The role of Neurosciences in Education… and vice versa

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Abstract

One of the key questions in education is how the learning process in the classroom takes place and how different environmental and individual circumstances (attention, motivation, nutrition, stimulus presentation, etc.) can enhance the child's capabilities to learn and to remember. These and other cognitive skills are shaped as a consequence of the infant brain activity. Therefore, the provision of any information (included that obtained using animal models) relating to how the brain builds up learning and memory should be of high adaptive value. It is considered that an effort is needed to establish both a common language between education and neuroscience and a clear framework for exchanging questions and data.

Keywords: learning, memory, neuroscience, animal models, brain circuits.

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El papel de las Neurociencias en la Educación… y viceversa

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Resumen

Una de las cuestiones más importantes en Educación es cómo tiene lugar el aprendizaje en el aula y cómo distintas circunstancias individuales y ambientales (atención, motivación, alimentación, presentación de la información, etc.) pueden incrementar las capacidades del alumno para aprender y recordar. Al igual que las demás, estas capacidades cognitivas son el resultado de la actividad cerebral del niño. Así pues, cualquier información de que se disponga relativa a cómo el cerebro genera aprendizaje y memoria (incluida la obtenida a partir de modelos animales) puede ser de un alto valor adaptativo. Por lo tanto, parece necesario y conveniente que se establezca un lenguaje común entre Educación y Neurociencia, así como un amplio marco de discusión para el intercambio de preguntas y de datos.

Palabras clave: aprendizaje, memoria, Neurociencia, modelos animales, circuitos cerebrales.

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Learning is the mechanism by which the nervous system adapts to environmental pressures and constraints by the generation of appropriate new behaviors. During actual learning, the neural information needs to be encoded, stored, and retrieved through memory processes. The acquisition of simple behaviors can be related to basic mechanisms of learning, while that of complex behaviors is achieved by multiple combinations of simple learning processes (Gruart, 2008).

Perceptive learning is used to know objects or personal characteristics; thus, a child can recognize a bell by its shape and/or sound. This perceptive learning can be extended into motor learning when the environmental knowledge is completed with an action—for example, the child plays the bell.

Associative learning is also a basic learning mechanism, and requires an association between two stimuli (classical or Pavlovian conditioning) or an association between a motor response and its consequences (instrumental or operant conditioning). Classical conditioning requires an environmental stimulus that evokes a reflex response; for example, each time that someone’s eye is blown at, he/she closes it. Furthermore, if the sound of a bell is systematically presented before the blowing, the person will close the eye right after the sound starts and well before the air comes. Instrumental conditioning paradigms make learning more diverse and flexible. For example, under some circumstances, a particular behavior is rewarded positively (which increases the behavior frequency) or negatively (and this punishment decreases the behavior frequency). The nature of the reward is not universal, but depends on a particular environment and on the individual’s preferences based on his/her past experience.

Relational learning is the most complex type of basic learning; it includes the recognition of an object, its spatial localization, and the sequence of actions that creates a particular situation. The child in the classroom not only learns about the shape of the bell, but can play it in different situations (a song, the end of the lesson, etc.). Such training allows the child to design future uses for the bell's sound in different contexts.

All these learning processes need memory that can be kept for a short or a long term. Indeed, a process of consolidation it is required to change a short-term memory into a long-term one. Memory is classified as declarative (or explicit) when it can be expressed using words, and non-declarative (or implicit) if it is demonstrated through actions. Memory loss is termed amnesia—it can be pathological when present in young people or when too extensive in older ones, and in both cases the person will experience severe learning difficulties.

Many laboratories, included ours at the Pablo de Olavide University, in Seville, try to identify the physiological basis of learning and memory processes by studying changes that take place in the nervous system during these phenomena. Various applied disciplines (education, medicine, economics, etc.) can exploit the different experimental results provided by the neurosciences.

Brain structure

Any human capability related to moving, thinking, or learning (among other cognitive processes) requires a brain. The nervous system appears in those species that can move effectively in their environment, and provides them with capabilities for sophisticated physical interactions, as well as for establishing social relationships. Successive evolutionary steps developed all the capabilities that are today studied as cognitive skills (Gruart, 2008).

