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Holographic pyramid as an instructional resource for inserting 3D images in the teaching of optical isomerism

Pirâmide holográfica como recurso instrucional para inserção de imagens 3D no ensino de isomeria óptica

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ABSTRACT

The New Digital Information and Communication Technologies and their applications in the teaching of Chemistry have been standing out as a contributor to the promotion of concepts that have abstraction. In search of innovations that can cooperate with the teaching of Optical Isomery, we investigated the collaboration of the teaching of this concept provided in a didactic sequence with a STS focus and with the contribution of a pedagogical didactic resource, the holographic pyramid for the representation of 3D images. The applied research is of a qualitative nature and the target audience was composed of 35 high school students from a state school located in Vera Cruz do Oeste, Paraná. The students participated in two classes that composed a didactic sequence addressing the "Optical Isomery and Medicines", and from the data collected, we analyzed the construction of knowledge and the establishment of the necessary relationships for learning. The methods of analysis were based on the procedures of Discursive Textual Analysis, the categorization was adapted and performed a *priori* by the deductive method with input in Bloom's Digital Taxonomy and from the Theory of Double Codification were interpreted the materials resulting from the application of the research. We observed that some students contemplate the three levels of cognitive processing established by Paivio (1971), being the representational, the referential and the associative, however, for other students we analyzed the need for different stimuli to establish concrete connections. We suggest the Double Coding Theory for the analysis of the teaching promoted from 3D images, contemplating the abstract concepts of Optical Isomery and we emphasize the importance of digital technology applied in the teaching methods of Chemistry.

Keywords: Double encoding theory, Optical isomery, 3D imaging, New digital technologies, STS approach.

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INTRODUCTION

The New Digital Information and Communication Technologies (NTDICs) and the teaching of Chemistry have been walking together with the purpose of improving techniques and methods that favor the possibility of concepts in the school environment. In this sense, we turn our gaze to the methods of teaching and acquisition of knowledge starting from technological devices used as a pedagogical didactic resource and inserted in the classes, bearing in mind that technology can collaborate with pedagogical practice and act as a contributor in the approach to concepts, favoring students in the establishment of concrete references that enable learning.

Thus, when thinking about a concept that requires 3D visualization for an in-depth understanding, we approach the content of Optical Isomery that is part of the curricular component of Organic Chemistry that is applied to students in the second and third year of High School. To approach this content, we developed a didactic sequence with a CTS focus and the use of a pedagogical didactic resource "holographic pyramid" for the reproduction of optical isomer structures in 3D accompanied by narratives of the underlying concepts of this curricular component.

Thus, we start from the knowledge of the Double Encoding Theory (BDT) of Allan Paivio (1971), and in this investigation we seek to answer the following research question: "*The use of 3D holographic images, made possible from a didactic sequence with a STS focus for the teaching of Optical Isomery, collaborates with the construction of concrete* memories?". In addition, we observed if there was referential, representational and associative processing, after analyzing the descriptions emitted by the students when establishing relationships from the imagination with the word "Optical Isomery".

For the analysis of the answers attributed to the questionnaire applied to the students after the approach with the didactic sequence, we followed the procedures of the Discursive Textual Analysis of Moraes and Galiazzi (2011), in which we used the deductive method to establish an a *priori* categorization, and we established agreement with the levels of knowledge adapting Bloom's Digital Taxonomy (Churches, 2008). To answer the research question, we assigned the units of analysis and interpreted them according to the Double Coding Theory, relating this to the attributions we expected as a response from the students.

Thus, we discuss the impacts of Digital Information and Communication Technologies (DICT) on teaching and the potential of the Double Coding Theory (DICT) for the analysis of teaching methods with an approach based on 3D images, promoted by a technological apparatus, the holographic pyramid. Next, we present the theoretical framework and methodology, in which

we describe the research participants and the procedures that led us to interpret the data. Finally, we present our findings based on a metatext articulated with the analyzed considerations based on the testimony collected in the research question directed to the students.

NEW DIGITAL INFORMATION AND COMMUNICATION TECHNOLOGIES AND THREE-DIMENSIONAL IMAGES IN CHEMISTRY TEACHING

Digital Information and Communication Technology (ICTD) continues to grow and has been applied to education in Brazil since the mid-70s. We can observe from the technological apparatuses that have undergone several transformations and innovations and currently we have easy access to tablets, computers and cell phones. Another factor observed is the growing number of applications, websites and software aimed at aiding didactics in the classroom, however, in order for these to be worked in a way that promotes knowledge and enables student learning, an in-depth study and a process of preparation of the teacher for the selection of appropriate material and according to the student's reality is required. We also observe the structural conditions available in the schools so that the adaptations made are creative and provide the student with contact with the new digital technologies applied to teaching.

It is important to highlight that when we use the term ICT and DICT, we refer to Leite (2021, p.57), who differentiates and defines them as follows: ICT (Information and Communication Technology) is where the available technologies "group computer and telecommunication tools such as: television, video, radio, internet, etc., and all these technologies have in common the use of telecommunication means that facilitate the dissemination of information", while TDICs is the use of digital technologies such as computers, *tablets*, *smartphones*, *smart TVs* and other digital devices that allow browsing the internet.

In this way, we can observe that there are countless contributions of the internet in our daily lives, and these aim to make life easier for a population in various aspects of society. Therefore, in the educational field, digital technology contributes to the teacher in the most varied pedagogical practices, being considered innovative and capable of promoting significant changes in teaching and school learning (Giordan, 2008).

However, in the educational space, mostly in public schools, students are faced with inequality and digital exclusion, as there is a shortage of computers, difficult access to the internet network, especially wireless internet (*wi-fi*), and also, extensive school curricula limit teachers in the use of creativity to adapt curricular content using applications, *software*, games and other technological alternatives that may collaborate with the teaching process.

