Design and Sensitive Configurations: Memory and Learning Neural Circuits Correlated with the Creative Processes in Design

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Abstract. The current study demonstrates an articulation between the learning and memory mental processes that organize our sensitive perception and creative process in design. Based on Eric Kandel's research on the multiple forms of learning using *Aplysia californica* (a giant sea slug), we have established correlated visual graphics that approach learning neural analogs to the apprehension of the sensible. The contemporary design sets subjective aspects of our being in the world, engendering modes of action that determine our behavior in everyday life. The aim of the current study is to reflect on didactic strategies and procedures that enhance the emergence of creative minds.

Keywords: Design · Neuroscience · Memory and learning · Creative process

1 Introduction

Many of the relations between habit and behavior are assimilated on a daily basis, particularly by refined technologies that increasingly multiply their communication artifacts. Innumerous examples illustrate this: from a simple kettle whistle indicating boiling water to Smartphone with constantly expanding functionalities; different accessories that regulate our well-being and monitor our health; and even smart refrigerators that guide our actions and help us incorporate new habits. If designers are in charge of developing interactions between human beings and their daily artifacts, design means generating modes of action in human beings based on their experience with the designed world. And if generating modes of action means imprinting memories and learning in the neural circuits of our conscious mind, design also means developing contexts [12], i.e., configuring subjective aspects of our being in the world.

In relatively recent studies of molecular biology or neurobiology, Kandel [5] elucidated neural reactions triggered by different patterns of sensory stimuli, which favor the assimilation of knowledge and its storage by studying the neural circuits of *Aplysia californica*. In his investigation, Kandel [6] assumes that there are several forms of learning produced by different stimuli patterns and combinations, and these variations originate differences in memory storage. Different stimuli patterns and combinations also potentiate the creative processes in design, and the creative action is a result of variations in such stimuli in our sensitive perception. Several studies have demonstrated

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that acquired experience influences esthetical judgments, and using functional magnetic resonance imaging (fMRI), they have also demonstrated the modulation of neural activity in memory and perceptual information processing-associated brain areas of specialized professionals [7].

Although contemporaneous design is the producer of the things that we interact with on a daily basis and that determine the context we live in, it is also responsible for the creation of other modes of existence, which make up the future. Designers should be sensitized through dissociative sensory stimuli to potentiate sensitive configurations that are able to generate creative practices to redesign our perceptions.

2 Cellular Neurobiology and Behavior

2.1 Memory and Learning

In his book "In search of memory," Kandel [5] established five principles that underlie the studies of neurobiology or science of the mind, seeking to elucidate the functioning of the human mind through molecular biology. The first principle is to consider mind and brain as inseparable. The brain is a complex biological organ, responsible for both simple motor behaviors and for acts considered as superior, such as speech, consciousness, and creation. From this point of view, the mind is considered as a set of complex operations performed by the brain. The second principle declares that specialized neuronal circuits perform mental functions in the brain and that these circuits occupy, spread out, or travel to several brain regions. Therefore, there is not a unique brain region that performs mental operations. The third principle states that nerve cells are the elementary signaling units of all neural circuits. The fourth establishes that neuronal circuits use specific molecules for generating signals within and between nerve cells. Finally, the fifth principle states the ancestry of signaling molecules because some of them were conserved over billions of years and were already present in the cells of our earliest ancestors.

Unicellular organisms, such as bacteria and yeast, and simple multicellular organisms, such as worms, flies, and snails, use the same signaling molecules used by humans to organize their maneuvers in the environment, in the governance of their daily lives. According to Kandel [5], the new science of the mind helps explain how we perceive, learn, remember, feel, and act. Besides, it establishes a new perspective of human biological evolution because the human mind has evolved from molecules utilized by our most humble ancestors, and the extraordinary conservation of molecular mechanisms that regulate many vital processes also applies to our mental life.