The nervous system comprises two types of cell: neurons (the basic units of the nervous system) and glial cells. Neurons typically have three parts: dendrites (branches that usually receive the neural signals), a soma (the neuronal body where the cell nucleus is found), and an axon, which is a prolongation with buttons at its terminals, making synapses (i.e., contacts) with dendrites and somas of other neurons.

Neurons show an attractive morphological diversity compared with tissue cells of other organs, such as skin, pancreas, or heart. The neuron body and its dendritic prolongations can adopt a great number of shapes and sizes. This morphological variability evokes a huge diversity in the functional capability of human beings (and of animals in general), not because our behaviors are unlimited (on the contrary, they are quite limited), but because it enables carrying out certain behaviors with great accuracy and precision.

Brain functions

The huge number of neurons and glial cells in the human nervous system require a precise functioning to produce all the behaviors and intellectual capabilities that characterize the human being (Gruart, 2008). Neurons sharing a function tend to be grouped in nuclei, and they communicate through their axons with other neurons located in proximal or distal structures, while neurons participating in functional maps are grouped in layers. An interesting historical question is whether each human capacity requires specific neuronal areas, totally specialized and independent of other areas responsible for different behaviors. One theory came from Franz Joseph Gall (at the beginning of the XIXth century), who identified about 30 intellectual and emotional capabilities located at different brain areas. He claimed that if someone was specialized in one of these capabilities, a protuberance in the corresponding area could be detected from the scalp. This idea of fine cerebral localization of any human capability seemed to be confirmed by some relevant clinical cases.

Phineas Cage was using a rock drill when the dynamite inside exploded accidentally. The rock drill passed through his left cheek and came out through the most rostral part of his brain—that is, the prefrontal cortex. Surprisingly, once he recovered from his injuries, doctors and relatives were unable to observe any special impairment in his everyday behavior. Eventually, they realized that Mr. Cage showed an impertinent and selfdestructive behavior, and that he had lost the capacity to assess the negative consequences of such poor behavior. This capability is today assigned to the medial prefrontal cerebral cortex.

Henry Gustav Molaison (the famous patient H.M.) suffered strong epileptic bouts due to an accident when he was a child. To prevent the fits, doctors decided to remove the neuronal areas where the crisis seemed to be generated—that is, the temporal lobes from both brain hemispheres, where a cortical structure called the hippocampus is located. After his recovery, Mr. Molaison showed an apparently normal behavior, but from then on he could not build and retain long-term memories. Any information, person, or situation was forgotten by him in a few minutes, so that he could not acquire new behaviors or recollections.

In accordance to available experimental evidences, the brain contains specialized areas for movement, memory, vision, etc. But each intellectual or complex capability requires the activation and coordination of many different brain areas. Moreover, recurrent circuits could be underlying different cognitive requirements, so that these intellectual capabilities could be conducted (and even recovered) through alternative pathways, called compensatory circuits (Rubia, 2000). One example of such multiple circuits is the one for context-dependent regulation of fear memory, which includes the hippocampus, the medial prefrontal cortex, and the prelimbic cortex and the amygdala. The presence of direct and indirect connections between these different structures offers many different possibilities for understanding and facing fear memories (Maren, Luan Phan & Liberzon, 2013).

Both learning and memory are cognitive capabilities that require the tuned functioning of distinct brain areas, mainly due to the great variability of concepts and motor acts to be learned and remembered, and their relationships. Various studies on amnesia suggest that memory loss is progressive and that some memories are more accessible than others. For example, amnesic patients may not remember what they had for breakfast, but can clearly recall when they used to play in the streets of their village.

Usually, they can remember common names (chair, glasses, or water), but not the proper names of their neighbors and relatives.