Thus, Leite (2019) addresses the use of strategies for the use of NTDICs for teaching and learning, as they are capable of providing support to the pedagogical process when incorporated into the class at strategic moments, however, for there to be significant changes in the educational process, the understanding of their use must be established, that is, The student should be clarified that the technology used in the classroom is a contributor, capable of enabling and promoting concepts that are difficult to visualize, making the learning process possible.

In view of the above, we analyze the teaching of Chemical Science made possible through DICTs, because there are contents considered abstract and difficult to visualize, that is, contents in which assimilation causes inadequate notions and makes it difficult for the student to interpret, Souza, Leite and Leite (2015, p.141) cite that "Chemistry is a discipline considered abstract, the understanding and formulation of mental models are necessary", In this sense, Digital Information and Communication Technologies, through *software*, applications and websites, can supply and collaborate in the formation of mental references, overcoming epistemological obstacles and developing the student's scientific mentality.

In agreement, we cite the article "Technologies in chemistry teaching: past, present and future" by Leite (2019), in which it was observed that the author traces a timeline of the use of computers for the teaching of chemistry and describes the evolution of technology applied to teaching following the innovations and technological apparatuses available over the last decades. In its history, experiences and works developed with students using new digital technologies are reported and we observe that, regarding the use of the computer, the citation of works developed that use it as an educational pedagogical resource for the teaching of Chemistry are scarce.

We emphasize that the introduction of NTDICs in Chemistry classes are characterized as contributing innovations in pedagogical practice, which favor the construction of knowledge, allowing the student to interact and produce meanings to the concepts, and according to Leal *et al*. (2018) The use of technology in the teaching process contributes to the active participation of the student, which is capable of transforming the educational space, the educational process and also enables innovations in teaching practice.

Regarding the teaching of Organic Chemistry, it should be noted that Ferreira, Arroio and Rezende (2011) approach the use of 3D modeling tools (three-dimensional) and 2D projection based on technological devices, which allow a representation of models and provide a better display of chemical arrangements, processes and phenomena and due to the microscopic and symbolic level of Chemistry, Software and applications can make the visualization of different structures accessible to human perception and useful in teaching and learning.

Thus, in view of the abstract aspects of Chemical Science, we highlight Organic Chemistry and the contents of Optical Isomery, because the concepts covered require the student to have a high domain of spatial visualization and 3D perception to identify the difference between substances, especially chirality. According to Rezende, Amauro and Rodrigues Filho (2016, p. 136), for the teaching of Optical Isomery in schools, the stick ball modeling is the one that still predominates in the representation of three-dimensional aspects, the authors also state that "the interconversion of 3D to 2D representations is usually neglected in the teaching of chemistry". Thus, we identified that, even if the modeling is represented virtually in 3D, when it is reproduced on the computer screen, *smart TV*, *tablets*, *smartphones* and overhead projectors, the student's visualization will be in 2D.

Raupp and Del Pino (2013), comment on the challenges of teaching stereochemistry in high school due to the dependence on visuospatial intelligence and the lack of three-dimensional visualization, or an inadequate visualization causing a greater difficulty in learning and, for this reason, for the teaching of Optical Isomery in order to achieve the understanding of the concepts, an approach is required that benefits teachers in the teaching process and students in the learning process, so that they can visualize molecular structures in 3D and that these are freely accessible and within the reach of the entire school society.

In view of this, when we think about structures for 3D representation, we revert to holograms, because digital holography is a technology that is under development and through computer graphics effects we observe in the media the use of three-dimensional images by film industries, musical events and advertising campaigns. In this context, when thinking about education and the difficulties of not having a high-efficiency 3D player so far, we are looking for resources that can provide us with this visualization and that at the same time presents a low cost and can be accessible and comprehensive to all school communities, so we came across the holographic pyramid prototype.

Thus, we revert to the use of holographic pyramid for school education and observe that the concentration of articles, theses and dissertations in this field of research focuses on the study of optics to explain light phenomena in the teaching of physics. This statement was proven through research and searches on *Google* Scholar, as it is a popular portal of articles and available to all, using keywords such as "holographic pyramid", "chemistry", "teaching" combined and with the help of Boolean operators *and and* quotation marks, delimiting the specific period between the year 2010 and 2022, in which we came across 198 publications, however, when the research is limited to the words "holographic pyramid" *and* "chemistry" for

the same period the results of publications in this context fall to 13 and when analyzing the publications found among these 13, we can mention the application of the resource not only to the teaching of Chemistry, but applications to the teaching of mathematics, biology, Early Childhood Education and the Arts.

According to Schiviani, Souza and Pereira (2018), when we approach the playful, the holographic pyramid has potential for teaching, as it can arouse the curiosity of viewers between different ages and within all levels of education, however, factors such as image adjustments, playback environment and angle of observation must be studied, As well as the teacher's approach, that is, the images, in order to be interpreted and determinant for learning, must be accompanied by explanatory and indicative narratives, directing naïve curiosity to the awakening of epistemiological.

In agreement, Araújo (2018) states that, although the images reproduced by holographic pyramids may contain conceptual errors from a scientific point of view and even if they are not classified as a hologram, but rather a prototype, this can arouse the student's curiosity and make the transition, providing learning, that is, the student can conserve the observed images and associate them with the narratives of the concepts to be studied reproduced by the teacher and thus, Keep what you've learned in long-term memory.

