# METAVISUALIZATION: AN IMPORTANT SKILL IN THE LEARNING CHEMISTRY

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## Abstract

*This paper is a theoretical discussion about three important concepts related with chemistry learning. The terms visualization, metacognition and metavisualization were reviewed in the literature, in regard to aspects of definition and importance as constructors of knowledge in science education, especially in chemistry. There is a stead growing body of research that recognizes the importance of being metacognitive in the learning process. Also, given the frequent use of visualization in chemistry instruction we began to encounter studies that suggest that metacognition in respect with visualization exits and it's referred to as "metavisualization". Particularly, this term has been perceived as a metavisual skill, where the student will monitor and regulate specifically their internal representations, helping him to build concepts in science. Many definitions have been found about these terms, however there seems to be a uniformity to consider its importance in the learning process of students, which allows us to conclude that there is still a great demand for research in this area to clarify many aspects regarding these cognitive and metacognitive processes.*
**Key words**: *metavisualization, metacognition, visualization, chemistry instruction.*

## Introduction

Historically, educational research has emphasized verbal learning while interest in visual learning has lagged behind. Visual literacy has been used as an interdisciplinary concept that includes theoretical perspectives, visual language perspectives, presentation perspectives, and technological development, including digitalization (Abersek, 2008). Nowadays, visualization tools and high performance computing have change the nature of chemistry research and have the promise to transform chemistry instruction. As the amount of information acquired through visual tools multiplies, the ability to understand, evaluate, and produce visual representations has become increasingly important in education. The visual thinking is essential to understand visual information and convert it into concepts (Bilbokaite, 2010).

Some authors (Ferreira & Arroio, 2009; Gilbert, 2005; Rapp & Kurby, 2008; Arroio & Honório, 2008) discuss several factors relevant to the visualization in science education, such as: understanding how the visual representation is transformed into knowledge, the importance of training mental models, skills in interpreting and processing of an image.

Chemistry teaching in structured models requires a very large capacity for abstraction of the students. Metacognitive experiences are placed between knowledge and metacognitive skills and are treated key link between an individual and a task as well as between monitoring and regulatory steps taken (Ledzinska & Postek, 2010). Accordingly, it is necessary that students have the metacognitive skill to visualization which we call in this work: metavisualization (see Figure 1).

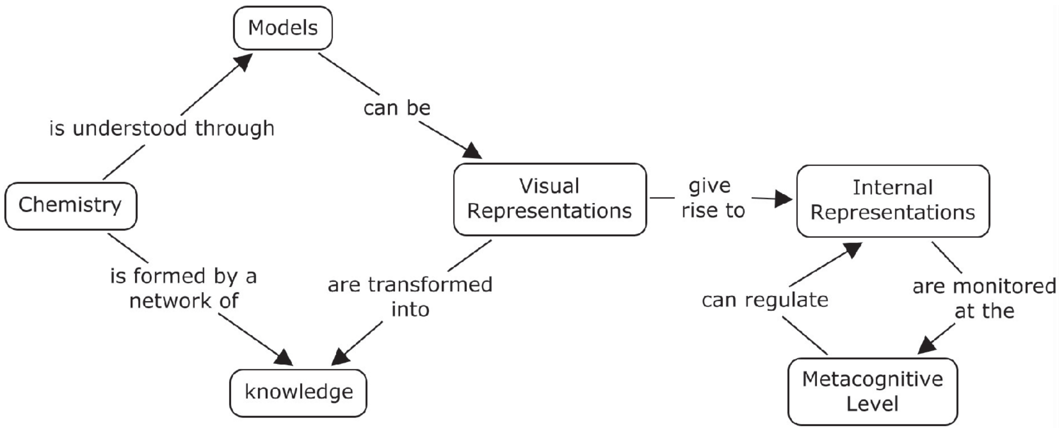


**Figure 1. Metavisualization skill in the construction of student knowledge.**

## Methodology of Research

The literature review was carried out in this article to aim to convey the reader what knowledge and ideas have been established on the metavisualization topic. Both in cognitive psychology as in science education. The articles were chosen more on conceptual issues and those that were related to science education, the keywords for selection were metacognition, visualization, metavisualization, visual abilities and science education. The performed steps of the literature review were done according to Taylor (2010):

- organizing the literature selection and review by relating it directly to the research focus, metavisualization;
- synthesizing results into a summary of what is and is not know;
- identifying areas of controversy in the literature;
- raising questions that need further research.

Metavisualization appears in recent works specifying metacognition in relation to the cognitive process of viewing.