Learning and memory are probably not isolated processes that take place in one specific brain area, but seem to be functional states that require different nervous structures and the correct temporal activation between them (Gruart, 2008). For this reason, learning is highly dependent on the individual’s motivational and emotional states, including their level of attention and their knowledge and prior skills. Finally, the characteristics of their sensorial receptors and muscles (in the case of requiring some movements) will also be important for the learning process. In this context, apart from the aforementioned hippocampus, and other structures included in the limbic system, it will be necessary to activate the amygdaloid nucleus, for its relation with the emotional aspects, and the basal ganglia and the cerebellum, related to the motor aspects, and many other cerebral cortical areas for achieving the most accurate learning and memory processes. In general, the cerebral cortex is the most evolved brain area and the site of the most precise and final analysis of the sensorial information, enabling us to perceive the environment. Moreover, the motor cortical areas assemble the motor commands that allow interaction with the physical and social environment.

Chemical connections

Any brain function requires communication between the neurons of a specific circuit (Gruart, 2008). The local sites of communication between neurons (the synapses) include the membrane from the axonal terminal button of the neuron that gives the information, a small intercellular space, and the membrane of the neuron that receives the information (normally, at its dendritic branches). The presynaptic neuron secretes a substance (named neurotransmitter) to the intercellular space, and this substance couples to the receptors of the postsynaptic neuron. The union between neurotransmitters and receptors is the starting signal for many different cascades of chemical signals that will eventually induce some specific neuronal response in the postsynaptic neuron. This chemical modulation is a general property of the nervous system and it also takes place during learning and memory processes.

The circumstance that the communication between neurons in the brain is chemical in nature is significant because it can explain some behavioral changes caused by specific chemical substances that interact at the synaptic level (Gruart, 2008). Some of these substances can be taken exogenously, such as alcohol, caffeine, cocaine, certain foods, etc. But other substances produced endogenously, such as the adrenaline or the glucocorticoids produced during a stressful situation, can also induce changes in the learning processes. The fact that many drugs can produce their effects at the synaptic level opens a bioethical (or neuroethical) discussion about the opportunity of using pills that will potentially increase the memory capabilities in healthy adults, including young adults (Gazzaniga, 2005; Lynch, Palmer & Gall, 2011). Cognitive enhancement can also be achieved through non-pharmacological means, using nutrition, physical exercise, sleep, meditation, mnemonic strategies, computer training, and brain stimulation. Many of these strategies can have the same level of efficacy as current pills, with lesser bioethical implications (Dresler et al., 2013).

Caffeine is the only psychoactive drug legally available to children, and its intake is very widespread in our society. The effect of caffeine and related substances (from tea, coffee, chocolate, cola soft drinks, etc.) modifies our behavior because they block the action of the internal adenosine at its receptor level (Fontinha et al., 2009). A high consumption of caffeine in children can cause several problems. For example, overnight abstinence from caffeine can cause fatigue and slowed thinking, and although taking some more caffeine rapidly reverses these effects, it does not appear to rise functioning to normal levels (Heatherley, Hancock & Rogers, 2006).

Glucose is also essential for brain function, and it should be provided in the daily diet. The lack of enough food (for example, by not having breakfast), or a deficiency in daily nutritional needs, can directly prevent learning and memory capabilities (Zuluaga, 2009). Nutritional chemistry studies the cycles and metabolic processes needed for cellular formation, neurotransmission, trophic factors, etc. Some of the required molecules can be produced by our organism, but others have to be obtained from the food.

Apart from changes produced by different substances and nutrients, learning can be affected by the individual's motivation, attention, emotion, etc. For example, mild physical and psychological stress appears to facilitate memory of an event when it is coincident with the event in place and time. Neuroscientific studies demonstrate that to enhance the memory, stress hormones and neurotransmitters must also converge in time and space with the brain activity associated with this memory (Joels et al., 2006). Stress hormones appear to facilitate memory when they are present at the time of learning, but have the opposite effect when they are present before, or a considerable time after, the learning event. Physical stressors, such as temperature and hunger, activate lower regions in the brain than does the psychological stress of receiving a stressful emotional message, which is more likely to activate limbic regions and to produce the stress hormone adrenaline in these regions. The coincidence in time and place promotes memory for the message, but not for any unrelated contextual information (McGaugh, 2004).