We highlight the use of images, especially if we observe the microscopic and symbolic levels of Chemistry, because there are numerous difficulties in encompassing these two levels, since the symbolic level involves formulas, equations and structures and the microscopic level involves movements and arrangements of molecules, atoms and particles, while macroscopic phenomena are subject to observation because, correspond to chemical processes that are perceptible to vision (Pauletti, Rosa and Catelli, 2014).

Considering that images are very important in the teaching of Chemistry, because this is a visual science and for the concepts to be understood it is necessary to awaken the imagination to generate a representation of the phenomenon studied. In this perspective, among the main theories of learning existing with applications for the study of teaching and learning promoted by images and with the use of the New Digital Information and Communication Technologies (NTDIC), we used in this research the one that best interpreted the investigation of the use of images accompanied by narratives applied to the teaching of Optical Isomery, the Theory of Double Encoding.

THEORY OF DOUBLE CODING

In view of the aspects involving 3D images and digital technologies, we highlight the Double Encoding Theory (BDT) by Allan Paivio (1971), because in his studies there is the point that the cognitive system is composed of two channels that cooperate with each other and maintain themselves independently by making connections, these are defined as the verbal and non-verbal channel, Also called imagery.

From this perspective, the non-verbal channel has its specialty in memorizing objects, scenes and events that do not involve words, that is, non-verbal events and the other channel is called verbal because it acts directly in the memorization of verbal language produced from writing or through speech and these two channels can operate independently. in parallel or together (Frederico, 2016).

Thus, we carried out a bibliographic survey in search of articles that covered BDD, this one in platforms of scientific journals such as *Capes-Cafe* and *Scielo* with Boolean operators "*and*" and "quotation marks" applied to the words "Double Coding Theory", "Chemistry" and "Teaching", and we observed that the use of this theory for the teaching of Chemistry is scarce, being found only one study in both portals. however, directed to images and the teaching of Physics with the implications of the Double Coding Theory of the authors Frederico and Gianotto (2016).

By consulting Allan Paivio's books *Imagery and verbal processes* (1971), *Imagery and text: A dual coding theory of reading and writing* (Sadoski and Paivio, 2001) and *Minds and Evolution: a Dual Coding Theoretical Approach* (Paivio, 2014), we consider the potential of BDT for the study of how images accompanied by narratives behave in the human brain and its potential to analyze the teaching promoted by the use of images applied to concepts considered abstract in the discipline of Chemistry.

According to Sadoski and Paivio (2001), the Double Encoding Theory presents factors that are in accordance with the assumptions of psychology, because in the verbal and non-verbal memorization systems, memories are continuous and one system has an effect on the other, so the knowledge acquired from the senses is stored in memories composed of records of sensory qualities. In this sense, when you smell an aroma, it will be identified as an aroma and when you see an object, it will be remembered as an object.

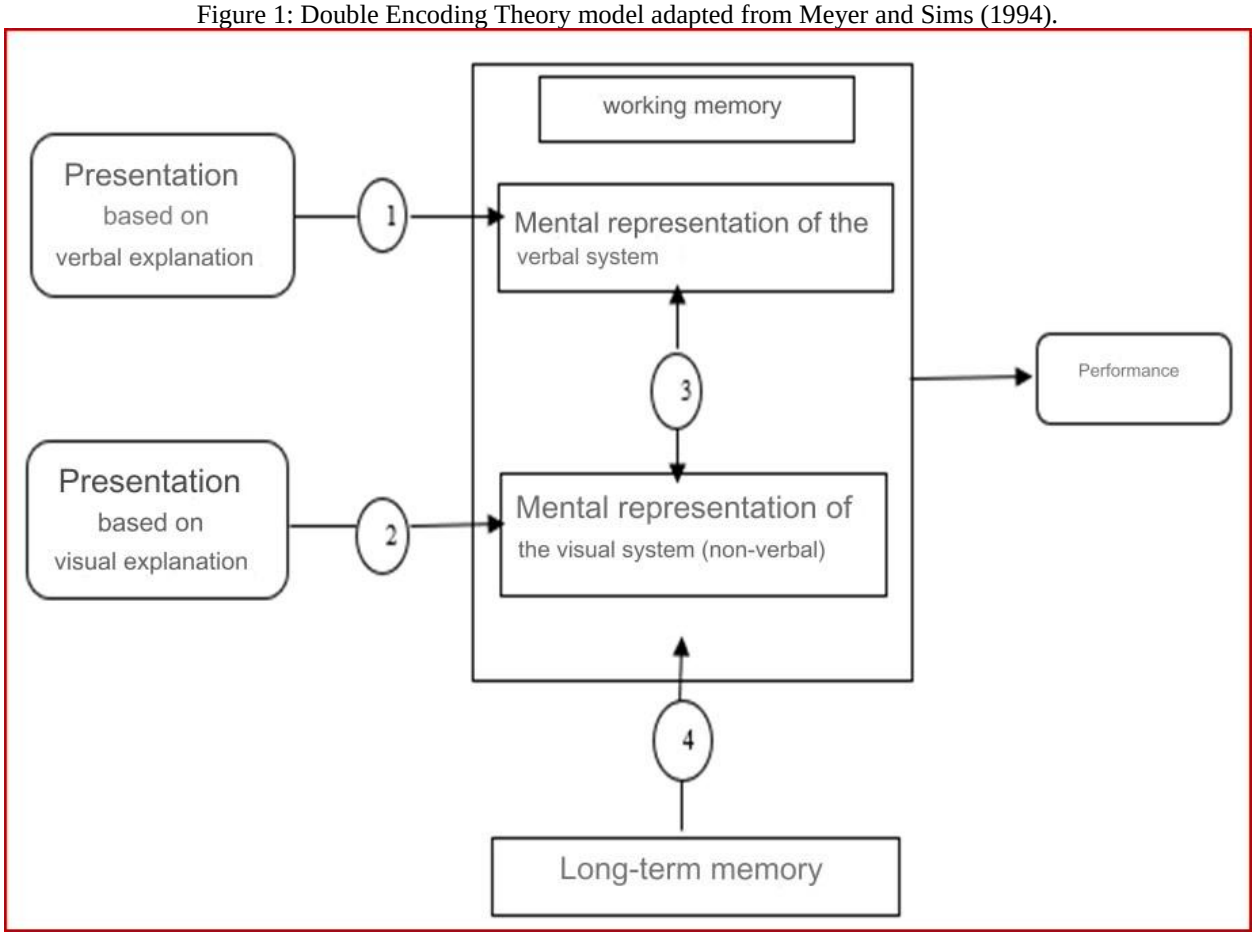
However, information can be processed in both channels, that is, using the imagery and verbal channel at the same time, mental representations are generated that will be stored in long-term memory. Therefore, the information encoded from the two channels will be naturally

