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The role of imagery in physics teaching: a focus on dual coding theory

El papel de las imágenes en la enseñanza de la física: un enfoque en la teoría de la codificación dual

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Abstract

This article is based on data obtained in a doctoral research in science education that aimed to investigate the possible contribution of imagery to the teaching of wave and study of light in high school. With a qualitative approach to interpretation, and having the Dual Coding Theory by Paivio coding as the main theoretical framework, it sought through some data collection tools to analyze how the imagery can contribute to the learning of such physical concepts. Based on the analysis of the evidence, it can be considered that such resources are able to contribute significantly to the learning of physical concepts.

Key words*: physical teaching, dual coding theory, imagery.*

Resumen

Este artículo se basa en los datos obtenidos en una investigación en la educación científica que tuvo como objetivo investigar la posible contribución de las imágenes de la ola de la enseñanza y el estudio de la luz en la escuela secundaria. Con un enfoque cualitativo a la interpretación, y que tiene la teoría de doble codificación de Paivio como el principal marco teórico, se buscó como las imágenes pueden contribuir a la formación de tales conceptos físicos. Con base en el análisis de las pruebas, se puede considerar que estos recursos son capaces de contribuir significativamente al aprendizaje de conceptos físicos.

Palabras clave*: enseñanza de la física, teoría de la codificación dual, imágenes.*

INTRODUCTION

Teachers of science (biology, physics and chemistry) as well as of other areas of knowledge, may, during the oral approach of some concepts and knowledge, face difficulties as to the way to discuss such knowledge due to the abstrtact nature of the subject. Facing this situation, teachers seek to address the abstraction using media and technology and other teaching resources. Some of these methods may be associated with the use and display of images, both static (photographs, drawings, diagrams) or moving (videos, simulations).

Thus, this work seeks to answer the following question: how are images able to contribute to the learning of physical concepts? Do they offer an advantage over the use of words?

To try to answer these and other questions, we sought answers on Dual Coding Theory (DCT) by Allan Paivio (2014), which among other factors, shows that the verbal and non-verbal representations are directly connected, in order to allow us to create images when we hear certain words and generate concepts and descriptions when we visualize images.

Dual Coding Theory

DCT proposed by Paivio (2014) discusses the idea that cognition involves the cooperative activity of two mental systems operating independently, but maintains links. One is a nonverbal system specialized in dealing with non-linguistic objects and events and the other is a verbal system, whose specialty is to deal directly with language.

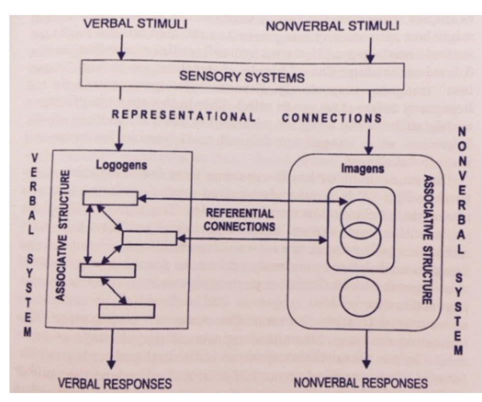

Figure 1-Structural Units of DCT, Sadoski, Paivio (2001)

Inside the DCT, Paivio (2014) discusses some terms that are essential for the understanding of the theory, they are: *logogen* and *imagen*. The word *logogen* refers to any word-evoking stimulus. An *imagen* is any image-evoking stimulus. An *imagen* may be visual or auditory (environmental sounds), tactile (identifying objects) and, finally, motor (gestures, behaviors and non-verbal behaviors. Motor *imagens* involve necessarily motor activity (eye movement, for example, accompany the visual image of the object). In this way, the *imagen* and *logogens* on TDC function as internal structures of specific procedures dealing with sensory-motor attributes of objects and words (Paivio, 2014, p. 40). In other words, the *logogen* would be a kind of word generator and *imagen* a generator of images.