The relationship between memory and emotion is also interdependent: people remember emotionally charged events better than neutral ones (Bechara et al., 1995). Strong emotion can impair memory for less-emotional events and information experienced at the same time. In addition, while strong emotions can aid memory, stress at high levels limits the ability to learn and remember over time. The impact of emotional events on the ability to learn demonstrates the importance of creating positive emotional climates during learning, taking into account both personal and organizational factors.

To effectively memorize and learn, people have to pay attention to the environmental stimuli and to the received information. Moreover, attention cycles during learning are interrelated with the working memory—that is, the capacity of storing and manipulating information related to the performance of cognitive tasks, such as reasoning, comprehension, and certain types of learning (Baddeley, 2009). The working memory is clearly limited in terms both of the amount of information that can be kept and of the time that it will be accessible. The brain filters all incoming sensory stimuli and selects for encoding only those that are relevant at that moment. As the brain cannot pay attention to all the incoming stimuli, it is assumed that it ignores information that, in terms of existing neural networks, is meaningless. Therefore, in designing learning experiences, those strategies that quickly, effectively, and powerfully grab the attention of the learner must be selected. Attention cycles are very well known, and a clear diminution of attention can be recorded after a certain time (depending on the task and the individual's age) of doing the same activity without introducing new stimulation (Gruart, Delgado-García, Escobar & Aguilar-Roblero, 2002).

Since encoding is the first of three successive memory stages (storage and retrieval are the other two), the quantity and quality of memory can be profoundly affected by multitasking. If a task is performed without multitasking, the hippocampus—a region of the brain involved in sorting, processing, and recalling information, and critical for declarative memory—remains active. Any distractive element (for example, a beep) shifts activity away from the hippocampus to the striatum, which is necessary for procedural memory (habitual tasks, such as riding a bike). Interestingly, memories in the hippocampus are easier to recall in situations different to that in which they were learned, whereas those stored in the striatum are tied closely to the specific situation. The implication is that learning with the striatum leads to knowledge that cannot be easily generalized in new situations (Foerde, Knowlton & Poldrack, 2006). Closely related to multitasking, new technologies induce the continuous use of partial attention. People constantly scan the environment for the best place to be connected at any given moment. New studies on multitasking and attention, combined with insights about the limitations of working memory, demonstrate that attention management is critical in the learning process.

Some strategies related to attention and—in particular—to attention enhancement have been proposed by Hendel-Giller et al. (2011) in the Maritz Institute White Paper. Their proposal is

> "- Eliminate multitasking to facilitate more efficient and effective encoding of knowledge
> - Minimize the load placed on working memory by limiting distractions and avoiding asking learners to process vast amounts of information at one time
> - Manage attention shifts, allowing learners sufficient time and space to make them
> - Utilize novelty and surprise while allowing learners to make connections with existing knowledge
> - Provide learners with awareness and skills training in attention management"

Brain changes during learning and memory

It has been proposed that a brain that has learned must be quantitatively and qualitatively different from another brain without these experiences of knowledge (Gruart, 2008). However, all human brains are similar in structure, and the minimal differences occasionally found are not always explained by suggested capabilities. For example, in spite of all the quantitative studies made on Einstein's brain, no structural basis for his geniality has so far been detected.

Many studies have demonstrated a distinct modification of electrical activities in a particular neuronal circuit during a certain function. The typical activity of these neurons is shown through changes in biopotentials that are known as action potentials. An action potential is the unit of activity for the neurons to communicate between each other, and it is used as a sort of neuronal language. Action potentials produced in one neuron travel through its axon to the terminal (presynaptic) buttons, where the neurotransmitter is released into the synaptic cleft and the released chemical substances activate the next neuron, by coupling at its (postsynaptic) receptors. The amount of activity, in terms of number of action potentials, is then proportional to the concentration of neurotransmitter released. Probably, the brain functions are supported on different neuronal circuits, and the frequency of action potentials during a certain period can increase or decrease in many different nuclei or layers.