## Results and Discussions

All these concepts – visualization, metacognition and metavisualization – have different meanings in the literature about psychology. Below we discuss each of them, based on literature review of these important terms in science education and in particular in chemistry.

### *Visualization*

Although visualization assumes different meanings according to the context, we can say that this term can have two different meanings: it can be used as a verb (to visualize) or a noun (visualization) (Gilbert, Reiner & Nakhleh, 2008). In the first case, the term visualization is the understanding of the meaning attributed to an internal representation. In the second one, visualization is an external representation that has been placed in the public realm in many forms (material object, visual, verbal, symbolic, etc.), and the mental representation produced by an individual from a visualization is an image.

But we found other usages for this term in psychology and educational research. According to Gobert (2007), there are three common academic usages of visualization: external visualization, internal visualization and as a type of spatial skill. In a simple way, we can say that visualization as an external representation refers to a representation typically used for learning (graphics, diagrams, models, simulations, animations, etc). These external representations have different characteristics, and thus different resources are needed for learners to attribute meaning. This approach is similar to what Gilbert, Reiner and Nakhleh (2008) referred as a noun (visualization).

A visualization as an internal representation is also used to describe internal mental representations, i.e., mental models used in mental imagery to solve problems. Furthermore, the internal representation can be information stored in memory that a person can restore, in addition to solve problems, to generate inferences e make decisions (Rapp & Kurby, 2008). This attribution is not consensual; there has been considerable disagreement among cognitive psychologists about internal visual representations in terms of their representational format (propositional/semantic or visual form) and their psychological validity.

Lastly, visualization is also used to describe a type of spatial skill. These two last attributions (internal visualization and visualization as a type of spatial skill) are more similar to what Gilbert, Reiner and Nakhleh (2008) describes as a verb (to visualize), to mentally act on a representation.

Each of these *types* of visualization described above appears with relevance on recent research in science education and it's important to note that these usages of the term visualization imply generally shared processes. For example, learning with an external visualization likely requires that one constructs a mental representation of the object or processes under investigation and this requires some spatial skills. So, we found in literature several studies that focus their attention generally on one of these *types* of visualization, but there are studies that cross these conventions for instance, studies about "visuospatial thinking" (Wu & Shah, 2004).

The studies that focus on visualization as external representations are trying to find out how we can best support learning with external representations and their role in science education. In research programs in which visualization is a verb, to visualize, researchers are concerned with the mental processes that are needed to learn from an external visualization and the knowledge acquisition strategies for acquiring information from complex visualizations in science.

When the spatial skills are the central topic of research, the important issues are: the role of spatial visualizations' skills on learning from external visualizations, what is the nature of these spatial skills and how could be developed.

So, the role of visualization in science and science education has been discussed in the last years in several studies, nevertheless research evidences are only in the beginning. There are more questions than answers; more research is needed to promote the effectiveness of this important resource (visualization).

### *Metacognition*

Cognition derives from the latin *cognitione*, meaning to acquire knowledge through perception. Metacognition is different from cognition, in its being necessary to understand how a task is performed, while cognition only requires that the task is made (Schraw, 2001). One may think that cognition helps the individual to achieve a certain specific purpose, while metacognition will try to ensure that the goal has been reached (Livingston, 1997), involving active monitoring and supervision of the task to be developed.

For example, a student may have the task of correctly represent some water molecules through a drawing (cognitive process) and shortly afterwards, thinking about their internal representation to just express your drawing or diagram (metacognitive); reflecting on how many links becomes the oxygen and hydrogen atoms, the geometry of the molecule, the hydrogen bonds and, therefore, he could maintain or modify the design done a priori, overseeing its initial objective, and that already gives evidence of the importance of metacognition in constructing of knowledge.

However, there are difficulties in defining the concept of metacognition (Larkin, 2006; Sandi-Urena, Cooper & Stevens, 2010; White 1988; Livingston, 1997), indicating that there is no uniformity in the literature of the term, because there are many meanings and understandings theme. Metacognition is often referred to in the literature as "thinking about one's own thinking", nevertheless we must consider the nature of metacognition is much more complex and involves various aspects.

Although metacognition has appeared in the works prior to the 1970's under other names, Flavell introduced in 1976 and defined what would be the metacognition, taking into account its various aspects *"...Metacognition refers to one's knowledge concerning one's own cognitive process and products or anything related to them..." pp 232.* Later, in the same page of the text, also adds the function of monitoring and regulation: *"…metacognition refers, among other things, to the active monitoring and consequent regulation and orchestration of these processes in relation to the cognitive objects…"* (Flavell, 1976).

