Contents lists available at Science-Gate

International Journal of Advanced and Applied Sciences

Journal homepage: http://www.science-gate.com/IJAAS.html

Study of creativity and architectural design of education based on the cognitive neuroscience

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A R T I C L E I N F O

Article history:
Received 12 February 2016
Received in revised form
22 April 2016
Accepted 22 April 2016

Keywords:
Cognitive neuroscience
Creativity
Prefrontal cortex
Design process
Design training

A B S T R A C T

One of the most contentious issues facing architecture and design education is the assessment of creativity. The concept of creativity has been presented in different and often conflicting ways, and across the design disciplines there is no understanding about creative processes and how they apply to learning and teaching experiences. In this paper by studying the mechanism of prefrontal cortex (PFC) brain region, we review and explain different dimensions of the creativity and design education process. Then by explaining creativity from the perspective of cognitive neuroscience, a theoretical framework is presented for optimizing the design process based on using the existing structures in the brain. According to the results, examining the function of PFC in creating creative thinking can provide useful information of the process of creating a creative idea for the researchers. Furthermore, investigating the relationships between this part and other parts of the brain can lead to understand the importance and status of the creativity in the brain activities. We found out that the primary creative insights include deliberate/cognitive, deliberate/emotional, spontaneous/cognitive, and spontaneous/emotional types. Considering the presented theoretical framework, a number of solutions are proposed for teaching design in architectural education systems.

1. Introduction

World War II and its crises caused many changes in design and its issues. From World War II till onwards, many theories have been proposed about the process of architecture and designing, and there are many thoughts and theories as to the process creative people go through during their creative periods; one of them is incubation theory in 1920 which is one of the four proposed stages of creativity: preparation, incubation, illumination, and verification. Another theory was Guilford's theory. According to Guilford's theoretical framework, thinking is divided into two categories of divergent and convergent, and divergent thinking is the basis of creativity (Guilford, 1950). According to him, divergent and convergent thinking are two types of human response to a set of problem. He defined convergent thinking as selecting the most appropriate solution which is based on use of knowledge and logic rules to reduce the number of possible solutions and focus on the most appropriate one. He also defined Divergent thinking as examining various solutions which require remembering the possible solutions or developing new solutions (Lawson, 2005). Although, several decades have been passed since the theorists have attempted to completely describe the design process, some important and essential parts of it have remained still unknown. This descriptive study conducted by using library method and reviewing previous related studies, evaluates the creativity from the perspective of neuroscience considering different functions of two hemispheres of the brain to describe the structure of creativity. In other words, this paper investigates different aspects of creativity in the brain with different neurological approach by studying the function of prefrontal cortex. In this paper we want to answer to the following questions:

(1). How is the mechanism of creativity and its function?

(2). How is the architectural design of education from the perspective of cognitive neuroscience?

2. Materials

2.1. Basic concepts in neuroscience

Neurons are the core components of the brain. All the mental states, from the simple perception to the complex cognitive activities, are the results of the

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activities of these neurons and connections among them. The main point is the high number of these neurons which is a reason for the complexity of the mental aspects of brain activity. According to estimations, in the cerebral cortex, where there are about 20 billion neurons, 60 trillion synapses (connections) are created. Another important issue in understanding the brain is the structural and functional categorization of the brain. Several categories with different approaches from different parts of the brain have been proposed. One of the most appropriate categorizations model for this study is MacLean (1990) (i.e., Evolutionary brain triune theory) suggesting that the human brain is in reality three brains in one: the reptilian complex, the limbic system and the neocortex. The reptilian complex, also known as reptilian brain, is the innermost layer of the brain which is responsible for species-typical instinctual behaviors involved in aggression, dominance, territoriality, and ritual displays including heartbeat and breath. The limbic system which consists of the septum, amygdalae, hypothalamus, hippocampal complex, and cingulate cortex, is responsible for the motivation and emotion involved in feeding, reproductive behavior, and parental behavior. The last layer is neocortex, also called asneomammalian complex consists of the cerebral neocortex, a structure found uniquely in higher mammals, specifically humans. MacLean regarded its addition as the most recent step in the evolution of the mammalian brain, conferring the ability for language, abstraction, planning, and perception. Neocortex is divided into four major lobes including frontal lobe, parietal lobe, temporal lobe, and occipital lobe, each of which has important role in cognitive structure .The one which is discussed in this study is the prefrontal cortex (PFC) which is the cerebral cortex covers the front part of the frontal lobe (Fig. 1). Fig. 2 shows different parts of prefrontal cortex.