Because of the overwhelming desire to understand the human psyche, Kandel focused its studies on the nerve cell, the neuron, for it is the key to understand brain function. Every living organism, from the simplest to the most complex, consists of the same basic units, the cells, which have specialized functions, although they have common biological traits. Liver cells, for example, play digestive functions related to metabolism, while nerve cells process information and communicate with each other in a particular manner, forming complete circuits that carry and transform information. The human brain has approximately 100 billion nerve cells, and their specific functions

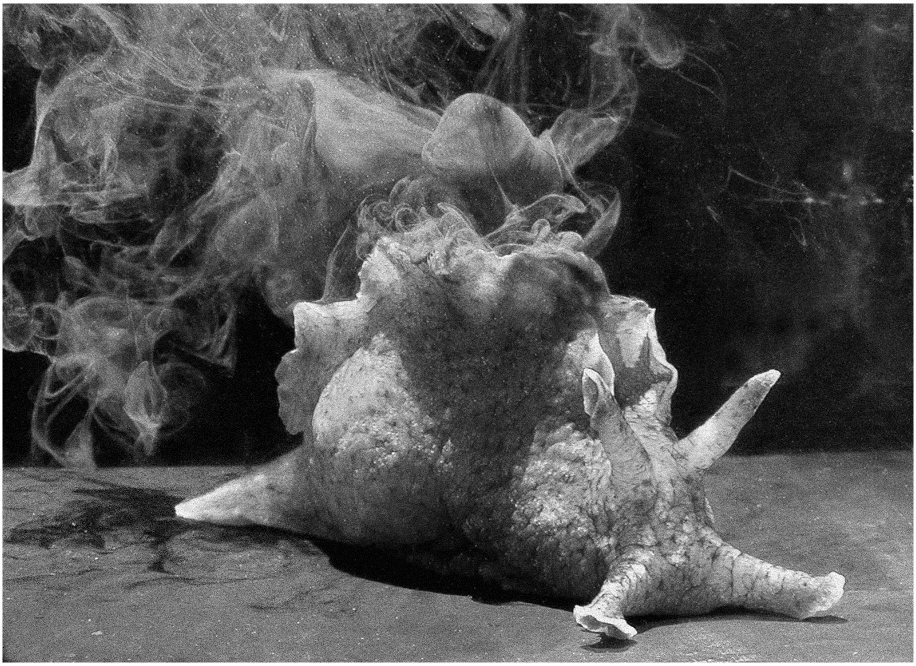

Fig. 1. Aplysia *californica.* (Source: Wikimedia commons).

do not reside within particular neurons themselves but in the connections between other cells within the neuronal circuit to which they belong. To explain determined mental processes by studying individual nerve cells, Kandel intended to analyze memory and learning using *Aplysia californica* (Fig. 1), a giant sea slug about thirty centimeters long. Its brain contains 20 thousand neurons grouped in nine separated clusters or ganglia. As each ganglion contains a relatively small number of cells, researchers can study single cells alterations so as to isolate ganglia-controlled behaviors.

But what is the reason for focusing research on memory and learning? According to Kandel [5, 6], our ability to acquire and store from the most simple to the most complex information is one of the most extraordinary aspects of human behavior. Memory provides continuity to our existence when it articulates past, present, and future. Without memory and the sharing of acquired knowledge, human cultural, artistic, and technological development would not have been possible. The entire process of retaining, storing, and retrieving acquired information starts in our cells, and it is subjected to both the information transmitted genetically throughout human existence and to everyday life experiences.

2.2 A Cellular Experiment

Back to *Aplysia californica.* Because *Aplysia* have some of the largest nerve cells of the animal kingdom that are visible even to the naked eye, its study allowed the mapping of individual neural cell connections, enabling the formulation of the exact wiring diagram of a behavior. What does that mean? Individual nerve cells generate action potentials—electrical signals that propagate over long distances inside the cells. Communication between cells, the synapse, consists of a physical–chemical interaction: electrical signals are translated into chemical signals in signaling cells; conversely, chemical signals are translated into electrical signals in receptor cells. Action potentials are "key signals" for information transmission on thoughts, emotions, and sensations from a brain region to another. When Kandel formulated a wiring diagram of a behavior, he recorded neural pathways of the electrical activity from an *Aplysia* nerve cell in a controlled manner and was able to verify synaptic alterations according to different applied stimuli patterns.