From this definition Flavell, beyond the character's awareness of themselves as the metacognitive process, we can then recognize in the literature, three distinct aspects of metacognition: knowledge about cognition, the monitoring and regulation of cognition (Flavell, 1976, 1979; Tobias & Everson, 2002), all of them, being seen as important for effective learning (Davidson, Deuser & Sternberg, 1995; Flavell 1976).

However, in the definition of metacognition, the authors do not always consider the three aspects which can cause some confusion in the concept. Metacognition is *"…knowledge and regulation of one's own cognitive system…"* pp.66 (Brown, 1987), is not mentioned explicitly the monitoring function, remembering that this does not always lead to regulation, but could be a precursor to the more elaborate process of regulation, i.e., to discern what you know from that you do not know can help advance processes as more advanced metacognitive regulation (control) (Tobias and Everson, 2002) (see Figure 2).

And yet, some researchers such as Cavanaugh and Perlmutter, do not consider the regulation and monitoring nor its significance, considering only what the person knows, saying: "... inclusion of executive process as an aspect of metamemory is counterproductive, since it adds little to understanding of memory knowledge per se and heightens perceptual confusion..." pp 15-16 (Cavanaugh & Perlmutter, 1982).

Although, there is no single accepted definition of metacognition and there are many aspects to consider, even beyond those that were mentioned here, there is a strong recognition of its importance in learning (Cooper, Sandi-Urena & Stevens, 2008; Anderson, Nashon & Thomas, 2007). Accordingly, there is consensus that this ability may be an important ally in solving problems (Antonietti, Ignazi & Perego, 2000; Davidson, Deuser & Sternberg, 1995; Flavell, 1976; Rickey & Stacy, 2000; Cooper, Sandi-Urena & Stevens, 2008; Sandi-Urena, Cooper & Stevens, 2010). Studies also indicate the great importance of metacognition in special education environments, such as college or improvement programs (Davidson, Deuser & Sternberg, 1995; Sandi-Urena, Cooper & Stevens, 2010) in which an individual needs to control and self-regulate their learning, seeking innovative solutions.

When the student is able to express the ability of metacognition, he can enhance their learning, and knowledge about their knowledge, allowing its self-regulation leading to a broader learn to learn, gaining autonomy for future learning; ie, students who have effectively developed metacognitive skills can estimate their knowledge in several different areas, following its continuous learning, dynamically updating their knowledge and future planning new learning (Everson & Tobias, 1998). These same authors (Tobias & Everson, 2002) present the following pyramid as a hierarchical model of metacognition (see Figure 2):

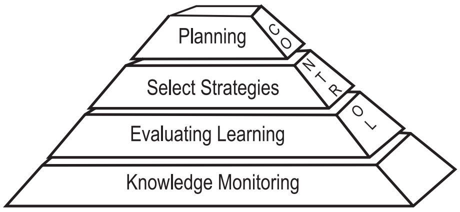


**Figure 2. A componential model of metacognition, Tobias & Everson, 2002, pp.1.**

At the base, we are monitoring the knowledge that can be considered a prerequisite for more advanced metacognitive processes can be achieved: evaluating, selecting strategies and planning knowledge. Tobias and Everson (2002) reported to be fundamental, first identify what the student knows from what he does not know, to move forward in the pyramid, ie, control and self-regulate learning. If the student is not able to make this distinction, he can not plan his learning.

You can finally say then, more broadly, that metacognition occurs when the individual plans, monitors and evaluates its own behavior in a cognitive learning environment (Ayersman, 1995).

For example, a given chemical problem is asked to calculate the enthalpy change of a certain chemical reaction. For this proposal, a table is provided in addition to the enthalpy of the products and reagents. The student needs to know first whether or not he understands what those concepts presented: chemical transformation, enthalpy and enthalpy changes associated with chemical reaction, because if he is unaware of these meanings, but knowing it, he can plan an effective way to solve the problem. Identifying what he knows or does not know about it, he would be monitoring his knowledge and could start planning for that point, selecting strategies and evaluating their learning constantly until reaching the proper resolution and to correct what has been proposed.

As the above reflections on visualization, so does metacognition with respect to a constant need for investment in future research because it is a relevant topic, very complex and still poorly investigated.

*Metavisualization*

Still in his article that defined metacognition, Flavell already proposed that cognitive processes could achieve a meta level: metamemory, metalearning or whatever (Flavell, 1976). Although he has not cited the visualization, it is a cognitive process as is learning or memory, think about it also refers to the meta level and that the suggestion of Gilbert, could be called metavisualization (Gilbert, 2005). We can understand the metavisualization, as it is a process to monitor and regulate the internal representation of the individual (see Figure 3).