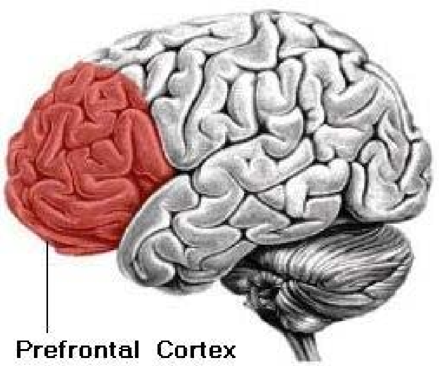

Fig. 1: Schema of prefrontal cortex

Another important issue about the human brain is its formation from two distinct neural systems, each designed to extract different kinds of information from the environment. The emotional brain is designed to attach a value tag to the incoming information that allows the person to evaluate the biological significance of a given event. On the other hand, a separate information processing line that is empty of any important information is designed to perform detailed feature analysis. This perceptual evaluation of the environment is used to construct sophisticated representations that function as the basis for cognitive processing. Each line of information processing contains a functional hierarchy in which increasingly higher order structures perform progressively more sophisticated computations. These two functional systems can be separated in anatomy as well as in the way they process information. While anatomical dissociation has received more attention, the process modularity of emotion and cognition—that is whether or not they compute information in a fundamentally different way—is still matter of some controversy (Dietrich, 2004).

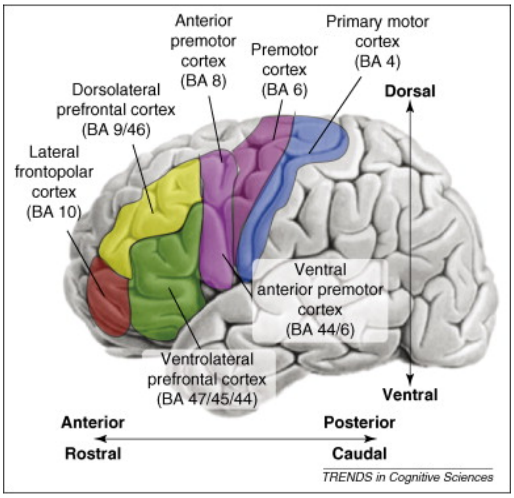

Fig. 2: Different parts of prefrontal cortex

In neurological examination of the design process, many parameters such as intelligence, motivation, memory, reasoning ability, age, and environmental conditions and training affect design process in the brain, but since each of them requires more specialized and detailed context, and the aim of this study is evaluation of the production process of the creative idea and its neurological structure, studying all them, or other factors were ignored in this paper. Also, specialized and complete review of the existing neurological structures was avoided, and it has been discussed as far as it is needed for design education.

2.2. Creativity and the function of PFC

Perhaps the single most important functional division in PFC is the central fissure. It demarcates the frontal lobe from the three posterior cortices: the temporal, the occipital, and the parietal. The functions of these three cortices are different from those of the frontal lobe. Their neurons are devoted primarily to perception and long-term memory. The primary sensory cortices of all sense modalities are located in the posterior cortices, and its association cortex further assembles and assimilates sensory information decoded initially in the primary cortex

