Visual Information Design in Virtual Environments and Its Importance in Cognitive Load and Learning

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Abstract: ***The possibilities offered by digital tools for visualization, distribution, and storage of educational resources, as well as for interaction and communication between professors and students, are broadly acknowledged. However, the role of graphical user interface design in digital educational environments has still not been sufficiently valued. In this paper, we support the idea that the arrangement, distribution, and visual attributes of graphic elements (i.e., what in the field of art is called composition) in the design of the graphic interface of educational environments is not only a matter of aesthetics. It also results in better understanding of the educational message and in a significant reduction of cognitive overload in the learning process. The relationship between visual stimuli and cognitive processes that favour learning is highlighted.***

Keywords: Information Visualization, Virtual Education, Visual Design, Cognitive Learning, Cognitive Load

1. Introduction

Due to the current importance of technological resources in educational activities, and the growing use of virtual environments, we emphasize the significance of using design criteria in the visual presentation of information. We believe that this is a determinant factor in the process of educational achievement and learning.

It is clear that our current society is demanding more efficient and higher-quality teaching and learning processes; however, this requires a coordinated convergence of the different knowledge areas engaged in the development of learning environments. Nevertheless, the use of technology by itself does not guarantee the effectiveness of the educational process, nor does it improve learning. While technology makes communication possible and thus advances the educational activity, the effectiveness of the cognitive process depends, to a great extent, on the choice of pedagogical and didactic strategies, as well as the visual design in which the information is displayed. This work is focused on the latter point, as we are confident that the design of information visualization has a major impact on learning even though it is often overlooked.

A large proportion of virtual education is usually an asynchronous and offsite process, in which the teacher is not physically present and there is no direct and immediate feedback to support the proper interpretation of the presented information. This differs from how it occurs in a traditional education setting, in which the teacher is face to face with the learners. Currently, virtual learning environments provide us with easier access to information, favouring the learning process. However, the transmission of knowledge no longer relies solely on the professor's ability to explain the content, but in this context, the visual design of the information takes on a prominent role.

In this regard, Mazza (2009) states that "what we are witnessing, in reality, is not an explosion of information, but rather an explosion of data, which we are continuously pressed to observe, process, and develop, for our family or work activities" (p.9). He describes it as a continuum that goes from data presentation to comprehension and understanding, explained through four stages, as shown in Figure 1:

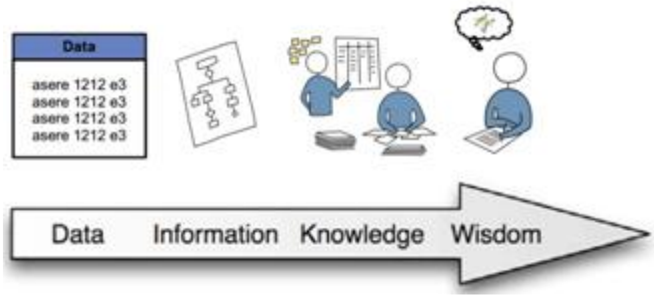

Figure 1: The continuum of understanding, according to Nathan Shedroff (Mazza, 2009, p. 9).

1) Learning as a cognitive process

Learning has been interpreted in many ways over the course of history. From Plato's time to the present day, numerous approaches and explanations of what it means to learn have been developed. However, it has only been since the rise of psychology as a scientific discipline that the learning processes have been explained in a moresystematic and organized manner. In this regard, the overall debate has, for a long time, revolved around two opposite approaches: the first one defines learning as an observable behavioural change (behaviourism); the second one assumes learning as a change in the individual's mental structures (constructivism). This latter approach is based on cognitive science and, for the moment, is the paradigm that has been better able to explain how people construct and acquire knowledge.

In general, the cognitive theory has been developed according to two main aspects: an explanation of the genesis or "construction" of knowledge (as the formation of concepts or categories) and the organization, storage, retrieval, and application of knowledge (in problem solving).

In this regard, a distinction can be made between *learning theories* and *instructional theories*. The former tries to explain how knowledge is acquired and concepts are formed; the latter focuses on defining learning strategies. Within the realm of instructional theories, we can find those of Ausubel, Bruner, and Glaser, while the writings of Piaget and Vygotsky are located within the area of learning theories, properly speaking.