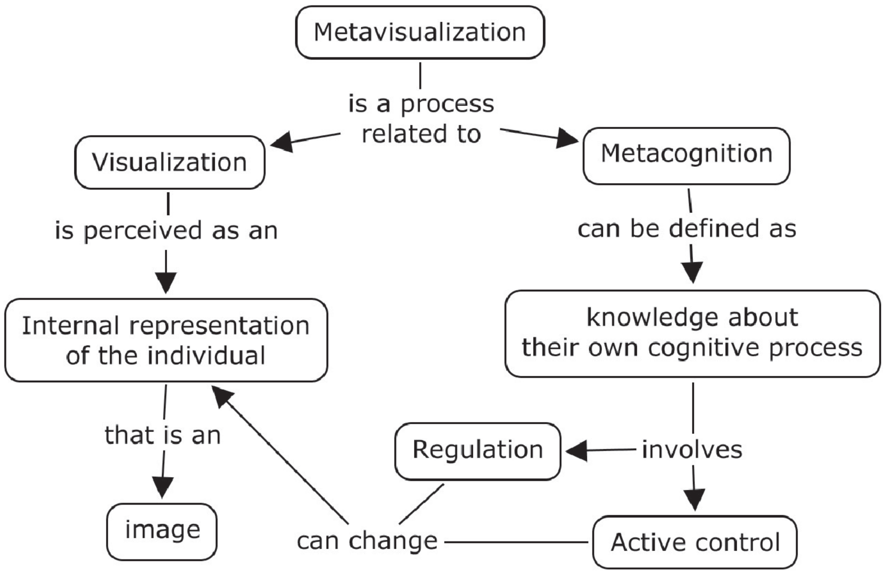


**Figure 3. Metavisualization – metacognition x visualization.**

Also according to Gilbert (2005), there are at least three metavisualization evidences that there must be:

The first is concerned with spatial intelligence proposed by Gardner in his theory of multiple intelligences in which presupposes the existence of at least seven types of intelligence: linguistic, musical, logical-mathematical, spatial, kinesthetic, interpersonal and intrapersonal (Gardner, 1985). Considering the spatial intelligence regarding the ability to perceive the visual world. Also according to him, all normal individuals possess all the intelligences at a basic level and they can be developed and enhanced under the influence not only genetic, but strongly by the environment with which the individual interacts. From this perspective, we can say it is possible for students to develop and improve the spatial intelligence, ultimately its metavisual capability.

The second evidence that Gilbert (2005) explains in the General Model of Memory proposed by Nelson & Narens, where we have two different levels of thought, which is the object level and the meta level. In this model, there is a flow to be followed in which the object level information leads to the meta level (monitoring) which exercises control on the object level (Nelson & Narens, 1994). By developing the metavisual ability, the student will become aware of monitoring, controlling the acquisition, retention, retrieval and modification of an image (Gilbert, 2005).

And the latest evidence reported by Gilbert (2005), believes that visualization is central in the thinking process. Therefore, it is essential that this be monitored and regulated in the conduct of the construction of knowledge.

Considering then the existence of metavisualization, how could it contribute to the overall learning and specifically in chemistry? To understand, for example, a chemical interaction, the student is asked to pass on three representational modes, macro, micro and symbolic (Johnstone, 1993), requiring him, among other skills, the metavisualization because it will be used to models (visualizations) and so, for there can be an active monitoring of their internal representations (as he sees), he must think and think hard about what was in his mind (the image), making a strong exercise of metacognition (see Figure 3).

Therefore, as the visualization, the ability to think about it, monitoring and regulating it, it becomes essential in the learning process in chemistry.

## Conclusions

Visualization is a crucial element in learning chemistry, as it is and produces models, and so it is necessary that students become metacognitive in relation to the visualization, i.e., to develop the metavisualization skill to appropriate the models used to explain different chemical content.

We believe that it is possible and necessary to develop a metavisual capability in all levels and modes of representation to really understand concepts in chemistry. Gilbert (2008) proposes several requirements that we consider to take care when we deal with chemistry instruction's environments, and once again it is referred the need for more research in this area, in order to give comprehensive explanations about these issues.

For the student**,** transitions between the different modes of representation: macro, micro and symbolic, he will have to create their internal representations and constantly monitor them (metacognition) to appropriate the knowledge properly. We can assume visual thinking as a background for concept thinking if we consider that mostly all phenomena in Natural Science Education are related with imagination and mental models in pupil´s minds. It is recommended a lot of investment in research still in the area in order to better understand the processing of metavisualization and its importance in learning in general, it is located a few still work in the area and many questions are being researched and answered.

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