Relationships of images with reality

Every human being, as an observer, accesses information from the world around him, makes use of his senses, such as sight, hearing, touch, smell and taste. All these sensory inputs, as well as language itself, make it easier to process the interaction of man with his environment. However, vision and hearing are the main instruments of cognition in human beings, as suggested by Costa (2005).

Costa also explains that:

> This prominence of vision over the other senses of the species is due to the development of mental processing capabilities of light stimuli. So, what distinguishes our view of other animals is the elaborate system of brain functions that organize the data of the senses into knowledge, experience and memory (Costa, 2005, p. 31).

On the other hand, the interpretation of an image, for example, will depend partly on our culture because our previous experiences are those that may contribute to reading an image. The images can be used for many functions, including this study, which involves teaching and learning processes related to concepts and physics content. Aumont (1995) highlights three main aspects that may be related to the functions of the images: the symbolic mode, the epistemic mode and the aesthetic mode.

Considering the symbolic, Aumont (1995) points out that by drawing on the Blackboard, for example, a representation of the solar system, where the planets revolve around the Sun, "following certain lines", the strokes that represent these lines symbolize its orbit. With respect to the epistemic mode, Aumont (1995, p. 80) asserts that the images bring us visual information about the world around us, "what can be known, including in some of their non-visual aspects". Images, such as photographs were extremely important resources to help establish (at the time) one of the revolutionary theories that have marked the physical world at the beginning of the 20th century: the theory of relativity of Albert Einstein.

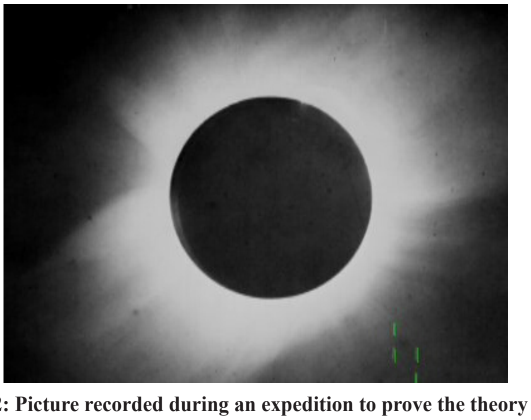

Figure 2: Picture recorded during an expedition to prove the theory in the city of Sobral,Brazil, in the year 1919.

Source: theory of relativity, available at: <http:www.apolo11.com/spacenews.php?posic="dat_20100211-091832.inc">(accessed on September 18, 2015).

In Newton's model, time and space constitute a field in which events unfolded, but without being affected by them. Space would be represented by 3 lines and the time would be separated from the space and considered as a single separate line, infinite in both directions (Hawking, p. 32, 2009). In relativity, the concept of spacetime is a single entity consisting of the 3 dimensions of space and time as a fourth dimension. In relation to the aesthetic mode, Aumont (1995) points out that the image is designed to please the audience and offering specific sensations. Who has not contemplated any painting, for example, and wasn't dazzled by the strokes, colors and shapes. The same author notes that this aesthetic function is practically inseparable from the image, i.e., even if an image is not focused on the "Arts", it carries a power that seems magical, able to tinker with human feeling.Nature offers us every day the most beautiful images. A typical example that involves this aesthetic aspect can be contemplated in the aurora borealis or Australs.

Figure 3: Aurora Borealis-Alaska (USA), 2013 Source: Northern lights, available at: <https:smediacacheak0.pinimg.com/originals/60/9c/fb/609cfbe13cb8c45934fcc8f2eef31b8a.jpg>, (accessed September 18, 2015).

The aurora borealis and the aurora australs are basically produced by the collision of energetic particles from the solar winds that are guided by the Earth's magnetic field, entering the atmosphere at the poles of the planet through the Birkeland currents. The lights are produced by the collision of these particles with molecules in the atmosphere.