(Dietrich; 2004). The frontal lobe, located just rostral to the central fissure, neither receive direct sensory input nor stores long-terms memory. PFC, which comprises approximately half of the frontal lobe in humans, integrates already highly processed information to enable still higher cognitive functions such as a self-construct (Keenan et al., 2000), self-reflective consciousness (Courtney et al., 1998), complex social function (Damasio, 1994), abstract thinking (Rylander, 1948) and cognitive flexibility. Three other cognitive functions, which play important role in the design process and creativity, and will be discussed in the following sections, are working memory, temporal integration, and sustained and directed attention (Fuster, 2000). In humans, these three functions have made the PFC, as an auxiliary processing engine, to help the overall processing of the brain and promote the brain processing level to a higher level. In other words, PFC strengthens, corrects and optimizes information processing in the brain. What we can conclude from this is the importance of understanding the problem and how to pay attention to it for solving problems in design and architecture. These two issues are considered to be the bases for solving the design problems, and if these two steps done better, it significantly increases the design quality. Problem perception specifies the initial information recalled to the working memory which is as a problem solving tool in architectural design and if the designer does not have an appropriate tool for solving the problem, he/she will not reach a perfect solution. Also, the ways for paying attention which includes the level and depth of attention, are determinants of how to recall the secondary recalled information; the higher attention level to the problem, the better and more relevant information is recalled, and the more attention depth to the problem, the more creative information is retrieved.

PFC is not a single unit. It is functionally divided into ventromedial (VMPFC) and dorsolateral (DLPFC) aspects (Fuster, 2002; Petrides and Baddeley, 1996). The most common deficits associated with VMPFC are inappropriate social behaviours, lack of moral judgment, few social inhibitions, few abstract thought processes, an inability to plan for the future, and/or difficulty of maintaining a plan of action (Dietrich, 2004). It appears that the VMPFC region is critical for internalizing the values and societal standards of a person's culture. Damasio (1994) suggested that the VMPFC, with its intricate connections to the limbic system, might assess the personal consequences of one's behavior, and that the resulting emotions are an essential prerequisite to making logical and rational decisions. Damage to the DLPFC does not involve changes in personality and emotion. The DLPFC does not receive direct innervations from subcortical structures such as the *amygdala* that are involved in affective behavior (Petrides and Pandya; 1999).

Working memory describes the ability to process information online. It is a monitoring system of ongoing events that temporarily keeps in mind information that is relevant to the situation, so that one can work with it. Electrophysiological reports (e.g., Quintana and Fuster; 1999) show that, as neurons of posterior cortices discover sensory information, a representation of that information is also present in working memory, so it can figure into the immediate decision-making process, so the working memory appears to be a need for cognitive flexibility, abstract thinking, strategic planning, access to long-term memory, and sentience. Overall, it can be stated that both VMPFC and DLPFC play important and essential roles in all the dimensions of creative thinking. The frontal lobe provides for cognitive flexibility and freedom, and releases us from the slavery of direct environmental triggers or the memory stored in the three posterior cortices (Dietrich, 2004).

3. Discussion

3.1. Creativity from the Perspective of Neuroscience

Understanding the difference in definition of creativity from different perspectives, and the definition of creativity in terms of neuroscience, is of great importance in clarifying different aspects of the design process. What is the definition of creativity in our mind is far from what happens in the brain. Creativity can be considered to be the creation of new connections based on the existing relationships which always happen in the brain. Production of novelty is not rare in human information processing. One only has to consider the combinational potential presented by human language to appreciate the brain's generative capacity. An assumption of the framework linking creative information processing to normative information processing is that every neural circuit that computes specific information also produces novel combinations of that information. Indeed, novelty might be inevitable in such a chaotic system. Furthermore, it is reasonable to assume that the more integrative the neural structure involved in the computations, the more combinational novelty might occur (Dietrich, 2004). Also, the characteristic of appropriateness is not inherent in each neural circuit but depends on higher order structures that are able to assess a set of very complex rules such as the person's cultural values. This means creativity is a Darwinian process; i.e. it needs a variation–selection process (Simonton, 2003). In other words, as it was mentioned above, the appropriateness of an idea or a new behavior is the result of the processing of the VMPFC on the formed ideas and behaviors, and investigating the results in the environment.