To be able to better understand the importance of the visualization of information in learning, we must resort to the genetic theory of knowledge developed by Piaget, which is still considered to be one of the best theories to explain knowledge acquisition. The reason for this is explained by Ferreiro (1999), who points out that "Piaget deals with the nuclear, core part of the learning process: the processes of knowledge acquisition" (p. 84). According to Piaget, learning occurs through a process called *equilibration*, which he defines as a natural and innate tendency of individuals to modify their mental schemas and provide coherence to the perceived environment. The *equilibration* process in turn triggers two other complementary processes: *assimilation* and *accommodation*. *Assimilation* is related to the reception of new information and *accommodation* to the changes generated in the structures in response to this process.

Innovative instructional theories on learning were generated from cognitive theories, such as the one proposed by Ausubel[1] focused on meaningful learning and Bruner's theory[2] on learning by discovery.

Bruner states that students construct their new ideas or concepts from the selection and transformation of information, generating hypotheses, and making decisions; Nickerson's[3] proposal focuses on how to teach thinking and learn to learn, supported by strategies such as concept mapping by Joseph Novak; and Bandura's[4] social cognitive theory, among others, demonstrates how the individual's behaviour plays an important role in learning.

Piaget's ideas regarding learning are still accepted today and confirmed by neuroscience. Castro Montero (2009) points out that

> Advances in the field of cognitive neuroscience have reaffirmed one of Jean Piaget's most important conclusions: that learning in humans and other mammals is generated through the reorganization of their cognitive structures as a consequence of adaptive processes to their environment. With modern medical technologies (e.g. fMRI, PET, and EEG)[5] and contributions from multiple brain injury studies, it has been possible to determine how and where the brain assimilates and accommodates information. (p. 1)

In broad terms, cognition[6] can be seen as the skill we have to assimilate and process data from different pathways such as perception, experiences, and beliefs within knowledge. Cognition encompasses different mental processes such as attention, memory, language, reasoning, decision making, and learning.

Bates (2019) explains how we construct knowledge from our perceptions. This action involves an important process in which we construct knowledge instead of "simply acquiring it via memorization or through transmission" (p. 82). Through these cognitive processes, we assimilate and relate the information to our prior knowledge, thus achieving knowledge and understanding (p. 82).

In this process, we should not lose sight of the very significant role played by the perception of information and, with it, the relevance of how the information is displayed. That is why we must be aware that "When a teacher tries to impart content to a class-group, he/she is not only instructing regarding what about the content (concepts, procedures, principles and/or values) but at the same time, he/she is showing how to deal with and how to present/represent this content to be learned" (Monereo, 1990, p. 6).

Thus, learning involves complex cognitive processes in which perception and the way information is presented are relevant. In this process, meanings and the relationship between concepts must be treated carefully in order to improve comprehension. In this respect, Schank (in Monereo, 1999) distinguishes three levels of the comprehension of information and describes these levels as

> a first level consisting of making sense, that is, the ability to explain the information with other words; a second level, which he calls cognitive comprehension, in which the subject extracts the structure or rule that underlies the information and can apply it to parallel examples; and a third level, which would correspond to deep learning, in which the subject adds personal experiences and emotions, generating new information, and which the author calls empathic comprehension. (p. 7)

The main functions involved in cognitive processes are perception, attention, memory, and thinking or reasoning. It should be noted that although language is not considered a cognitive process, it is the tool that allows us to express what we have learned. These cognitive processes help us to

[1]David Paul Ausubel, American psychologist, author of several books on educational psychology, including *School Learning: An Introduction to Educational Psychology* (1969) and *Educational Psychology: A Cognitive View* (1968).

[2]Jerome Bruner, American psychologist, author of works including *The Process of Education* (1977) and *Acts of Meaning: Four Lectures on Mind and Culture* (1990).

[3]Raymond S. Nickerson, American psychologist, author of many books about critical thinking, such as *Teaching to Think* (1985).

[4] Albert Bandura, Canadian psychologist, author of the book *Social Foundations of Thought and Action: A Social Cognitive Theory* (1986).