METHODOLOGY

This study is qualitative, as in "the central research interest is on the issue of the meanings that people attach to events and objects, in their actions and interactions within a social context and in the elucidation and exposition of these meanings by researcher" (Moreira, 2011, p. 47). Therefore, it is believed that a word able to characterise this research would be, according to Erickson (1986), Moreira, 2011) the interpretative research. In this sense, the interpretative researcher is one that registers events, gets data, transforms them into assertions, noting participatively from within the environment researched, cautiously, not focused on data and samples in the quantitative sense, but on groups and subjects in particular, seeking to analyse certain instances and identify what is unique about them and what can be generalized in similar situations (Moreira , 2011, p. 50). The pedagogical actions proposed, if structured during 19 lesson hours (1 quarter, between the months of June and September 2014) during which waves are introduced and light is studied. During this period, the professor/researcher chooses the teaching and methodological references related to the teaching and learning of such themes. He or she tries to register in the best possible way, all events related to this research, through data collection instruments such as: the comments and audio and video records (all lessons were recorded and records were made in the research journal) , interview (conducted at the end of the teaching sequence) and questionnaires (applied in an interleaved manner, during the implementation of sequence). The students who were part of this study were students of 2nd year of high school, with 27 students, 13 boys and 14 girls of the state public school network in the State of Paraná, Brazil, and, to preserve their identities, the subjects will be identified by the "S" + "name initial". The content covered during the survey was waves: wave properties, types of waves, physical properties of hearing, speech, the electromagnetic spectrum and physical properties of light: physical characteristics of light, wave-particle duality of light, physical properties of vision and sense of colors, which used images (static and in motion) to discuss, highlight and contextualise the concepts related to such content. After the implementation of the teaching sequence and by means of the instruments of data collection it was possible to structure a corpus of discussions related to the use of images for teaching physics.

Contribution of images checked in questionnaires

During the introduction wave image resources were used, such as still images and videos illustrating situations involving wave phenomena. In this way, the students were asked about the relationship and the role of the wave image resources with the knowledge discussed. All 27 subjects, without exception, have stated that the wave image resources contributed to the understanding of the phenomena studied.

The use of teaching resources with images, it may seem, at first, like a tool that, due to its graphic composition of colors, movements, traces, composition, with audio (or not), among other aspects, can contribute to processes that involve teaching and learning, due to their aesthetic attributes. With the image as a goal, Aumont (1995) has three important aspects: the aesthetic (colors), the symbolic (to the extent that it represents something) and the epistemic (how the knowledge is linked). In this sense, the image goes beyond the borders of simple representation, since processing is directly connected to the cognitive functions. One primary cognitive function is memory. The brain as an organ of cognition has an extraordinary capacity to store or capture an almost infinite quantity of information and, very quickly, associate the information, not only in terms of the past, but also, adapt it to novel situations in terms of the future. But, what is the relationship of these issues with the images used to teach concepts of physics? To be useful, things learned must be in working memory. The more significanance and the more importance the information has for the subject, the more useful it is. The "depth of cognitive activity and putting the information into practice" can influence the recoverability and mobilization of the information (Fonseca, 2013, p. 68). This suggests that, if we make the information meaningful enough, coding it semantically (as in the case of images), it can be recovered more effectively. Paivio (2014) shows precisely that the images may have certain superiority to the words as images are encoded in a single time, in a form of verbal and non-verbal (illustrated).