After some persistent mental activity, and after showing some real new ability, such as semantic knowledge, relational, motor behavior, etc., the neuronal activity can be followed by an ultra-structural modification. In this regard, many scientific studies conclude that the number of synaptic contacts can be increased as a consequence of the learning process, and some enlargement of the cerebral cortical motor areas corresponding to the fingers has been found in expert pianists. The connections best prepared for this possible plastic modification are probably those in and from the cerebral cortex, rather than other subcortical structures that should be preserved for more-basic functions throughout the individual’s life. Donald Hebb proposed (Hebb, 1949) that learning might exist at the level of synapses. His proposition leads to the well-known sentence "neurons that fire together wire together”, and two cells that are strengthened in this way are today called a "Hebbian synapse". From Hebb's hypothesis, researchers have tried to prove that neurons that are repeatedly used grow stronger synapses and more-effective neuronal networks. And the more they fire, the more they send out new branches looking for useful new connections (Schwartz & Begley, 2003). Following these approaches, it has been proposed that the brain is a plastic structure with two different ways to consolidate learning: i) altering existing connections by forming new buttons from previous ones, making existing pathways more efficient and suitable; and ii) creating brand new brain connections by forming new buttons from the division of existing ones, thereby increasing the overall synaptic density.

The term plasticity applied to the nervous system could coexist with the idea of homeostasis, as a method of autoregulation of production, which in turn will impact on regulation of future decisions and memories. Such a naturally adaptive mechanism optimizes the contribution of different types of prediction error signal to future decisions and actions according to the pattern of recent successes and failures in prediction (Mizumori, 2013). At the cellular, subcellular, or synaptic levels, homeostatic plastic mechanisms may regulate cell excitability around a neuronal activity set point such that neurons retain maximal responsivity to future inputs (Turrigiano & Nelson, 2004). This process enables neurons to achieve a balance between synaptic stability and flexibility.

It seems that experts and novices learn differently, since novices can hold less new information, while experts can go quickly through sensory data and identify which are the important issues (Zull, 2002). Experts could have more connections and interconnections, stronger ties between connections, and a better-organized knowledge structure. This will make it easier for them to acquire and to assimilate new information and to retrieve prior knowledge.

Ontogeny of learning and memory capabilities

Different intellectual and motor capabilities are acquired while the nervous structures related to these capabilities reach the right level of maturation (Gruart, 2008). The brain of the newborn requires following different maturity phases in order to acquire and to show its different capabilities and abilities. Some of these abilities present critical periods in which they can be developed easily; for example, there is a critical period for learning how to play the piano, another one for learning a second or a third language, etc.

Neural structures related to different learning and memory processes require different maturation times. The neural areas related to movement are the first to be consolidated, so it is easier to acquire motor behaviors, such as to swim or to ride a bicycle, and to remember them for a long time. However, some researchers have refused to accept the presence of such critical periods (Alferink & Farmer-Dougan, 2010; Devonshire & Dommett, 2010) because they claim that with enough training most abilities can be learned at different periods of life. Nevertheless, it still has to be stressed that an individual will not reach the same degree of accuracy playing tennis or learning Chinese if he/she started the training as an adult rather than as a child. The critical period for the development of a human child's binocular vision is thought to be between three and eight months, with sensitivity to damage extending up to at least three years of age (Siegler, 2006). Further critical periods have been identified for the development of hearing and of the vestibular system (Eugéne, Deforges, Vibert & Vidal, 2009). Other capabilities, such as structural and complex thinking, can be initiated as a child, but the consolidation could cover from adolescence to adulthood. Critical periods differ from sensitive periods, which are more-extended periods during development when an individual is more receptive to specific types of environmental stimulus, usually because nervous system development is especially sensitive to certain sensory stimuli. Whatever the role of enrichment environments, 0-3 years can be considered an important period for brain development; but so, it appears, should later childhood.

In general, learning and memory also require the maturation of other nervous system structures. The child will accomplish new abilities when the brain allows them, but some capabilities are inherent to the human condition—such as, for example, face recognition, which is possible from the first hours after birth. In contrast, remembering specific episodes can take place only in children of four or five years old. Moreover, there is a period (which researchers have named “infantile amnesia”) indicating that the only memories from this period are the ones created by the individual or reconstructed from images and adult explanations.