[5]In the study of brain functions, techniques and tools that provide brain imaging are currently used and are often represented by acronyms. Thus, fMRI stands for Functional Magnetic Resonance Imaging, PET stands for Positron Emission Tomography, and EEG refers to Electroencephalography.

[6] The term "cognitive" refers to knowledge, and the term "cognition" is the ability to know.

incorporate new knowledge through the interpretation of information so that we can later make decisions about it.

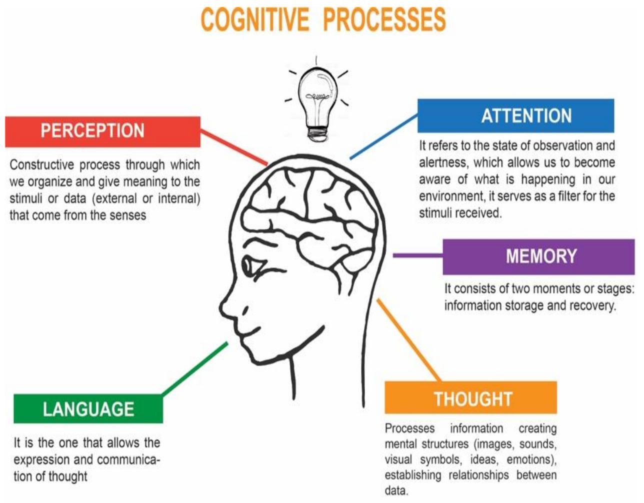

Figure 2: Diagram of cognitive processes according to Klinger and Vadillo (2000). Elaborated by María Teresa Olalde Ramos.

Cognitive perception allows us to organize and understand the world through the stimuli we receive mainly through the five senses.

Attention is a cognitive process that enables us to focus on a given stimulus or an activity, in order to process it more deeply in consciousness. But it is also considered the controlling mechanism for regulating the remaining cognitive processes, from perception to learning or complex reasoning.

Memory is the cognitive function that allows us to encode, store, and retrieve information about experiences or previous knowledge. It is a basic process for learning and is what allows us to create a sense of identity.

Thinking is a key function in all cognitive processes because it enables the integration of all the information that is received (*assimilation*) and establishes relationships between this information and previous knowledge (*accommodation*). For this purpose, it makes use of reasoning, synthesis, and problem solving, that is, of the executive functions, which, according to Robert J. Sternberg (1989), carry out actions to achieve established purposes.

2) Memory in the educational process

Learning is not possible without memory, which is the capacity of an individual to react based on the information they have previously acquired. Memory is not a simple passive process of receiving information; it is an active process based on the mental resources we have, because in order for this information to be used, it must be retained to be used again. Newell and Simon (1972) report the existence of a human system of information storage and usage formed by long-term memory and short-term memory. According to such a model, the human mind receives information, processes it, stores it, and generates a response. The processing is started through the sensory registration of stimuli coming from the environment. This information is selected and filtered by attention and perception mechanisms. Thus, only a portion of the information is codified and carried to short-term memory. In this sense, Woolfolk (2016) points out that stimulus from the environment (input) flow into the sensory registers, one for each sensing modality (seeing, hearing, tasting, etc.). From there, some information is encoded and moves to short-term memory. Short-term memory holds information very briefly, combines it with information from long-term memory, and with enough effort, moves some information into long-term memory storage. (p. 319)

Figure 3 shows a graphical representation of the memory system in human information processing.

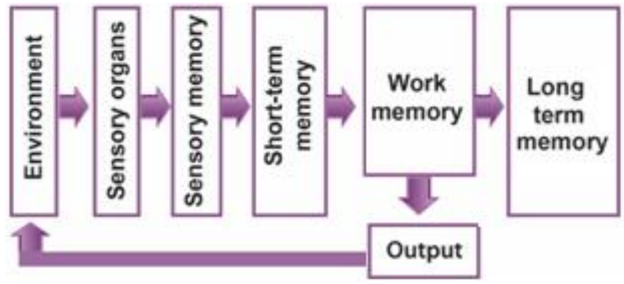

Figure 3: Diagram of the Bruer and Estes memory system Created by María Teresa Olalde Ramos (2017), based on Klinger and Vadillo (2000, p. 60).

