role when it comes to the stress caused on the brain (e.g., as the stress caused to students when conducting assessments). She mentions that although memories can be stored throughout the brain, the ability to remember relies on the pre-frontal cortex, and the activity in the pre-frontal cortex can be inhibited or lessen by the amygdala when we are stressed. Specifically, Willis (2016) mentions how distress impairs the ability to learn, the maintenance of physical health, and the inhibition of neural plasticity; and this occurs when the amygdala senses threat and becomes over-activated impeding new sensory information to pass through it to access the memory and association circuits. In other words, according to Willis, the amygdala determines what is safe and what is dangerous having the power to hijack the brain in high anxiety, terror or fear states and activating a fight, flight and fright response. In Vogel and Schwabe's (2016) words, this fight, flight, fright response protects us from immediate danger. As per Purnell (2020b), the hijacking state of our brain "impinges on learning and can interfere with the brain's ability to comprehend, process information and retain memories." In addition to what occurs right after the hijacking state of the brain, Nagel and Scholes (2016, p. 185-189) refer that the brain redirects the energy of the body to the lungs, heart and major muscle groups to ensure the person's survival. Conditions such as chronic stress has shown to "weaken prefrontal cortex (PFC) functional connectivity and PFC regulation of the amygdala" (Arnsten, 2015). Cozolino (2013a) indicates how stressful situations activate the release of the stress hormone cortisol provoking interference with neural growth. Besides, he remarks how fear makes thinking rigid, shuts down exploration, and drives to "neophobia".

In order to avoid all the above-mentioned detrimental consequences on memory and learning in educational settings, Cozolino (2013b, p. 235) states that it is crucial for educators to be "amygdala whisperers by using their warmth and empathic caring nature and create a state of mind that increases neuroplasticity and learning." Cozolino (2014) refers to neuroplasticity as the process that reflects the ability of neurons to change their structure and relationships to one another in reaction to experience. It can also be considered "brain-based teaching strategies that reduce classroom anxiety and increase student connection to their lessons" as Willis (2016) suggests, leading educators to help their students learn more effectively. Cozolino (2014) notes that educators need to understand that the brain grows best when low levels of stress and supportive relationships are established, as he points out, neuroscience has revealed that secure relationships have proved emotional regulation and low levels of arousal which maximizes biochemical processes. He highlighted how this activation of emotional circuits promotes intelligence, cognition and executive brain systems.

Besides, Willis (2014) claims that it is important to know student's strengths and interests when enduring understanding wants to be constructed. She mentions that from the beginning of each unit, not only students' strengths but also weaknesses need to be incorporated into authentic learning experiences; concurrently, feedback, metacognition, and revision need to be included to promote a variety of cognitive and emotional benefits leading to academic success. It includes being aware of the effects of stress on the brain and the learning process. As mentioned earlier, stress can lead to a detrimental impact on the learning and memory process (Vogel and Schwabe, 2016); therefore, strategies should be considered to avoid the complex effects that stress causes. For instance, Cox (2018) mentions the importance of creating strategies to lessen stress during exams. She also includes strategies such as, preparing prior settings comparable to those that will be experienced in the test situation, completion of practice questions under time pressure, deep breaths, and exercise.

Purnell (2020b) points out how the neurotransmitter dopamine plays a role when it comes to engaging students and promoting a positive educational environment. He emphasizes that educators need to know how to stimulate the neurotransmitter dopamine by the inclusion of some dopamine boosters such as movement, enjoyable music, optimism, choice, positive humor, and positive peer interaction due to the fact that "when dopamine is released in the brain, it promotes feelings of pleasure, a deep satisfaction, and a drive to continue or repeat the action that triggered the pleasurable response (McTighe & Willis, 2019, p. 20)".

As per Howard and Jay (2019), the learning process can be involved in terms of three categories. Those involved with engagement—which includes subcortical emotional processes. Those for building knowledge and understanding—which demands activity in the frontal working memory regions of the brain. And those for consolidating learning—which will shift and distribute that activity to other parts of the cortex. The first representation of a new understanding in our brain or the building of knowledge usually requires attention, effort, and conscious processing of information. This effort encompasses activating the working memory network—which involves conscious attention and is included in the frontal regions of the brain. As the incoming information is grasped or manipulated, and as new knowledge is being built, the working memory network—those regions in the frontal lobes—will increase their activation. According to Brod et al. (2013), the regions in the pre-frontal cortex help detect the fit of new incoming knowledge with what is already known and help retrieve this prior knowledge. It is important to point out that as learning requires us to keep different pieces of information in our conscious attention at the same time, and our ability to do so is limited; when we are stressed, the access to our working memory is reduced which limits our cognitive ability to solve a problem and causes a struggle to maintain attentional focus (Howard & Jay, 2019).