Neuroscience has shown the surprising extent to which the brain is still developing in adolescence, particularly with regard to the frontal and parietal cortices, where synaptic pruning does not begin until after puberty (Huttenlocher, 1979). A second type of change occurring in these brain regions during puberty involves myelination. This is the process by which the axons, carrying messages from and to neurons, become insulated by a fatty substance called myelin, improving the efficiency with which information is communicated among neurons and circuits. In the frontal and parietal lobes, myelination increases considerably throughout adolescence and, to a less dramatic extent, throughout adulthood, facilitating an increase in the speed with which neural communication occurs in these brain areas (Blakemore & Choudhury, 2006). One could expect that the teenage brain is less ready than an adult brain to carry out a range of different processes. These include directing attention, planning future tasks, inhibiting inappropriate behavior, multitasking, and a variety of socially orientated tasks, as well as discontinuities in abilities underlying social communication, such as taking the viewpoint of another person, or so-called perspective taking (Blakemore & Choudhury, 2006; Choudhury, Blakemore & Charman, 2006). Just as linguistically critical (or sensitive) periods have been linked to synaptic pruning in very young children, continuing synaptic pruning in adolescence suggests the possibility of sensitive periods here too. For example, some research has shown that teenagers activate different areas of the brain from adults when learning algebraic equations, and this difference has been associated with a more robust process of long-term storage than that used by adults (Luna, 2004; Qin et al., 2004).

What can animal models tell about children's education?

The possibility that the developing of concepts and abstractions was an exclusive human capability has long been an unproved hypothesis. However, many experiments done in laboratories, and other observations made in the animal's environment, lead to the conclusion that many species develop various concepts, such as for example, that of quantity. Thus, different species, such as birds, rats, or monkeys, have the capability to distinguish between containers that have different numbers of objects, and they can even do certain very simple arithmetical operations. For example, all these species can choose between two different black boxes into which have been introduced, successively, a different number of objects (Ridley, 2004; Gruart, 2008). Unpublished experiments from our laboratory indicate that rats can choose the manipulation of different levers or even touch-screens depending on the number of pellets provided as a reward.

A developed type of thinking is when an individual creates a tool to achieve a goal. Over the years, different species have been found to have this type of behavior—for example, birds that make hooks for fishing, or use small stones for cracking eggs, and African chimpanzees that fashion and use small sticks to reach the termites in the termite hill. After many observations, relevant data has been accumulated to defend the idea that there is some level of thinking in non-human species. However, a question not yet answered concerns real rational intentionality versus some innate predisposition in the behavior shown. Probably, both factors are intermingled.

The basic principles of any of these cognitive processes can be found in many different species, and therefore can be used for comparison between different groups of animals, and with human beings, too. Researchers interested in the basis of learning and memory processes have introduced many different protocols trying to reproduce human behavior during these cognitive actions. But it has to be stressed that there are clear differences between species that make them more prepared for certain behaviors as well as incapable of developing others. Rats and mice—two species of rodent used in the laboratory—have completely different ethograms. For example, both of them can press a lever to get a piece of food that they like, but the precision of the movements, the time needed for finishing the action, the capacity to pay attention to a light that indicates that the lever is ready, etc., are quite different, apart from any individual differences they present, as humans also do.

Many authors interested in the topic of education have been pointing to some data from the field of neuroscience that could fit in with their interests, particularly with regard to learning and memory processes—for example, the idea that memory formation occurs as a consequence of changes in the patterns of connectivity between neurons in a functional process usually named synaptic plasticity. More precisely, two types of synaptic plasticity have been proposed: i) long-term potentiation (LTP); and ii) long-term depression (LTD). One of the most basic assumptions of contemporary neuroscience is that newly acquired learning capabilities are registered and stored in the form of functional (and/or structural) changes in synaptic efficiency (Hebb, 1949; Lynch, 2004; Bliss, Collingridge & Laroche, 2006; Gruart & Delgado-García, 2007). There are many excellent studies on the subcellular and molecular events underlying learning-dependent synaptic changes, as well as on the electrophysiological (*in vitro*) processes feasibly related to learning and memory phenomena generated *in vivo* (Bliss & Collingridge, 1993; Engert & Bonhoeffer, 1999; Malenka & Nicoll, 1999; Lynch, 2004). However, for many years, not much information was available regarding synaptic functional events taking place during the learning process in alert behaving animals. This experimental limitation was an important drawback for the proper understanding of functional neural states supporting the acquisition of new motor and/or cognitive abilities (Delgado-García & Gruart 2006; Gruart & Delgado-García, 2007). It should also be kept in mind that understanding the many different molecular and subcellular dynamic processes that have been recorded and documented in behaving animals is extremely difficult, and there might be more than one interpretation. For example, different mono-, di-, and poly-synaptic effects evoked during the acquisition and/or retrieval processes can be involved in the modulation of the related physiological responses.