Learning involves complex cognitive processes, in which several factors are implicated, such as *long-term memory*, *short-term memory*, *working memory*, *previous knowledge*, and, of course, how information is displayed. Mayer (2014) points out that to facilitate learning it is essential to reduce what is known as *cognitive overload*. *Cognitive load* is defined as the processing capability of the working memory involved in cognitive activities. According to Mayer (2014), "Reducing extraneous cognitive load frees working memory capacity and so may permit an increase inthe working resources devoted to intrinsic cognitive load, increasing germane cognitive load" (p. 38).

Based on the above, it is clear that the cognitive process starts with the sensory organs' activation. In the context of multimedia educational materials, visual perception is relevant. In this way, the relevance of the display of information visualization in educational materials design becomes obvious. The design of virtual spaces for learning requires clear guidelines that enable optimal performance, ensuring efficiency in the handling of information within the learning environments, and the use of clearly established didactic strategies based on recognized educational theories.

In this sense, what we propose is the *design of information visualization* based on principles supported by the approaches and contributions arising from three fields of knowledge that interact in the process. These fields, represented schematically in Figure 4, are:

- *visualization of information (*concepts, relationships, graphic attributes, data, etc.);
- *education* (learning theories, instructional theories, didactic strategies, etc.); and
- *communication design (*visual features, usability, semiotics).

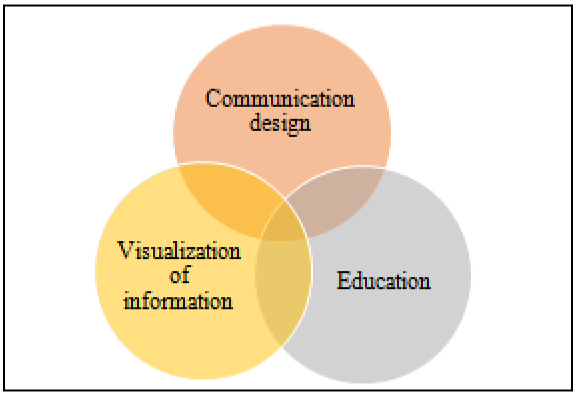

Figure 4: Fields of knowledge linked to the design of virtual learning environments.
Source: Own creation

The role of memory in the cognitive process is schematically represented in Figure 5.

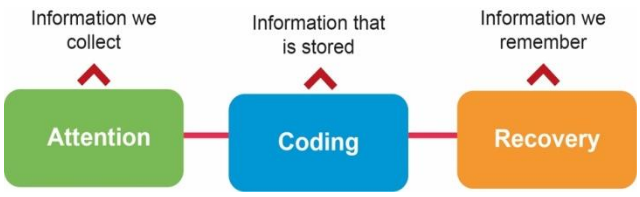

Figure 5: Cognitive process and memory. Own creation according to https://sites.google.com/site/pedagogianunez/elementos-fundamentales (May 28, 2022).

Although memory is in charge of retaining and retrieving information, there are different types of memory that, although involved in the process, do not function in the same way because they have different levels of information storage.

It is worth mentioning that the brain is our learning organ, which works as a dynamic processor of information. Our brain is constantly searching for meanings, which have great importance in the process of decoding information. This is indispensable to achieving the adequate retention of information, and the storage in memory.[7] According to Kruse (1998), "learning is a 'sociocognitive act' tying social interaction, cognitive processing, and language together in an interactive manner" (p. 75).

Zepeda (1994) says that "All human faculties are engaged in learning. Sensations, perception, attention, memory, conscience, intelligence, will, imagination, in short, all of them participate in some way in this fundamental process of the human being" (p. 176).Learning is not only about memorizing information; it also includes other cognitive processes that imply knowing, understanding, applying, analysing, synthesizing, and evaluating, among others. Cognitive processes determine our performance in mental or cognitive activities and enable thinking to take place, by making an effort and overcoming obstacles.