Another very important matter that its understanding would cause to realize the importance of the theoretical foundations of the design process is the role of the PFC in the creative process which affects the design process in three steps: First, to evaluate the appropriateness of a novel thought, one should be conscious of it. Secondly, by occurring insight, the PFC bears higher cognitive functions to the problem. Many insights may be incorrect, incomplete, or trivial, so judging which insights to choose and which to discard needs PFC integration. Thirdly, PFC implements the expression of the insight and arranges action in accordance with internal goals such as aesthetic or scientific goals (Dietrich, 2004). Fig. 3 depicts the hierarchy of design process.

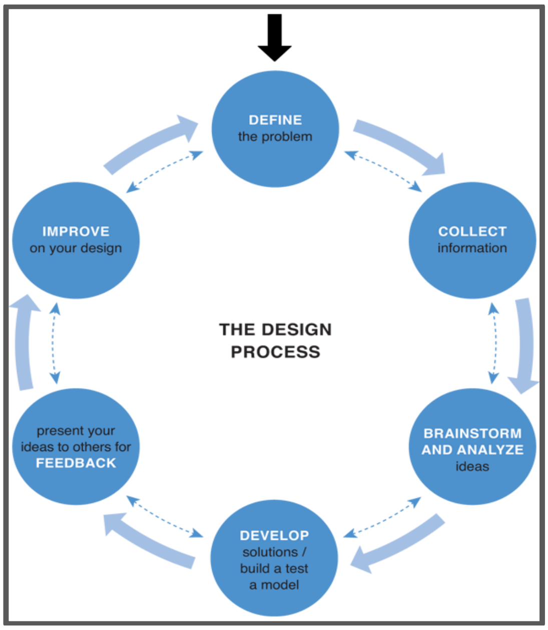

Fig. 3: Different steps of design process

According to what was mentioned above, the most important point regarding the general structure of an educational system is to pay attention to the integrity among all the details and generalities of the system, from individual exercises presented in a lesson to the relationship between the important courses in the educational chain. It is possible to achieve this integration only by understanding the purpose of architecture education, and adherence to a set of basic principles when designing educational system. Neurological approach to this issue is rooted in the limitation of the working memory, and mental discipline is the only way to achieve the highest level of designing with this limited capacity, because cognitive disorder in mental structure reduce the quality recalling information to the working memory at each stage.

3.2. Types of creative insights

Creative insights are primary components of the brain circuits and after formation, they enter into the structure of creative thinking or PFC. Therefore, the categorization of the basic insights can be a fundamental and appropriate method for creating a theoretical framework to promote the design and its teaching. Creative insights can occur in emotional or cognitive structures, or by two modes of processing: deliberate or spontaneous. Fig. 4 presents four types of creative insights mediated by a neural circuit.

The capacity of consciousness can be defined through deliberate and spontaneous processing modes. Each of these modes can direct some computations in one of the emotional or cognitive structures. In this section, we review four types of creative insights according to Dietrich (2004). Creative works arise naturally from a mix of these four basic components.