Notwithstanding, long-term potentiation is widely considered the leading candidate as the mechanism underlying associative learning (Bliss & Collingridge, 1993; Malenka & Nicoll, 1999; Martin, Grimwood & Morris, 2000; Bliss, Collingridge & Laroche, 2006; Citri & Malenka, 2008). Long-term potentiation is usually evoked (both *in vitro* and *in vivo*) by high-frequency stimulation of selected afferent axonal pathways, resulting in a long-lasting enhancement of synaptic efficacy. In this sense, a pertinent question has been whether long-term potentiation is the underlying neural mechanism for memory storage and learning formation or, on the contrary, long-term potentiation is just an experimental phenomenon that produces some neural effects resembling those processes. The hippocampus has been widely used as a model structure for the study of different cortical functions (learning, memory, emotion, motivation, etc.) and, in general, many different types of plastic neural mechanism. Indeed, the hippocampal formation is a cortical structure identified as an excellent experimental model for the study of the changes in strength that take place at the synaptic level during a wide variety of learning and memory tasks, as well as in specific clinical disorders (Andersen et al., 2007).

In contrast, long-term depression refers to an enduring decrease in synaptic efficiency. This is a mechanism thought to explain, for example, how neurons in the perirhinal cortex (a region in the temporal lobe) decrease their output as a stimulus is repeatedly presented. This process has been related to the ability to recognize familiarity.

Together with the cellular mechanisms taking place during learning and memory processes, there different factors modifying synaptic strength, such as environment, development, and brain-related diseases. The hippocampus plays an active role during the performance of involved behavioral displays. It has been reported that the dorsal hippocampus conveys relevant information to the ventral tegmental area concerning the context as a whole, enabling a rapid activation of dopaminergic neurons to promote salience attribution to the conditioned contexts (Luo et al., 2011). It is well known that the environmental clues underlying learning are extremely important. Interactions between the organism and its environment can lead to important neurobehavioral changes, and for several decades environmental enrichment (increasing sensory, motor, and cognitive stimulations) has been used to induce these changes in both intact and injured central nervous systems. The term "enriched environment" as an experimental process was introduced in the late 1940s by Donald Hebb (1949). Although there is no strict consensus on which environmental enrichment paradigms are the best, "enriched" animals are usually kept in larger groups and in big cages containing tunnels, nesting materials, toys, and running wheels, making the environment more complex and variable. Molecular and cellular studies have demonstrated that these housing conditions result in both anatomical and physiological changes in the brain of animals subjected to them, as compared with animals living in more-standard conditions. These changes include an increase in the total weight, amount of protein content, and thickness of the cerebral cortex. In this regard, the hippocampal region is one of the most interesting brain areas for determining the effects of enrichment on the neural tissue. It has been reported that environmental and social enrichments increase hippocampal neurogenesis, the integration of these newly generated neurons into functional circuits, and the strength in the perforant pathway to the dentate gyrus and the CA3-CA1 synapses (Green & Greenough, 1986; Foster & Dumas 2001; van Praag et al., 2002; Madroñal et al., 2010).