3) Perception and visualization of information in learning

According to the above, learning comprises several cognitive processes ranging from the perception of information, its comprehension, and interpretation to its subsequent storage in the memory. Perception is the process through which the brain processes the sensations or stimuli that it receives through the senses. Comprehension is a mental process through which the receiver creates a mental image to which he/she gives meaning from the data received. The process of interpretation is usually done unconsciously, although sometimes it can be consciously controlled.

It is impossible not to make interpretations of all that we perceive; everything is always interpreted, although interpretations could be different. This is because the interpretation of information is a personal and unique activity for each individual, depending on the internal data available to each person. Hence, the importance of using verbal and visual language adequate for people, according to their context, to improve their understanding of the information and learning.

Dondis (1974) says that "Language has held a unique place in human learning. It has functioned as a means of storing and transporting information, a vehicle for exchanging ideas, and as a way for the human mind to conceptualize" (p. 8).

Taking into account that virtual learning is strongly supported by the visual display of content, and based on the perspective of Bertoline et al. (1992), we can say that, in the learning process, the visualization of information is a fundamental factor in cognition. But what can we understand by information visualization? For Ware (2004), information visualization "is the use of interactive visual representations of abstract data to amplify cognition" (p. xvii). In the same sense, Kessentini and Jeffers (2020) say that the purpose of information visualization is "to transform a huge amount of data into a graphical representation to simplify the users' data analysis and understanding" (p. 420).

Achieving learning through virtual resources depends not only on the facility of access to information and the students' best intentions but also on many other factors that are involved in virtual learning and the development of didactic materials, as shown in Figure 6.

[7]Learning depends on the information that we can retrieve or remember as proof that we have learned, hence the importance of memorizing information. However, it should be noted that short-term memory saturation and cognitive overload can affect learning.

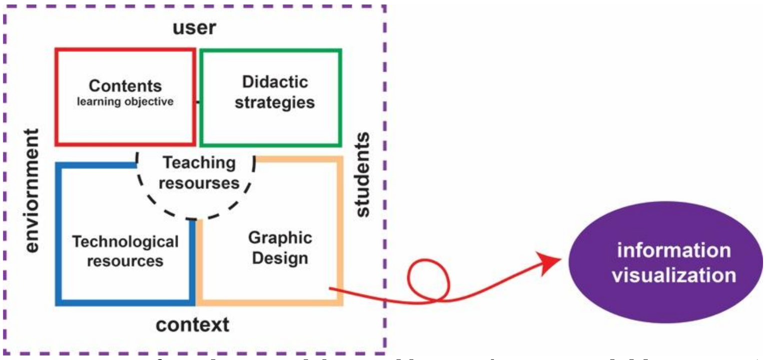

Figure 6: User interface design. Elaborated by María Teresa Olalde Ramos (2017).

While on the one hand we have the content and didactic strategies, on the other hand we have the availability of technological resources. Regarding these, we must be aware of the importance of interface design in the success of educational environments. This is where our work as designers of information visualization lies.

4) Role of Design in Learning

As we know, one of the fundamental functions of design is the handling of visual language, that is, of visual elements, their properties, and their arrangement in space, which is known in the field of art as "composition". As Casakin and Kreitler (2014) mention, "design education is marked by the intensive use of visual images, both imaginary and real" (p. 165).That is why the ability to handle form and image is recognized as part of the designer's training in general. And it is why Faimon and Weigand (2004) write that "Designers are essentially visual thinkers" (p. 11). This ability to handle such language is what distinguishes the designer, even though he or she is often seen only as the one responsible for "beautifying" a product. As Wong (1991) points out, "mere beautification is one aspect of design, but the design is much more than this" (p.5).The ability of the designer to handle visual language is widely recognized.

Dondis (1974), for his part, states that "The process of composition is the most crucial step in the visual problem solving" given that this process has "strong implications on what the viewer receives" (p. 20). Accordingly, measured analysis of each of the elements and their relative arrangement in the virtual space is required, in concordance with the educational intention pursued.

We believe that the composition principles in art and design (balance, symmetry, colour, proportion, contrast, etc.), which have been studied and applied by many authors in analogue environments are still applicable in digital scenarios, even though there are specific conditions that must be taken into account (such as those derived from the technical characteristics of the display device and software).