Kandel assumed that there are several modes of learning created by different stimuli patterns and combinations, and their variations cause differences in memory storage. According to Santiago Ramón y Cajal (1852–1934), the Spanish anatomist who formulated the basis for modern thinking on the nervous system, knowledge acquisition, or learning alters the strength of synaptic connections between neurons. Kandel structured his research in the reformulation of Ramón y Cajal's theory because for Cajal, learning is the result of a single process. When Kandel realized the multiple forms of learning, he proposed to study how and when changes in the synaptic connections occur and how they are modified by different stimuli patterns that generate differences in memory storage. To structure his study, Kandel considered Brenda Milner's studies on memory and translated Ivan Pavlov's behavioral protocols into biological protocols.

2.3 Neural Analogues of Learning

Pavlov established three reflex learning patterns from instructions about how a sensory stimulus should be presented to provide assimilation of knowledge. These are habituation, sensitization, and classical conditioning. Kandel transported this question into biology, seeking how different stimulation patterns created different forms of synaptic plasticity, an approach that he called neural analogues of learning. To achieve this, he proposed to simulate sensory stimulation patterns on *Aplysia* nerve cells, simulating different learning forms established by Pavlov. For the experiment, Kandel dissected the *Aplysia's* abdominal ganglion, which contains 2000 nerve cells, and introduced microelectrodes in one of them. Then, he recorded the cellular responses to various stimuli sequences applied in neural pathways that converged to this specific cell.

It is required to present Kandel and his team's experimental procedures and results, even if briefly, so that we can understand how the research works. First of all, it is important to note that the neuron is composed of three components: the cell body, which consists of the nucleus and cytoplasm; the axon, which is a unique extension of the cell body through which the impulses that transmit information from the neuron to other cells travel; and the dendrites, numerous extensions that receive stimuli from the environment, from epithelial cells or from other neurons [10]. To specify a neural pathway is to produce stimuli in a bundle of axons that will transmit the information to a specific cell.

2.4 Protocols: Habituation, Sensitization, and Classical Conditioning

On the procedures and results. A weak electrical stimulation produced by a particular neural pathway, if repeated ten times, causes cell synaptic potential to gradually decrease. In other words, reflex learning through habituation weakens the response to the original stimulus. When the stimulus is interrupted for a certain period and subsequently applied again, the cell responds back with almost its original strength. Habituation, in its simplest learning form, provides both the possibility to disregard recurring useless stimuli, which may hinder our attention to new things and to anesthetize our perception of automatic and repeated everyday gestures. However, it always indicates a weakening of synaptic communication between neurons.

The sensitization protocol procedure consists of the application of two different unassociated stimuli in different neural pathways. Using the *Aplysia's* abdominal ganglion, Kandel applied a weak stimulus once or twice in the same neural pathway used for habituation experiments. The induced synaptic potential served as a parameter to the cell response at the end of the experiment. Then, a series of five stronger stimuli were applied in a different neural pathway. When the first path was stimulated again, the cell synaptic response had increased, indicating a strengthening of the connections. The strong stimuli series applied to the second pathway increased cell response potential to the weak stimulus initially applied. Kandel concluded that a non-associative form of reflex learning strengthens synaptic connections.

In the classical conditioning protocol, two stimuli were also applied but this time in an associated manner. Repeatedly, a weak stimulus applied in a neural pathway was followed by a strong stimulus applied in another pathway. The cell understands that, by receiving the first one, it must prepare for the second, which means a synaptic potential increase for the weak stimulus. However, synaptic connection strengthening depends on the pairing of two stimuli. What differentiates the classical conditioning from the sensitization protocol is the fact that the non-associative learning form that occurs in sensitization potentially enhances responses to stimuli in general and not only in relation to paired stimuli.