assimilated and generate the understanding of the objective of the study, while the mental representations stored through only one channel will only be stored as mental representations, which may hinder their retrieval for the circulating memory (Paivio, 1971).

Scholars of this theory, such as Meyer and Sims (1994) describe that the information transmitted through the verbal canal and absorbed in the auditory canal is processed satisfactorily, in this sense the authors perform an adaptation of the Double Encoding Theory, where they demonstrate how the mental representation is constructed in a student from an oral narration and from a visual explanation, is presented by means of an animation.

The diagram represented in Figure 1 shows the representation created by the authors of a model of the Double Encoding Theory applied to multimedia learning, where the number 1 refers to the construction of representational verbal connections, the number 2 refers to the construction of visual representational connections, the number 3 refers to the construction of references and the number 4 refers to the retrieval of information in long-term memory resulting in of this process the action.

Figure 1: Double Encoding Theory model adapted from Meyer and Sims (1994).



Source: Authors, 2023.

In the same way, Paivio (1971) portrays that a material presented to the student starting from the imagetic channel and integrated with the verbal channel can be well adapted to the student's working memory, collaborating with the learning process. Meyer and Sims (1994) demonstrate within this system the construction of referential memories and mental representations elaborated from the verbal and non-verbal channel and their influence on the student's performance, which can be observed in their performance when faced with a situation in which the rescue of established memories may be necessary.

In this sense, when watching an animation accompanied by a narration successively, at a first moment in which students are not adapted to this methodology, the rescue of the references established in the working memory may be difficult, however, to students with experience in a teaching made possible from images, they may be able to build mental references from words and link them to images, And when they were requested in the working memory, the words or images will be retrieved in the long-term memory, providing a connection that promotes knowledge, as there will be the establishment of links between learning and different situations or moments of life, whether school or social.

Therefore, in the Double Coding Theory, the learning process can be carried out from associations established in the cognitive system, either through the verbal channel or through the imagery channel, and also with the reconciliation of both channels. Paivio (1971) described three levels of cognitive processing, which occur to the individual when receiving information through the verbal or non-verbal channel, which is representational, referential and associative processing.

In summary, representational processing happens when an activation is established by a verbal or visual reproduction, that is, it can be activated by a word or image, in this way, when listening to a word the verbal representation will be activated and will generate an image, which represents what was said, simultaneously constituting a representation in the short-term memory, that according to Paivio (2014), from stimuli the channels can be activated directly, establishing a representation according to what is visualized or heard.

On the other hand, for referential processing to occur, it is necessary to activate one channel by the other, thus, when viewing an image, the imagetic channel is activated and establishes references to a certain word that represents it, awakening the verbal channel, or when using the verbal channel and reproducing a word, the non-verbal system can be activated by creating a reference with a certain image, It is related to the word that was heard.

According to these considerations, Paivio (2014) states that the associations between images, objects and words allow them to be named and identified, establishing references and collaborating for a broad development of language properties, which favor the educational process, technology and the creative thinking of the learner. Therefore, associative processing is indicative of the occurrence of activations of supplementary information, which are related to words (*logogens*) and images (*image*), in this way, the connections between the verbal and non-verbal system are simultaneously established, thus there is an association of a word to an image and vice versa, starting from the associative process (Paivio, 2014).

To use the Double Encoding Theory in an analysis, we must observe the three levels of cognitive processing and work with the one that best suits the objective of the study. Starting from the association of the concepts with images, we highlight the potential of associative processing as an enabler of information retrieval by individuals in current memory, based on long-term memory, because this processing uses the two channels concomitantly, promoting and enhancing the ability to connect verbal information and imagery information in the learning process.

In view of this, we observed that the use of images in the teaching of Chemistry collaborates with the explanation, exemplification of the teacher and the understanding of the content by the student. Explanations and exemplifications, when accompanied by descriptive conceptual narration, can enable the process of retrieving information in long-term memory, because when there are references, they are awakened and recovered in current memory, and information can be modified and enriched and later stored in long-term memory to be recovered at some other time in life. in which a word is heard, seen, or in the view of an image.

Therefore, considering the establishment of referential links with mental information, we found that the Double Encoding Theory contributes to the analysis of how students learn the concepts of Optical Isomery, promoted by 3D holographic images and applied from a pedagogical didactic resource, the holographic pyramid, which contributes and enables the concepts accompanied by narratives.

Thus, we present from the DCT, the process of knowledge acquisition with the help of the technological apparatus that reproduces 3D images accompanied by narratives and evidences, from the students' discourse, the impressions they express when faced with a new form of pedagogical approach, with the use of didactic resources for the teaching of one of the concepts considered abstract within the studies of Chemical science.