We must keep in mind that visual elements, along with their characteristics (colour, texture, proportion, size, etc.) and their placement in the interface produce specific sensations in the user (balance–tension or rest–stress, for example). These attributes may promote or inhibit the learning process. As Dondis (1974) points out, "Human visual experience is primary in learning to understand and respond to the environment" (p. 2).

Although there are no unbreakable rules for the design of an educational interface, this does not mean that the principles of composition and the basic language of the design of educational virtual environments should be ignored. All elements, empty spaces, and their spatial location should have a reason for being. Ambiguity in the arrangement of visual elements should be avoided (tension or balance, for example, should be clearly defined). The spatial arrangement of the elements should not be fortuitous, but the product of a specific and well-planned intention aimed at facilitating understanding and, above all, avoiding cognitive overload.

On the other hand, in an educational process, it is of key relevance to maintain the student's attention, with the purpose of not interrupting or interfering with the cognitive process of learning. In this way, we would be able to reach educational objectives optimally. In this sense, simplicity is a factor that plays in favour of the usability of educational environments. As Maeda (2006) points out, in the design of all kind of products, simplicity "has become a key strategic tool" (p. iv). In this context, the interaction and visualization of information for education is emerging as a strong action field of design. But it will be necessary to deepen the study of theories, methods, and processes on the design of human–computer visual interaction.

2. Conclusions

Since perception is the starting point of the cognitive process, the impact of information visualization on learning is obvious. As Mazza (2009) emphasizes, "The visual representations help us to illustrate concepts that, if expressed verbally, we would find difficult to explain clearly to a listener", adding that "When we have data with which we need to illustrate concepts, ideas, and properties intrinsic to that data, the use of visual representation offers us a valid communication tool" (p. 4).

The visualization of information not only considers the content of the message but also uses the visual characteristics in favour of the user. In this sense, design has a great deal to contribute, since graphic properties

> are very quickly and efficiently processed by visual perception. Visual attributes like color, size, proximity, and movement are immediately taken in and processed by the perceptual ability of vision, even before the

complex cognitive processes of the human mind come into play. (Mazza, 2009, p. 3).

In this sense, it is clear that design, as a discipline, is a strategic factor in the visualization of information and, therefore, in the learning process. However, cognitive theories and multimedia learning principles that are currently learning paradigms have not yet strongly emphasized the role of design and the arrangement of the visualization of educational information.

Piaget had already established the place of information in learning, based on the processes of *assimilation* and *accommodation*.

> Assimilation involves trying to understand something new by fitting it into what we already know. At times, we may have to distort the new information to make it fit.… Accommodation occurs when we must change existing schemes to respond to a new situation. If we cannot make new data fit any existing schemes, then we must develop more appropriate structures. We adjust our thinking to fit the new information, instead of adjusting the information to fit our thinking. (Woolfolk, 2016, p. 72)

In this sense, the design of information becomes relevant in learning. It is clear that the visual arrangement of information strongly impacts cognitive processes in such a way that it could facilitate its comprehension and interpretation, or it could produce cognitive overload.

It is necessary to keep in mind our responsibility as designers and strive to achieve a visual organization that will facilitate the cognitive activity of students. As has been mentioned, one of the main factors involved in the virtual educational process is the ease of access to information. We must ensure that the design of the user interface is based on a structure and navigation suitable for the user to allow him or her to concentrate on the content and not distract attention from trying to understand the continuity and sequence of the educational message.

Lastly, we would like to highlight three points to consider in the design of educational materials and virtual environments:

1) Ausubel's theory clearly explains the relevance of exposing the content in an organized and meaningful way for students. Here is where the pedagogical foundations define lines of action for the design of educational materials and virtual environments.
2) Learning is a complex process that involves the human processing of information. In this sense, visual design plays a fundamental role to avoid cognitive overload and motivate attention to the content that is relevant to the educational programme in question.
3) The visual arrangement of information plays a key role in the educational process. In this sense, simplicity and visual composition are the main factors to be considered by the designer. Let us remember that the process of acquiring and organizing knowledge is a complex cognitive activity, so any unnecessary visual element can distract the learner and interfere negatively with that person's learning.

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