Interesting fact: a giant-sea slug, with no brain or mind, responded with precise behavior to stimuli provoked by scientists. It is rather curious, particularly for us, who are lay in molecular biology, to think that our cells behave similarly and to think how it is possible that the complexity of our conscious mind result from neuronal circuits generated in simple biological structures like those of *Aplysia*. This is, however, precisely the challenge of biology of the mind scientists.

The evidence of synaptic plasticity showing that synaptic strength can be easily modified from different patterns of activities suggests that learning changes the flow of information in neural circuits [5, 6]. Faced with a synaptic strength that is strengthened or weakened, by different stimulation patterns, one can glimpse how the consolidation of a memory can anatomically change our cells. Research on *Aplysia* defined the biological basis of learning and memory and, therefore, defined the relationship between the functioning of neural systems and the modes of action that engender behavior.

2.5 Types and Forms of Memory

All processes of learning and memory begin on working memory. Its specificity is fleetingness and its function is the management of immediate reality. It is similar to saving a phone number that will be used and forgotten soon after. Working memory is processed in the prefrontal cortex, which is connected to brain regions linked to mood, consciousness, and emotions [4]. This is the reason why emotional states influence our attention and disturb the working memory, changing immediate responses that put us in action. Although working memory lasts seconds or a few minutes at the most, it is also articulated to existing memories to decide whether the newly acquired information is useful, if there is any relation with past experience, or any record indicating that it is worth a greater attention to retain the memory. Temporal parameters differentiate short- and long-term memories.

Short- and long-term memories are defined on the basis of information consolidation, i.e., the more consolidated is the information received, the greater is its duration. According to Kandel [5], information that persists had to be processed in a comprehensive and/or deep way, and this occurs through attention and significant and systematic associations of the acquired knowledge. Biologically speaking, short- and long-term memories occur in different anatomical sites and trigger chemical potentials differently. Short-term memories alter synapse function, unlike long-term memory, which anatomically alters the cell [6]. A short-term memory lasts a few hours (or even seconds), is stored only as long as required, and then may be discarded or acquire relevance and be transformed into a long-term memory. Izquierdo [4] compares short-term memory with temporary accommodation, whereas long-term memory is our own home.

There is not a unique brain area where our memories are stored, as there is not one brain region that performs mental operations. Our memory is spread in a fragmented fashion throughout the various brain areas. When we recall a beach evening with friends, for example, each of the recalled sensations activate its corresponding cortical area: the smell of the sea activates the olfactory areas; the images of landscape or people activate the visual areas; the sound of the waves activate auditory areas; and the emotions felt activate the amygdala (complex cell nuclei responsible for the emotional tone of lived experience). The hippocampus, a cellular structure located in the temporal lobes, is essential for memory; however, there is nothing stored there; this region is only the key to connections [11].

When we focus on information content, memories are called declarative or procedural. Declarative memories can be episodic or semantic and relate to events and general knowledge. Procedural memories refer to the memories acquired by motor or sensory abilities, being closer to habit reflex learning, and are confirmed in action [1, 4]. There is no point in stating one has the memory of knowing how to drive, one just simply drives. Memories are also considered explicit or implicit, according to the degree of awareness one has of them.

Memory systems are not static; therefore, episodic memories blend with semantic memories, and explicit memories become implicit in time. Mother tongue, for example, is an unconsciously acquired semantic memory and is therefore implicit, but declarative. Driving depends on a conscious (explicit) learning that becomes a habit, an automatic action, and therefore a procedural memory. Scrambling of memory types is a result of the involvement of multiple neural network circuits on the learning process and storage of our memories.

Understanding the cellular basis of human behavior opens up a vast research field for teaching and learning creative processes within design. A design focused on the subject and its mode of existence, which aims at the required transformation of social behaviors so that we can envision a more sustainable collective future life on the planet.