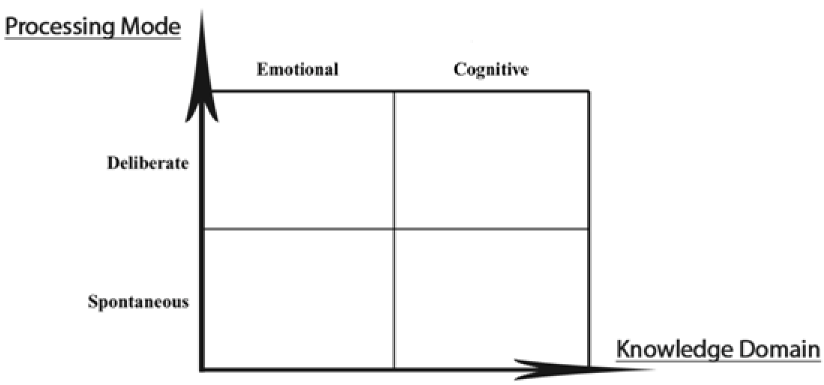

Fig. 4: Four types of creative insights

3.2.1. Deliberate mode- cognitive structures

Insights of this type, from the perspective of neuroscience, originally are in PFC. the frontal attentional network, which is in the prefrontal cortex, searches for the information related to the task in three posterior cortices. The next activation of posterior cortices is related to processing within the network, so that the prefrontal circuits, which have higher and various cognitive functions, can control the information. As the name implies, the characteristic of these insights is being intentional, and whenever the person want, he can order the brain to create these insights. These processes are made on the cognitive information which are highly available to the frontal attentional network and have the ability to be recalled deliberately by the frontal attentional network. Due to the limitation of the attention power to understand the problem and recall the information, the most important strategy in a educational system for using insights of this type is to teach the students how to pay attention to the problem and retrieve information properly in solving it. Detailed analysis and step-by-step training by the students can be an appropriate solution to achieve this end.

3.2.2. Deliberate mode- emotional structures

This type of insight is also produced by the frontal attentional network. The difference between this type of insights and the above mentioned one is that instead of searching information in posterior cortices areas, attention which is directed towards retrieving affective memory which is stored in emotional structure. This causes the retrieved information to be in the working memory buffer and manipulated for more insights.

The information that is processed deliberately in this step, contrary to the insights of the previous modes, is huge and more unavailable than the cognitive information, and since they do not have regular and reasonable structure, they cannot be used for solving a design problem, generally, but they are useful for the steps that are related to presenting an initial concept. Also, they can be more useful than cognitive information-based insights in abstract designs or for space design. The strategies that can be proposed to optimize the role of these insights in the design process, are as following: (a) enriching the emotional memory in specialized aspects related to design-based courses, (b) providing the perfect platform for feelings in educational processes and attracting attention to the emotional information by understanding and investigating the emotional structure for more and deeper access of frontal attentional system to their structure; e.g. providing practices without any cognitive or logical goal such as playing with colors, shapes, lights and shadows, reflections and many other concepts in architecture, and then their cognitive analysis and evaluation by professors and students simultaneously.

3.2.3. Spontaneous mode- cognitive structures

According to Neuroanatomy, this type of insight is formed in three posterior cortices during related unconscious thinking. The involvement of the basal ganglia in spontaneous learning and autonomic behaviors indicates that the basal ganglia also have a role in information processing in the spontaneous mode. Due to lack of periodic regulation of the frontal attentional network, such thinking when is presented spontaneously in working memory, is capable of entering consciousness. Since there is no intention with these intuitive insights, they are often referred as mysterious and are simply forgotten, while in many cases where the design problem has not been solved by the deliberate attentional system (as a convergent structure), these intuitive insights can be useful because they can be presented in divergent form (Dietrich, 2004).

If the designer's mind be greatly involved in the designing problem, even when the designer does not pay attention to the problem spontaneously, these insights are created spontaneously by autonomic structures existing in the person's consciousness, and sometimes, enter into the working memory or PFC. The quality of the presented solutions by this type of insight is so good such that many researchers have studied it, and proposed solutions based on incubation theory e.g. thinking about the subject of the design before sleeping or presenting a conception for the problem upon waking from sleep for its optimal use in design process.

The main strategy which is proposed in this study for using these insights is to lengthen the time of problem solving to get out of the designer's focus and at the same time, using some method for internalizing the problem for the designer. An appropriate technique for this purpose is to think about the problem (a few days after encountering the problem and understanding its dimensions completely) when the person is involved in doing something else like cooking or watching TV all day, or carrying a notebook to record the ideas that are formed. It should be mentioned that this is useful when the person allocates time for attention and deliberate problem solving it to evaluate the created ideas.