Spatial learning, rotarod performance, and instrumental conditioning are three learning paradigms in which acquisition is improved after exposure to enriched environments (Madroñal et al. 2010). It seems that only those forms of learning that require precise motor abilities are improved by an enriched environment. This is not the case in the classical conditioning of the eyelid responses, for which no special motor capability is necessary; thus, there was no improvement in this type of associative learning evoked by an enriched environment (Madroñal et al., 2010). Moreover, environmental enrichment is the main factor responsible for an improved learning process, while the social factor (comparing a single mouse in a cage with a group of four mice in the same cage) does not have any significant effect on any of the selected tasks (Madroñal et al., 2010). Interestingly, in the same study, it was tested whether a putative hippocampal cell proliferation and neurogenesis caused by an enriched environment could explain the learning improvement, but no definite conclusion could be reached (Madroñal et al., 2010).

Studies have also demonstrated that infants are more likely to learn from a person (teacher or peer) than from an inanimate device. If a robot's behavior becomes more social, the interest shown by an infant to connect with it and learn from it increases (Meltzoff, Kuhl, Movellan & Sejnowski, 2009). In our laboratory we have demonstrated that a mouse (the observer) that watches another mouse (the demonstrator) doing a task can later on do the task much faster and with better accuracy (Jurado-Parras, Gruart & Delgado-García, 2012). The task was to press a lever to obtain a pellet of food in a Skinner-box. In this type of instrumental conditioning, the behavioral effects of stimulating some brain areas at the time that the mouse touched the lever were also checked. The same protocol was followed with the observers receiving the stimulation in the same brain areas when the demonstrators pressed the lever. Electrical stimulation of the medial prefrontal cortex produces a disruption of the behavior sequence to obtain the food (press the lever - go to the food dispenser - take the food - eat). The mouse suddenly stops, touches its body, starts grooming, and only from time to time reaches the food dispenser and eats the pellet. In contrast, stimulation of the nucleus accumbens probably produces the same signal of satisfaction that the food does, and for this reason the mouse presses the lever as much as possible without collecting the food obtained. Finally, stimulation of the hippocampus does not produce any change in the behavioral sequence of the mouse. Medial prefrontal cortex stimulation cancels the benefits of the observation, nucleus accumbens stimulation enhances observational learning, and hippocampal stimulation does not produce any change in execution by the observer when it is introduced into the Skinner box and can use the lever and the food dispenser (Jurado-Parras, Gruart & Delgado-García, 2012). These results found in mice could be useful for testing some hypotheses in favor of a more social education, although researchers in the field might feel that this is an exclusively human capability (Liberman, 2012). Similar studies offer data and arguments for using animal models to study processes widely used in educational frameworks, such as selective attention, working memory, and animal intelligence (Matzel & Kolata, 2010).

Some authors have started to see clear advantages in using data collected from animal protocols and from human experiments (for example, using neuroimaging) for implementation in education (Goswami, 2004, 2006). None of these studies will be sufficient by themselves, but the scientific results will certainly be useful for improving children's education if applied in the corresponding context. Many researchers have started to determine the type of relationship that should be established between education and neuroscience and the framework that would guarantee the success of exchanging data (Ansari & Coch, 2006; Pickering & Howard-Jones, 2007; Varma, McCandliss & Schwartz, 2008; Devonshire & Dommett, 2010; Hook & Farah, 2013). On the other hand, there are also educators clearly against the possibility of introducing cognitive neuroscience findings into educational contexts (Purdy & Morrison, 2009; Alferink & Farmer-Dougan, 2010).

Conclusion

Neuroscience provides a considerable amount of data related to cognitive processes (learning and memory, attention, motivation, etc.) that can be useful in the educational field. However, the differences in language, interests, and interpretations of each discipline hamper communication between them and, in particular, the appropriate implementation in the classroom of data obtained at the bench. Probably, earlier success in the partnership between neuroscience and medicine and, more recently, between neuroscience and economics, can be used as a framework to design common goals and proceedings. Varma, McCandliss & Schwartz (2008) have proposed a multidisciplinary synergic model where both fields will unite knowledge in a common discipline, educational neuroscience, that could integrate neuroscientific procedures with behavioral methods to address issues related with learning and education. Essentially, some of the questions arising in the classroom could be designed and tested using neuroscientific tools, and many of the data found in neuroscientific experiments could provide interesting and workable hypotheses to be tested in the classroom. Of course, this should be done after taking all the necessary steps, as is done in pre-clinical and clinical trials before using a new treatment in patients.

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