METHODOLOGICAL APPROACH

The research carried out is of a qualitative nature, and for the application and data collection we elaborated a didactic sequence with a CTS focus, using the pedagogical didactic resource, the holographic pyramid, to promote the concepts of Optical Isomery. The structured approach was implemented at the Marquês de Paranaguá State College, located in Vera Cruz do Oeste, Paraná.

Students from the 3rd year of high school were part of this study, 15 in the afternoon and 20 in the evening, totaling 35 participants, aged between 16 and 22 years. After authorization from the school's management team and the Chemistry teacher, two hours of class were made available for the implementation, which took place on the return of students to the school, who were until now, in remote learning due to the period of the coronavirus pandemic (COVID-19).

The development of the didactic sequence with a CTS focus entitled "*Optical Isomery and medicines*" with the use of the holographic pyramid to promote 3D images, accompanied by narratives of the concepts made by the researcher, following the presentation of the structures of lactic acid, chloroquine and hydroxychloroquine, occurred in an expository way in the first hour of class and in an interactive way in the second hour of class. Thus, it was detailed that the structures presented have optical isomers and are present in drugs and biological reactions in the human body. At the end of the class, an open question was applied to the qualitative research with the following description: "*Relate the word below to what comes to your imagination: OPTICAL ISOMERIA."*

We used the Discursive Textual Analysis of Moraes and Galiazzi (2011) for the unitarization, categorization and production of the metatext, due to its self-intuitive processes, involving the analysis of the responses. For the formation of the *corpus*, the fragmentation of the texts produced by the deponents was explored and then we obtained the units of analysis, which were later categorized by the deductive method and the relations with the proposed theory were established.

For the production of the metatext, the new emergent was captured, that is, we assimilated the information resulting from the analysis process. After combining our findings with the elements established in the previous steps, we carried out a self-organized process, which involved the communication of the results and presented new understandings that were manifested from the entire analysis process.

Thus, when fragmenting the *corpus* into units of analysis, we looked for similar units of meaning that demonstrated the concepts of Optical Isomery or that reported part of these

concepts addressed in class, either in writing or represented by drawings, symbolizing the images that were reproduced with the contribution of the holographic pyramid.

As the categorization was elaborated a *priori*, by the deductive method, we chose to relate the category to the level of learning development, following the concepts of Bloom's Digital Taxonomy (Churches, 2008), which was appropriate for this research, as we used only the highest level, which is "create". This category was selected because it encompasses cognitive development and competence, so from learning the student is able to apply it and create knowledge.

With the categorization already established, we adapted the description of the theory by making correlations with what was expected in response to the statement that composed the investigation. The initial categorization can be seen in Chart 1:

Analyze, from the word ISOMERIA ÓPTICA, the verbal representation of the

Higher order category	**Description of the theory (Churches, 2008)**	**Description adapted for this research according to the units of analysis**
To create	Bringing the elements together to form something coherent with the theory, planning and producing so that the elements are reorganized and give rise to a new pattern or a new structure.	Analyze, using the word OPTICAL ISOMERY, the verbal representation of concepts or reproduction of drawings referring to what was presented in the implemented didactic sequence.

Source: The Authors (2023).

The adaptation of the category aims to validate the use of holographic images and their contributions in the teaching of the concepts of Optical Isomery, emphasizing the collaboration of the didactic resource for the construction of the student's knowledge and in the appropriation of the concepts if permanent in the long-term memory. In the statement proposed for the research, the storage of information about the Optical Isomery in the memory of the deponent was analyzed and whether they would attribute this information based on concepts described verbally or imageically, that is, they would use drawings of the images.

Coming from our analyses and the unitarization process, two emerging categories emerged, which were presented by the intuitive method, as they came from *insights* and after an intense impregnation in the analyzed data. Therefore, in the a *priori* create category, only the students who verbally represented, from writing, the concepts or fragments that were pronounced during the presentation of the images followed by the narratives and presented the reproduction of drawings referring to the understanding of the concepts and the establishment of connections,

even if erroneous with what was proposed in the didactic sequence, were allocated. as shown in Chart 1.

In the emergent category one, which emerged after the impregnation in the analysis of the answers, the students who did not indicate appropriation of the concepts and associated the word "Optical Isomery" to the didactic resource were allocated, as they mentioned the 3D images or holograms, thus we called this category "associates with the didactic resource".

In the emergent category two, which also emerged, after impregnation in the initial analyses, we allocated the students who emitted associations that were not part of the concepts, the pedagogical didactic resource or the STS approach used in the approach to the concepts, which was adopted in the didactic sequence that was proposed to them, this emerging category we call "other associations".

Thus, for the description and interpretation of the initial, intermediate and final data analyzed from the attributions of the deponents, we sought to preserve their identity and for this, we established the acronym "AV1" or "AN1", where A represents Student, V represents Afternoon, N represents Nocturnal and the number that accompanies them represents the order of analysis of the answers attributed to the study statement made available for the qualitative research.

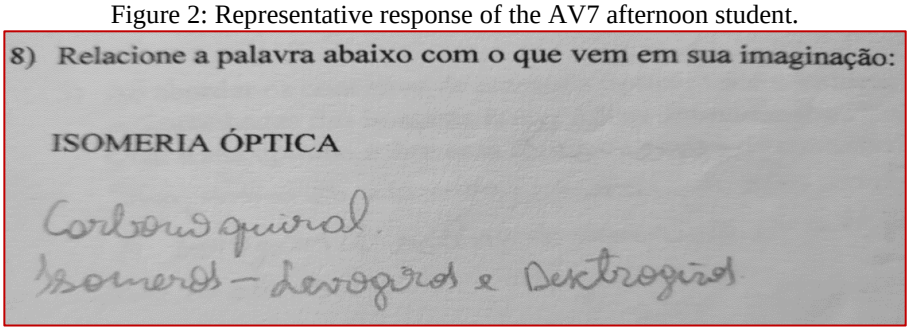
DATA ANALYSIS AND INTERPRETATION

In order to contemplate the a *priori* category to create, we analyzed the answers attributed to the research statement, in which it was expected that the students who contemplated it, cited concepts or reproduced images of the optical isomers. In the research statement, students were given the opportunity to create and use their imagination in order to analyze whether they would activate the verbal system, the non-verbal system, the two interconnected systems or neither of the systems.