3 Creative Minds

3.1 Create: Rearrange to Formulate Other Senses

Our state of consciousness, in its different levels, is the condition of our existence, and is essential to our survival [2]. Consciousness is the creator of the manifested senses in our sensitive perceptions that occur in the approximation to the world around us, and there is an increasing number of experiments about the neurobiology of perception [3], such as brain activity monitoring (electroencephalographic recordings) during a visit to a conceptual art exhibition [8]; evidence of neural activity modulation in brain areas associated with memory and processing of perceptual information in the neural circuits of architects faced with visual esthetic judgment [7]. Our subjectivity is being investigated in laboratories using more sophisticated and less invasive technologies. Neurobiology studies samples, records, monitoring, and infers operating modes of mental circuitry, but what are the acquired and stored data that will be analyzed in these studies? What are the possible correlates between brain functioning and creativity teaching? How to enhance creative processes from understanding neurobiology?

Our mind responds to learning protocols just as our cells, i.e., several non-associated stimuli, as in sensitization, potentiate creative processes. The repetition of the same, as in habituation, weakens the synaptic connections anesthetizing our attention. This is why habit is the greatest enemy of creation. Classical conditioning is limited because it depends on presumed data, although it increases synaptic potential.

Creativity is inherent to human beings; however, it depends on the content learned and how we are encouraged to process the information received. To teach someone how to expand their creation potential means to develop strategies to sensitize perception and keep it in a permanent state of alert.

3.2 Visual Graphics Parameters

The translation of learning protocols into graphic materials allows us to clearly illustrate our attention focus on a given image. For this, we use a modular creation exercise,[1] matching the organization of a fixed element within a larger framework [9]. This type

[1] This exercise was applied, in its many variations, during the 20 years I taught design at Mackenzie Presbyterian University (São Paulo–Brazil), producing a significant sampling of the presented analyzes.

of exercise is widely used in the basic disciplines of design degrees and is fundamental for the creation of patterns in the area of surface design.

The starting point is an abstract plateau (Fig. 2), drawn from a plant picture fragment, a black figure inside a white square background. Rather, it is not exactly a background because the figure touches the square edges, making the form and the resulting counter-forms change their roles to the extent of our attention. This is a well-known relation within *gestalt* laws and a completely studied phenomenon proven by recent neuroscience research on visual perception. Our visual perception prioritizes either; we cannot perceive shape and counter-shape at the same time.

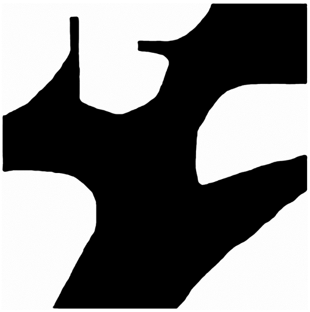

Fig. 2. Standard module (Source: Personal archive)

In the first example (Fig. 3), the composition of the standard module is organized by repeating the same protocol, as in habituation. A single stimulus is repeated many times. When we glanced at this image, we understood its *modus operandi* and lost interest because we realized that there would be no change in its sequence. It can be repeated to infinity.

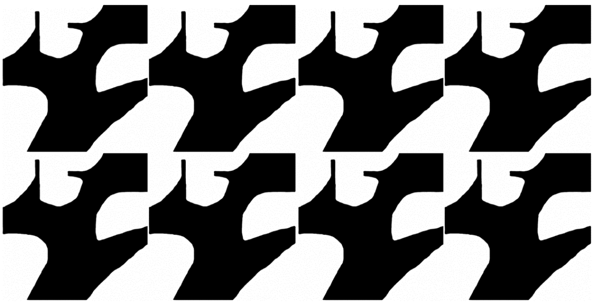

Fig. 3. Module A – habituation (Source: Personal archive)

In the second example (Fig. 4), the structure of the composition is not so evident. There is a system but it takes a closer look to realize the assumption of the compositional organization. Following the standard modules sequence, we realized that repetition was composed of two identical and one different (90° rotation) module. Stimuli are paired as in classical conditioning protocol because for every two modules, one is rotated. It is a more stimulating image than the first example because there is a greater variation of resulting counter forms.