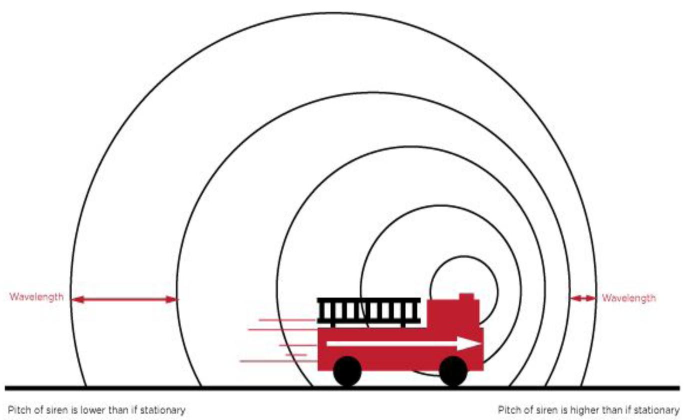

Figure 4: representation of sound waves (doppler effect)
Source: doppler effect, available at:
http://watershipdown42.weebly.com/the-doppler-effect-and-sound-interference.html

Therefore, during the teaching sequence, when referring to the doppler effect, for example, in addition to discussing verbally its nature and issues related to its features, images should be strategically used. This way information for both systems (verbal and non-verbal) is being encoded, thus allowing this information to be saved to the memory more effectively. The sound waves represented by blue circles between the sound source and the observer show that the observer receives a larger number of waves per unit time. Thus, the subject may relate to this phenomenon by reading the term doppler effect or viewing a photo/video from a moving ambulance, or even create a mental image to represent this phenomenon when encountering this concept and vice versa. Other questions were developed in order to investigate the possible contributions of the images used, such as: "*During the discussions of the wave, we saw some videos. Write what are the possible contributions to the understanding of the concepts discussed*." All subjects have cited possible contributions of the videos, in which we can group into two categories:

I - Contributes to understanding of the concept/knowledge/phenomenon.
II - Contributes to relationship of theory to practice.

Basically 60% of students argued that the images have contributed mainly to the understanding of the concepts, knowledge and discussed phenomena, since images offer more elements for the understanding. Among such notes entered in category I include:

> *The videos demonstrate the right way and are more interesting. If it was only spoken, maybe you thought wrong (SJA).*
>
> *The videos have a visual effect mapped images integrating movement visualization. Any resource that can enrich the approach is beneficial and contributes to an approach with the concepts (SLR).*
>
> *Classes without videos wouldn't have the same effect, it would be difficult to understand, the videos made it easier to understand the subject matter studied (SMA).*

The remaining 40% already mentioned that one of the main contributions of resources involving images used resides precisely to help to relate the theory discussed with the practice, i.e. how the phenomena discussed in the classroom can be related directly or indirectly with the world around us:

Is easier to see something going on than listening to someone talking about it. This happens with the videos, the videos make us understand the phenomena in practice (SGU).

The videos show us in a real way the concepts and interpret better the content, see the real situation we understand better (SAT).

Help in the understanding of the theories in the environment in which we live (SJR).

In both categories, the testimonies converge to the realization that the images offer "an element" to contribute to understanding of a particular concept. According to Sadoski and Fuse (2001) combining images with text, for example, significantly increased the understanding of terms and meanings.This is due to the fact that, according to the TDC, both verbal and non-verbal systems are interconnected, collaborating with each other by reference links between the *imagen* and *logogen*, which are the units responsible for the generation of words and images respectively. In this perspective Meyer (2002) explains that the visual brain functions are a kind of organization of cognitive activity with certain settings, called neural *patterns*[1]. For more elaborate sensations, the construction of a visual image needs the cooperation of other brain abilities, such as memory and emotion. The net result is that "the sensory stimuli forge a network of interconnected neurons, in which the driving force of the system is represented by the intensity of the stimulus" (Meyer , 2002, p. 102). This strengthens the thesis that when images are used correctly in educational contexts they can have a greater effect, since they are doubly coded.