3.2.4. Spontaneous mode-emotional structures

This type of insight occurs when the neural activity of structures, which are responsible for processing the emotional information, is represented spontaneously in working memory. Since the process of conscious information is highly limited, it seems that the neural structures compete to have an access to consciousness. Experiencing the existence of the emotional information created spontaneously in conscious information processing has a profound effect on the individual and can be considered as "phenomenological state" which are known as "an epiphany, or a religious experience" (Dietrich, 2004). An important point in this study is that due to the strong emotional instigation of some of these insights may lead to very creative results which often are useful in the fields of art and abstraction.

This type of insights in cases where a person have a very profoundly experience in a specialized field, can create a great and influential creativity. According to many studies, the rise and flourishing of this kind of creativity is from 35 to 39 years old. The way by which these insights can be used in the design process is having ongoing and purposeful exercises every day for several years without interruption which makes concepts penetrate deep into the mental structures and the designer can present deep concepts based on years of cognitive thinking and emotional experience. Overall, it can be said that in the information processing system, with more emotion, there will be lower cognitive level, but if a design originate from the deep emotions of the designer, the possibility to create a deep emotional connection between the design and user can significantly increase. In the existing range of processing, if the basic insight originates from a more deliberate mode, it will be closer to the solution of the design problem, but due to the limited content of the working memory, less dimensions of the problem can be answered. Since the architectural design parameters are very high and beyond the capacity of working memory, use of processing in spontaneous mode can help the process of the architectural design through different methods; therefore, by using different methods, different design methods and subsequently, different educational structures can be designed or optimized and various educational strategies can be proposed for improving the architectural design and educational level. Table 1 summarizes different strategies in design process and education.

Table 1: A presentation of strategies in design education based on four types of creativity

Creative insights	The characteristics of the basic insights	The use in design process	Optimization strategies in design process	Guidelines and exercises
Deliberate/cognitive	Controllable start and finish time on regular and available information	Suitable for early and late stages of design Suitable for checking intermediate stages	Managing attention in problem conception, and recalling information	Explaining the importance of attention in all the design processes in basic design courses
Deliberate /emotional	Controllable start and finish time on irregular and massive information	Suitable for presenting the primary concepts Suitable for abstract design, and space design	Enriching the emotional memory Providing a platform for the development of emotional information	playing with colors, shapes light, shadows or lines
Spontaneous/cognitive	Uncontrollable processing time on regular and available information	Suitable for problems with large and complicated parameters Suitable for the problems which cannot be solved using convergent solutions	Lengthening the problem-solving process Internalizing the problem for the designer	Solving the problem along with the daily activities
Spontaneous / emotional	Uncontrollable processing time on irregular and massive information	Suitable for the individuals with enough experience and skill Suitable for the intuitive solutions	Providing ongoing, long-term and purposeful exercises	Carrying a sketch notebook for geometry and graphic exercises

4. Conclusion

Although it is difficult to explain creativity and design process from the perspective of cognitive neuroscience, it can play an important and effective role in clarifying different dimensions of this issue and confirming or rejecting the scientific achievements of the studies conducted on other dimensions of this issue. Examining the function of PFC as the most effective part of the brain in creating creative thinking can provide useful information of the process of creating a creative idea for the researchers. Furthermore, investigating the relationships between this part and other parts of the brain can lead to understand the importance and status of the creativity in the brain activities. Categorizing the primary insights of the brain as the inputs of the system which creates creative thinking can provide a very useful and systematic theoretical framework for analyzing design training. In this study, the presented categorization for the primary insights includes deliberate/cognitive, deliberate/emotional, spontaneous/cognitive, and spontaneous/emotional. The highest efficiency of the brain in terms of improving the level of designing can be achieved when the structures governing the brain are understood and different parts of the brain are strengthen according to the structures. The strategies and solutions which were proposed in this study while explaining the structures of the brain governing the system which creates creative thinking.

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