From our analyses, we observed that in the afternoon there was a predominance of the verbal system, because the answers attributed to the questionnaire were expressed from writing, and in the night there was the occurrence of some associations made by drawings of organic structures, in addition to writing. Thus, our first consideration attributes that, while in the afternoon there is a predominance of only the verbal system or none of the systems, in the evening there was the presence of the verbal and non-verbal systems and the two interconnected systems.

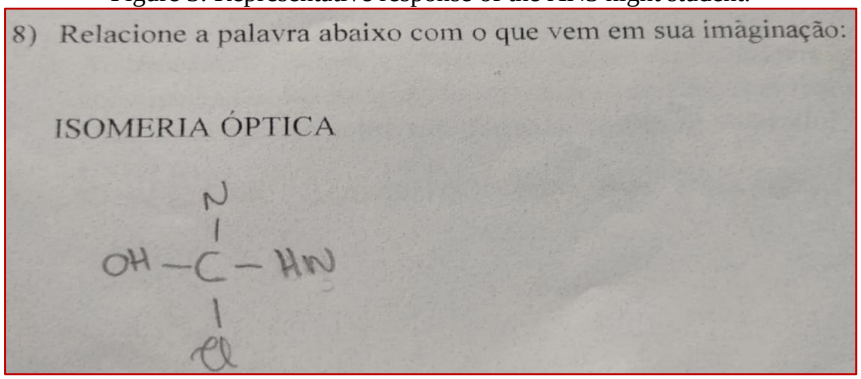
In this context, we exemplify with the afternoon student, AV7 and the evening students, AN3, AN7, AN11 and AN17, who contemplated the category create, established a *priori*, according to the adaptation made for this research of the description of Bloom's Digital Taxonomy (Churches, 2010), for citing part of the concepts or reproducing drawings that induced the concepts provided in class, as can be seen in Figures 2, 3 and 4, represented below:

Figure 2: Representative response of the AV7 afternoon student.



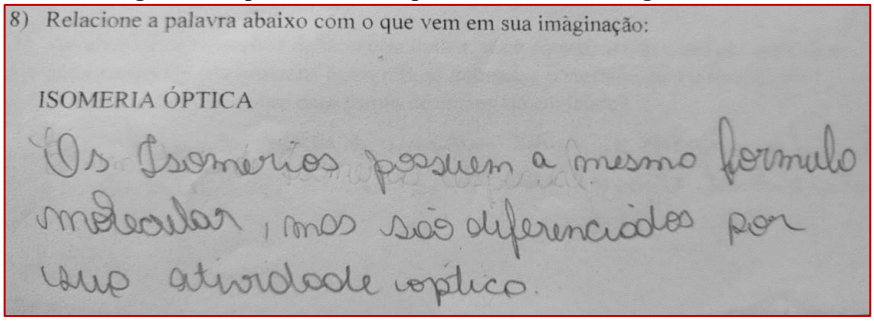
Source: The Authors (2023).

Figure 3: Representative response of the AN3 night student.



Source: The Authors (2023).

Figure 4: Representative response of the AN10 night student.



Source: The Authors (2023).

From this analysis, we attribute that the students of the afternoon period within the three levels of processing established by Paivio (1971), contemplate the referential processing,

because, according to Sadoski and Paivio (2001), the verbal system and the non-verbal system can operate separately or connected reproducing verbal or non-verbal responses.

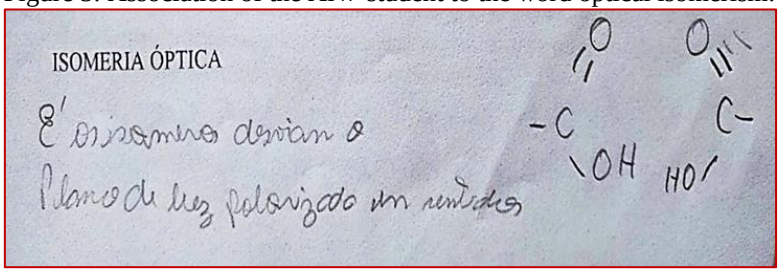
We observed that the connections established by the students, in this case, were expressed only in the form of words, which represent only the verbal system, which was activated by referential connections, emerging the words that represent fragments of the concepts of Optical Isomery.

In the evening period, we considered that the three levels of processing were contemplated in the students' answers, i.e., the representational, referential and associative processing. We highlight associative processing due to the connections established and the structures that have been formed within the cognitive system. Thus, we attribute that the students of the night period, who contemplated the category create, when visualizing the word "Optical Isomery", remembered the concepts and the images reproduced in the holographic pyramid used to represent them.

Visual perception contributes to human cognition, as vision stands out as a way to transform knowledge into memory, however, images that are not inserted in our daily lives hinder the process of interpretation and the development of other mental resources to be processed (Frederico and Gianotto, 2016). We can infer that these students, who contemplated the category of create, were able to activate and retrieve in their long-term memory, isolated or joint events, and transform them into logical associations, being referenced the word "Optical Isomery", corresponding to the approach used in the class promoted through the didactic sequence and technological apparatus.