Contribution of the images recorded in the remarks

The notes that will be mentioned in this section were structured in chronological form, as the development of the teaching sequence, from the observations recorded in the class diary and in video and audio records. Something noteworthy was the visible student enthusiasm related to the place where most of the classes were held, which was in the science lab and, also, enthusiasm for the resources used (PC, datashow, digital whiteboard, among others). Virtually all the students remained very attentive to the approaches of the first class meeting, especially as to slides, images and video submitted. There was good participation of the students at the second class meeting. Student attention was greatest when viewing images and videos related to the content. The graphics, accented by colors, forms, movements and dynamics of images contributed to draw the attention of the students. Under these conditions, there is a need to implement and intensify educational actions aimed at teaching that combine words and images, as proposed in DCT, is advocated by Lieury (2001). Beginning with the fifth class an approach, which encompassed other disciplines, especially biology, to contemplate, for example, the hearing aid. This combining of disciplines (mainly between physics and biology) also occurred to relate the unit on speech production and waves with human vision. It was noticed that when scientific concepts are discussed so that it relates to daily life, the participation of the students increased to the extent that they had questions

1 Set of neurons in charge of a certain brain activity and organize in order to optimize the functional activity

and inquiries regarding various aspects of the subject under study, such as: hearing problems, vision, lens types, snoring, physiological influence on the production of voice (male and female), perception and application of wave phenomena in medicine, technology, nature and everyday life, sense of color, influence of the brain on issues of perception, among several others. Images played a key role in this process. For example, to represent the process of human hearing, videos and images were used that sought to represent the way the (sound), can be picked up by our auditory system, and how sound interacts with the external, middle and internal ear, and the role played by each section prior to the issuance of electrical signals that are sent to the brain so that it can translate such signals in phonemes and words. In one of the videos for example, to represent part of the inner ear, images like the following are exhibited .

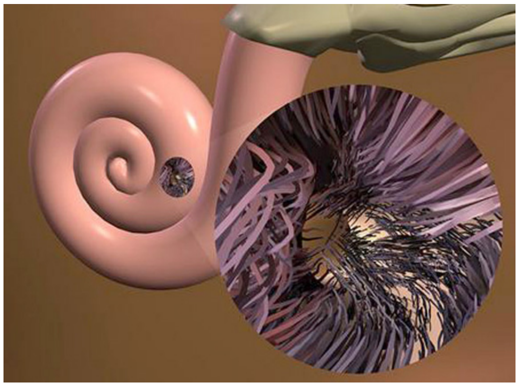

Figure 5 - Representation of the cochlea and the basilar membrane
Source: cochlea, available at: http://www.biologia.seed.pr.gov.br/modules/galeria/detalhe.php?foto=464&evento=3 (accessed 18 September 2015).

The figure represents part of the cochlea and the basilar membrane showing one of the last paths of vibration (sound) before being sent to the optic nerve and subsequent processing in the brain. It is important to stress that it is up to the teacher to highlight images, such as displayed above, which takes a form that seeks to represent something while not being a faithful representation of such organ and structure. In this perspective, Fonseca points out that it is the brain with its functional plasticity that determines how we learn. Fonseca (2013, p. 123)"Human cognition can learn and teach through media coverage", that is, learning depends on the teacher's pedagogical action. For this reason, it is very important that the teacher is aware of his or her responsibility for the approach that will be adopted.

Verified implications in interview

The interview was basically on 4 issues. One of them will be discussed here, which was to check the students' opinions about the role assumed by the images in the processes surrounding the teaching and learning of physics concepts: *"During our meetings images were used to contribute to the learning of physics concepts. How do you rate the role of images in this process?"* Briefly, such notes focused around 3 main aspects, as described in the table below.

Table 1- Role of images for learning - positive responses

Aspect	Percentage
Contributed to understanding of concepts	78%
Contributed to memorization of concepts	56%
Contributed to the relationship of theory to practice	56%