### 3. Memory, learning and the brain

“There is no learning without memory, and language learning in particular, with the enormous load of vocabulary that it requires, is largely a memory task” (Thornbury, 2006, p. 129).

Memory, as a core aspect in the learning process is described by VandenBos (2015) as “the ability to retain information or a representation of past experience.” According to Halpern (2014, p. 109), information that is stored in long-term memory appears in associative networks “which are spider like organizations of information in which closely related topics are located near each other and those that bear little relationship to each other are farther away.” She illustrates the case of less related topics by mentioning the words “woman-printer”, which denote little relation between them. The author also states that “objects, emotions, and actions that frequently occur together become linked in memory so that when we retrieve information, one memory reminds us of a related concept, which reminds us of another, and so on” (p. 60). Additionally, she suggests that the type of information to be remembered, what the person already knows, “the length of the retention interval, and noncognitive factors like health and motivation”, will influence what and how one learns and remembers (p. 107).

When learning new information, there are different factors to take into consideration. For instance, Halpern (2014, p. 59) notes that “time” is the core element that marks the relationship between both learning and memory and influences learning in two senses. One is related to the amount of learned information or knowledge retrieved throughout different points in a line time. The other is referred to the time devoted to learning a certain topic, which is associated with the time of attention kept or focused on the learning object. Those aspects are important factors that not only determine how much one learns but also influence the performance of both short and long-term memories. Furthermore, “images” play an important role in memory and in the learning process as well. Halpern (2014, p. 98) notes that “research has shown that images are best when they are interacting and when they are vivid and detailed.” Additionally, Halpern (2014, p. 96) points out regarding the importance of memory aids, such as internal memory aids, as powerful tools for remembering words. For example, the use of peg words and images that are used as “hooks” for information that is going to be learned later in the future. Concomitant, the use of a mnemonic approach to instruction is suggested for remembering words or information more effectively (McKeown & Curtis, 1987). It may be argued that in young children, images, songs, rhymes and the like may constitute internal memory aids that may serve as hooks for recalling words more effectively, which can be part of the mnemonic approach to instruction.

On the other hand, the brain as part of the body’s nervous system, coordinates all of the body’s functions and as Purnell (2020a) notes, is the physiological dimension where memory and learning occur. He adds that the goal of learning is to move information to long-term memory and to do so, memories need to be retrieved regularly. Purnell (2020a) mentions how essential is to remember that “learning is a function of memory, encoding, and consolidation, which, in turn, are processes that change the brain physically.” Here, the author explains how the brain discards, retains and changes information in response to new and repeated experiences by citing an example given by McTighe and Willis (2019) about how the repeated practice of children tying shoelaces makes the associated neurons repeatedly activate in sequences, which strengthens the circuit of connected neurons each time.

Worthy is to note how the effect of practice on the brain plays a significant role in shifting activity from working memory regions to regions more involved with automatic unconscious processing. A study of adults learning complex mathematics carried out by Delazer et al. (2003, p.75) showed how practice helps consolidate freshly-learned mental processes until individuals are able to do them almost without thinking. This consolidation means that the knowledge not only becomes more permanent, but accessing it becomes quicker, easier, less conscious, and more automatic. Consequently, this leads to reduce the burden on our working memory so that once the WM is liberated, it can be occupied by new information, and we are ready to move on and learn more.

According to Purnell (2020a), “neurologically, memories are formed when experience is encoded through patterns, whereby cells interact with each other.” Scientists from the University of California (University of California, 2001) discovered almost twenty years ago that brain cells could form temporary or permanent connections in response to stimuli. This discovery indicated that the brain could change structurally, influencing how individuals store and retrieve memory, and it showed as well the link between the stimulation of cells and the creation of a memory. In this study, it was also found that a protein termed actin—that is inside cells—could be stimulated to move toward neurons to which they are connected. Activity in the first cell triggered actin movement in neighboring neurons. The activation of this temporary movement would last five minutes then quickly disappear. Nevertheless, if the original cell were repeatedly stimulated four times in one hour, the synapse would physically divide, producing new synapses that would produce a permanent change. This finding emphasizes how repetition or exposure to experience can induce or consolidate memory.

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