We observed that the AN7 student stands out from the others, as he used the interconnected representational and associative system to establish the association. Even if the activation of the imagery channel was presented erroneously, the student verbally described one of the concepts presented and sketched the representation from the image, which indicates the previous knowledge of oxygenated organic functions. We can see this representation in the image in figure 5.

Figure 5: Association of the AN7 student to the word optical isomerism.



Source: The Authors (2023).

In general, we understand that the verbal stimuli used during the classes, accompanied by non-verbal stimuli, represented by images, activated the sensory system, generating representational connections and forming an associative structure, in which the student expressed the associations made in the form of verbal and non-verbal response.

We also allocated in the category create, the students AV1, AV4, AV5, AV6, AV9, AN4, AN8, AN10 and AN14, from the transcription of the students' answers we concluded, that they are able to rescue in their memory the verbal reference of fragments quoted and addressed during the application of the didactic sequence.

- **AV1** – *A Mirror: Levogyrators and Dextrogyres.*
- **AV4** – *Levorots and Dextrorotators.*
- **AV5** – *Isomery: two different objects, but made with the same materials (elements), Optics: use of light, ability to deflect light (levogiro and dextrogiro).*
- **AV6** – *Chiral carbon, isomers – levogyrus and dextrorotus.*
- **AV9** – *Mirror reflecting what we see, levogyres and dextrogiros.*
- **AN4** – *It is a type of spatial isomeria or stereoisomery.*
- **AN8** – *To stop, to fit because it is the same, but not to fit because it has a difference. Ex: a hand in front of the mirror.*
- **AN10** – *The isomers have the same molecular formula, but are differentiated by their optical activity.*
- **AN14** – *Different beams of light that go to both the right and left sides.*

Therefore, in the a priori create category, the allocated students were the ones who established some connection with the concepts addressed in the class, however, due to the brief citations, we observed that they remember only the characteristics presented of the Optical Isomers, where it is not possible to interpret if there was appropriation of the concepts, or only

the establishment of referential links with some of the characteristics that represent them. We consider that these students have only mastered parts of the concept presented.

We understand that students AV1, AV4, AV5, AV6, AV9, AN4, AN8, AN10 and AN14 used the referential structure because they were able to associate the Optical Isomery to some fragments of the concepts addressed in class, however, they do not describe them completely and do not make differentiations and attributions. Possibly, when using drugs with the STS approach to approach the concepts, due relevance was not attributed to these students.

When thinking about the elaboration of the didactic sequence, we deduce that the drugs may have been used at some point in the students' lives, but we consider that in relation to the classes, they are not able to retrieve in their memory well-constituted aspects such as relating the enantiomers, arising from the explanation using the drugs chloroquine and hydroxychloroquine, because they are not common to students, even though it stood out during the pandemic period. Thus, the citation of the "mirror" that was used as an example, attracted greater attention and was memorized due to the "mirror" being present in the students' daily lives and being part of their culture.

In this sense, Paivio (2014) points out that, for the derivation of knowledge, episodic memory is used, as it helps in the memories of lived experiences and the information that is relevant is stored and can be retrieved when there is a stimulus, whether auditory or visual, however, for this occurrence these memories must be significant for individuals, which, already having some pre-established reference, can change them and construct new meanings.

Considering the episodic memory, we observed that the third-year students had not made contact with the studies of stereoisomerism until the moment of the application of the research and, thus, we verified the need for consolidated concepts that precede the content of the Optical Isomery for the constitution and attribution of meanings to be produced later by students.

As observed, varied responses were emitted when establishing connections with the word "Optical Isomery", and from the immersion and allocation established in the analysis of the a *priori* category to create, they led us to evidence them starting from intuitively emergent categories, as they did not contemplate the descriptions that were established in the first moment, however, after immersion in the units of analysis, The assignments carried out mediated our investigations, enabling new discoveries.

Thus, the emergent category one was evidenced, which we called "associates with the didactic resource", and in it we allocated the students who associated the word "Optical Isomery"

only to the didactic resource that was used to expose the structures, which were accompanied by a narration of the concepts performed by the teacher.

After the application of the didactic sequence and the presentation of the content with the help of the pedagogical didactic resource the holographic pyramid, the students performed the attributions of the word Optical Isomery with the 3D images, the holograms and the visualization, that is, the established associations made reference to the didactic resource. Therefore, in order to analyze and interpret these associations established in the didactic resource, we allocated students AV3, AV8, AV10, AN2, AN13 and AN15 in the emerging category one, as we can see in the transcribed and representative answers below:

- **AV3** – *In my imagination it would be something visual like an ologram*.
- **AV8** – *A way to visualize formulas and make them easier to understand*.
- **AV10** – *Some existing object, person, or something being transmitted in 3D*.
- **AN2** – *Image, view the isomeria from various angles*.
- **AN13** – *Projection through drawings and mirroring*.
- **AN15** – *The concept and the drawings*.

Based on the analysis, we clarify that the students who contemplated this emerging category were those who considered the connections between the "Optical Isomery" and the images reproduced from the technological apparatus. Based on the theoretical studies of Paivio (2014), we point out that the verbal system of these students was activated by associative connections, leading them to reference the word with the pedagogical didactic resource that provided the visualization of the concepts, because due to the use of technology, the aesthetic and symbolic mode was awakened in the students' brain functions.

In addition, Paivio (2014) describes that in associative processing, the association between images, objects, and words is what allows the attribution of a name to them, and in this way, a referential process is formed, which can contribute to a broad development of properties about language, education, technology, and creative thinking. In fact, we verified that the attraction to the technology used captured the attention of the students who contemplated the emerging category one and we evidenced that the connections between the verbal system and the visual system were activated, however, the verbal transfer capacity of these students turned to the holographic images, the didactic resource and the projection used in the classes.