Paivio (2014) clarifies that the capture of information and its encoding occurs more effectively when using both the verbal and visual/auditory channels. A particular concept can be presented in different ways based on its characteristics. In fact, verbal elements can be more effective to convey certain information, while non-verbal elements can be for other information. In these circumstances, when we use images beyond words (written or spoken) to discuss, teach or show certain concepts and phenomena, for example, we will be expanding the students' paths to understanding, since we would be increasing the processing of the concept and, consequently, increasing the chances of recovery (in memory). In this regard, Fonseca (2013, p. 68) claims that the way information is processed (controlled and regulated) by the subject and how it is cognitively and emotionally enabled can determine qualitatively the functions of memory, hence the importance of strategies of "training and educating of mnemonics strategies" such as show, imagine, categorize, verbalize, among others. In line with these findings, when addressing cognitively learning human being, the Fonseca still stresses that any learning whether symbolic or not, involves complex cognitive processes and subcomponents.It constitutes an organized and articulated integration and retention processes, sequential processing and simultaneous multimodal data and planning procedures and information expression (Fonseca , 2013, p. 62). The importance of multimodal data processing and expression of information suggests that the use of resources go beyond the oral approach and include images/videos, thereby stimulating brain and cognitive functions.

IMPLICATIONS FOR THE TEACHING OF PHYSICAL CONCEPTS

When you plan and implement the teaching sequence to teach concepts and skills related to the study of light and waves, use whenever possible, images, videos and diagrams. With that, seek to promote a favourable environment for learning such concepts and skills. Using images creates a situation that contributes to the expansion of the possibilities of the participants (students) to remember and, consequently, internalize these concepts so that they can be connected in different situations and contexts. In addition, when using a picture or video, the concept can be encoded in two systems: the verbal and the non-verbal. This enables the establishment of relationships and interconnections between themselves and can trigger *imagens* and *logogens* capable of generating words and images. Therefore, the approach to concepts with the use of images along with words influences the learning processes triggering cognitive elementsin different brain regions. Using these stimuli, nearly all participants demonstrated enthusiasm and effectively participated in the discussions and activities. This is not observed in classes considered "traditional", i.e. teaching only through oral explanation.

Consequently, with greater involvement and participation, the students performed the problems (with a mathematical approach involving the waves), assimilating most of the concepts in the discussions (including the use of the images), as demonstrated by the results of evaluations applied at the end of the sequence. All participants were able to deliver minimum required grade in the class, i.e. 100% of participants achieved a score of 6.0 (six) or more. The final assessment was aimed at verifying the learning of the concepts covered in the forms: theoretical, mathematical and imagery, in which the results are summarised in the table below.

Table 2 – Evaluation results

The Theoretical approach	The Mathematics approach	The Imagetics approach
Percentage above 60% success	Percentage above 60% success	Percentage above 60% success
100%	100%	100%

Faced with such data, it can be seen that the approach adopted (using images) to discuss wave concepts and study of light was able to contribute to the processes of teaching and learning of physics, since all participants in the evaluation received a satisfactory score or better.

CONCLUSIONS

According to DCT, the use of images supplies more *logogens* and *imagens* which are, respectively, the generators of words and images. In this work we sought to demonstrate how images and other factors can contribute beneficially to the processes of teaching and learning of knowledge related mainly to the discipline of physics. We found that when a physical phenomenon is approached using both the verbal system (concepts) and the non-verbal (images/videos) we expanded the possibilities of recalling such information.

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Delving students' metacognition based on reflective and impulsive cognitive style in problem solving about solubility.

Exploración de la metacognición de los alumnos basada en estilo impulsivo en la solución de problemas de la solubilidad

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Abstract.

This study aimed to explore students' metacognition in solving the solubility problem based on reflective and impulsive cognitive style. This qualitative research data included both documents of written tests and deep interviews. Subjects were students of a high school in East Java, Indonesia. The results showed that student with reflective cognitive style did metacognitive activities more systematically therefore they could solve the problem easily, considered all alternatives before making a decision, were able to make improvements, focused, and re-examined their activities. The subjects with impulsive cognitive style carried out metacognitive activities hastily in solving problems, not realizing that error had occurred, not analyzing for conformity with the objectives, not recognizing the mistakes so improvements were not possible, not considering the alternatives in making decisions, and not conducting an evaluation. This research was useful in designing learning strategies that aimed to optimize students' metacognition in solving problems.