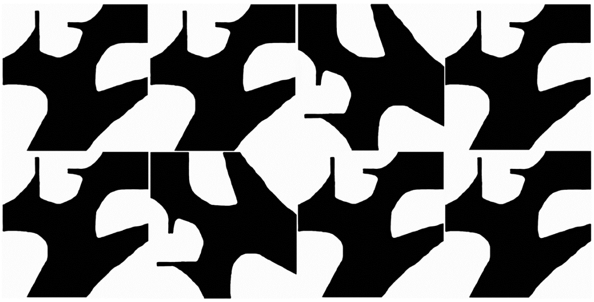

Fig. 4. Module B – classic conditioning (Source: Personal archive)

Finally, the composition from the third example (Fig. 5) is organized in a random manner by repetition of what is different. The default module rotation does not follow a fixed sequence and the composition of the whole results from small choices given by each square position within the compositional mesh. Gaze scans the image and grasps infinite possibilities of articulation of a single standard module. The multiple visual stimuli this image offers sharpen our perception. As in sensitization, we remain alert, as we have no idea of what will be the next step; we do not know what will the picture path follow. In this case, the strength of the resulting counter-forms is even greater.

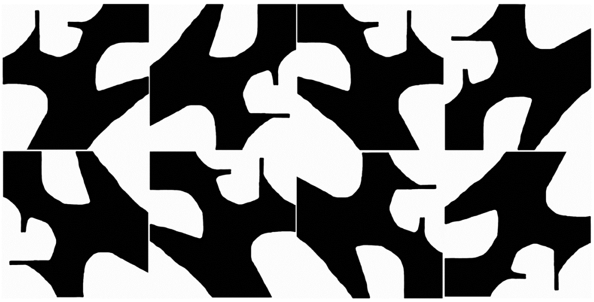

Fig. 5. Module C – sensitization (Source: Personal archive)

It is important to note that we are not talking about esthetic judgment or "beauty" parameters; our analysis mainly aims at the strategies and procedures that encourage sensitive perception as fundamental to the formation of creative minds that are able to alter given points of view to experience the potential of risk. Another important point is that the proposal focus does not reside only in achieved visual results. Instead, performing processes and critical analysis of the image are as important as the result.

4 Creative Process in Design

Contemporary design is beyond the act of giving a new, efficient, and beautiful appearance to chairs, household items, cars, packaging, books, or even add a formal veneer to intrinsic features of objects so they better respond to current market and sale teams or to produce and consume even more. Designers are social innovators directly responsible for everyday interactions among humans, their artifacts, and their surrounding environments. Thus, the issues raised by contemporary designs are based on the forms of existence; on social behaviors required to better live in a more sustainable world. Therefore, designers design contexts and consequences [12].

The expansion of the meaning of design turns its creative process into a much more complex task than responding to given problems or formally elaborating artifacts that make up our visible environment. To design today is to configure the sensitive aspects of our existence. This requires that designers have a more comprehensive training and a high creative potential to question prevailing demands. It is worth mentioning the following: it is about knowing how to discuss and not only respond to pre-existing problems [13].

Creation exercises, performed from the sensitization protocol, are essential for the consolidation of creative memory. As already mentioned, habit is the greatest enemy of creation; paradoxically, one must get used to being creative. The consolidation of sensitive perception learning, such as the consolidation of any learning, requires attention and significant associations to make processed information relevant. It is to transform the creative process, which is dependent on a conscious explicit learning (declarative memory), into a habit, an automatic and, therefore, implicit action (procedural memory). It is to learn how to get used to withdrawal. It is the repetition of different. After all, to create is to reorganize for developing other senses.

5 Conclusion

Several years of investigation with *Aplysia* defined the biological basis of learning and memory and consequently defined the relations between the functioning of neural systems and modes of action that generate behaviors. The emergence of creative minds involves an articulation between cognitive processes, emotions and our sensitive perception, and different brain regions are recruited to handle the task. And sometimes it is important embracing the messiness of the creative process for daydreaming, to loosen the ordinary associations, allow your mind to roam free, imagine new possibilities, and silence the inner critic.

Life never favors inanition; therefore, we are both designers of ourselves and designers of a designed material world that strongly needs our sensitive perception to experience life to its fullest.

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