However, there were students who, when making their associations, attributed them to factors external to what we expected, that is, these students did not make associations with the

STS approach used in the approach by means of medications, they did not associate them with the concepts promoted about Optical Isomery or with the pedagogical didactic resource used in the application of the didactic sequence. Thus, these students were allocated to emergent category two, which we called "other associations", being AV2, AV7, AN3, AN5, AN6, AN9 and AN16, we followed this referral due to the representative responses obtained and which can be observed below:

- **AV2** and **AV7** – *Something to do with vision*.
- **AN3** – *Drawing*.
- **AN5** – *A drawing comes to my mind*.
- **AN6** – *Something related to light*.
- **AN9** – *Image*.
- **AN16** – *Various points of view of some object*.

We can infer that the students who contemplated the emerging category two were those who did not establish connections with the concepts addressed during the classes and, therefore, are unable to describe or associate them with the word "Optical Isomery" when viewing it. From the point of view of the Double Coding Theory (Paivio, 2014), we consider that for these students there was no representational connection with the new information that was promoted from the classes and thus, they were not able to emit a verbal or non-verbal representation in response to the questionnaire.

In view of the above, we emphasize that for these students there was no establishment of connections between the concepts approached from the technology and the word "Optical Isomery", which was made available in the research statement. In order for the association to occur in an assertive way, a previous experience of the students would be requested, in a school teaching promoted from technological devices and facilitated by images, in this way, they could generate connections and assertive representations and would be prepared for the interpretation and construction of meanings.

We analyzed that the attributions performed by these students refer to referential connections existing in their daily lives, such as cartoons and light, which are factors already constituted in their memory since childhood and that were rescued during the approach in class, but there was no change in the information already consolidated in the long-term memory.

In this sense, we highlight, according to Clark and Paivio (1991), that the activation of the verbal and non-verbal system and the elaboration of representations and connections may

vary according to each individual, depending on the accesses made possible in their long-term memory with previously established experiences. Therefore, we defined that the amount of stimuli needed during the class for pre-established mental records to be activated could have a greater load of relationships with everyday life, enabling an integration between the promoted concepts and existing references.

Furthermore, Clark and Paivio (1991) point out that the lack of concrete references makes it difficult to establish connections between a word and an image, which can become abstract in the representation to be generated by the student's memory. However, the possibility of images accompanied by narratives of the concepts can contribute to the activation of the verbal system from the visual activation and generate significant representations to the students, as they were inserted in a new methodology that will later contribute to the memories when the verbal or non-verbal system is activated.

Finally, we emphasize the importance of the non-verbal system in the construction of educational knowledge, because concrete images, which represent the concepts, help in the comprehension and retention of these, enabling the student to associate the content with mental images. Therefore, for concepts that have abstraction and need imagery references for understanding, we recognize the potential of 3D images, promoted by a holographic pyramid for the teaching of Optical Isomery, applied in a didactic sequence with a STS focus.

FINAL THOUGHTS

In this article, we seek to analyze the collaboration of 3D holographic images as contributors to the teaching of Optical Isomery in an approach with a STS focus and their collaboration in the construction of concrete memories. Thus, when we analyzed the associations emitted by the students when the word "Optical Isomery" was made available in a research questionnaire, we found that not all of them contemplated the a *priori* category to create, based on what we expected when applying the research.

However, the students who contemplated it were those of whom we consider to have used the three levels of processing established by Paivio (1971), which are referential, representational and associative processing. We observed that the verbal system was the one that predominated among a majority of the students, who could also express the answers from images and demonstrate knowledge from the non-verbal system. We conclude that the 3D holographic images contributed to the process of building concrete memories, however, the teaching based on

images should be improved throughout the academic trajectory of the students, being able to achieve greater meanings among them.

The teaching method based on a didactic sequence, with a CTS focus and the use of the didactic resource holographic pyramid for the presentation of concepts through 3D images, contributed to the storage of information in long-term memory, where it can be retrieved in the presence of some stimulus, whether by the verbal or non-verbal system. as demonstrated in the a *priori* create category.

However, some students need more experience in teaching promoted by technological devices, we point out this conclusion due to the answers attributed to the questionnaire that were allocated in the emergent category one, called "associates with the didactic resource". We warn that, if there is a scarcity of technology in the classroom, when the teacher performs an intervention with technological didactic resources, it stands out.

When students are not adapted to using technology for learning, their understanding is focused on the understanding of the didactic resource and seeks to understand how the technological process works, interfering in the understanding of the concepts promoted in the classroom. In view of this, we highlight the importance of teaching promoted from technological devices and its contribution to learning, because by getting used to technology applied to teaching, the student will turn his attention to the knowledge to be acquired and not only to the didactic resource itself.

We show that the path that leads students to the construction of knowledge must be well consolidated with concrete references, from which they can retrieve in their memory and attribute new meanings that enable learning. According to the Double Coding Theory, pre-established experiences can help the teacher in the elaboration of the class and in the architecture of the stimuli used in it, favoring an integration between the promoted concepts and existing references (Frederico, 2016). For this, previous contact with the contents of stereoisomery is necessary, favoring the understanding of the concepts of Optical Isomery.

By virtue of the aforementioned facts, when analyzing and studying the construction of knowledge from images, we emphasize the potential of the Double Encoding Theory for data analysis, when applied the use of images for teaching, mainly, contemplating abstract contents that represent the microscopic and symbolic levels existing in the teaching of Chemical science, also contemplating Optical Isomery. And we conclude that the use of didactic pedagogical resources offered by technological devices, such as the holographic pyramid, are essential in the school environment, motivating and allowing the consolidation of learning.

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