Key words*: metacognition, problem solving, reflective and impulsive cognitive style.*

Resumen

Este estudio tuvo como objetivo explorar la metacognición de los estudiantes en la solución de los problemas de solubilidad y el estilo cognitivo de ellos reflexivo e impulsivo. Estos datos de investigación cualitativa incluyen, los datos de prueba escrita y entrevista en profundidad. Los estudiantes eran de una escuela secundaria en el este de Java, Indonesia. Los resultados mostraron que el estudiante con el estilo cognitivo reflexivo hizo actividades metacognitivas de manera más sistemática por lo tanto resuelven el problema fácilmente, consideradas todas las alternativas antes de tomar una decisión, pueden hacer mejoras, y volvieron a examinar sus actividades. Los estudiantes con el estilo cognitivo impulsivo llevan a cabo actividades metacognitivas no completas en la resolución de problemas, sin darse cuenta si se produjo el error, sin el análisis de la conformidad con los objetivos. Al fin no hacen mejoras, sin considerar las alternativas en la toma de decisiones, y no realizan una evaluación. Esta investigación fue útil en el diseño de estrategias de aprendizaje que tenían como objetivo optimizar la metacognición de los estudiantes en la solución de problemas.

Palabras clave*: metacognición, resolución de problemas, el estilo cognitivo reflexivo e impulsivo.*

INTRODUCTION

Cognitive learning style is an individual habit in information processing. Cognitive style explains the mode of someone's habit who is stable in perceiving, remembering, thinking, or solving problems. Cognitive style was usually characterized as a personality dimension which influences attitudes, values, and social interaction (Kozhevnikov, M., 2007, p. 464).

Cognitive styles of each student in processing and learning new information used different ways. For example, some individuals chose to learn by participating actively, while others chose to sit contemplatively and reflect on ideas or theories; several other individuals preferred to make a written record, while others preferred to use diagrams or pictures. This difference was called the learning style (Prajapati, B., et.al. 2011).

In teaching-learning teachers have to investigate and explore students' differences in order to adapt the education in accordance with the difference. Students will develop according to their respective capabilities. Teachers need to provide a cognitive problem that leads to conflict and curiosity of students, thus encouraging students to solve it themselves. Students will observe, assess, and connect it with their initial knowledge. This action is a self reflection that requires skill to design, monitor, and assess learning process that is defined in the form of self problems against the phenomena around them. Students also need to embed, or change the way they think at the same time. Any processes that determine answers or make decisions affect students' mastery and implementation of metacognitive processes.

According to Sandi-Urena, S. (2008), there are two main metacognition components generally identified: metacognitive knowledge (or knowledge of cognition,) and metacognitive skillfulness (or regulation of cognition.) Knowledge of cognition refers to the awareness of the individuals about their cognition, that is: knowing about things (declarative knowledge), knowing how to do things (procedural knowledge) and knowing why and when to do things (conditional knowledge).

The knowledge of students' metacognition becomes a benchmark of students' ability in solving chemistry problems. Chemical problem solving skills with a variety of different ways are influenced by cognitive styles such as reflective and impulsive cognitive style.

This study used solubility and solubility product problem solving which contained conceptual and procedural knowledge. Conceptual knowledge was regarding to the relevance of concepts including the concept of chemical equilibrium, electrolytes, concentration, and temperature, while procedural knowledge was related to the phase or sequences of work which are required for certain concepts. The characteristics of these materials were according to the students' metacognitive skills component that included planning, monitoring, and evaluating. Schunk and Zimmerman (1994) suggested that learners with high metacognitive ability knew whether they had completed or not in controlling the academic tasks and could customize their learning. According to Pulmones (2007) that prolonged engagement of students in classroom activities designed in a constructivist environment gives ample opportunities for students to demonstrate their overt planning, monitoring and evaluation behaviors. Purposely asking