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UNCOVERING THE ORIGINS OF MENTAL IMAGES ABOUT THE CONCEPT OF LIGHT: THE DIFFERENCE BETWEEN NOVICE AND EXPERT MEDIATION LEVELS PROFILE

Desvendando as origens das imagens mentais sobre o conceito de luz: a diferença entre o perfil dos níveis de mediação iniciante e especialista

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Abstract

This study investigates the mental imagery formed by two Physics undergraduates following their interaction with a mobile application analyzing emission and absorption light spectra. The tool, an instance of extracerebral cognitive processing, served to illuminate the internal cognitive mechanisms the students employed to understand novel knowledge. Guided by the Cognitive Networks Mediation Theory (CNMT), which underscores the significance of external tools in facilitating cognition, and drawing upon Bachelard's Epistemological Profile and Mortimer's Conceptual Profile, a novel 'Mediation Level' Profile is proposed. This profile represents the preferred type of mediation each student employed to elucidate their observations and understandings. The research utilized the Report Aloud Protocol to analyze students' verbal and gestural communications, revealing a complex pattern of various mental images developed through interaction with external objects via different levels of mediation. Notably, the psychophysical and hypercultural mediation levels stood out among the students. The implications of these findings for Physics education and future research directions are discussed, underscoring the utility of mobile applications as a supplementary tool in laboratory settings and the complexity of mental imagery in understanding physical phenomena.

Keywords: Physics Spectroscopy; Physics Teaching; Cognitive Networks Mediation Theory; Mediation Level Profile.

Resumo

Este estudo investiga as imagens mentais geradas por dois alunos de graduação em Física após a interação com um aplicativo móvel que analisa espectros de emissão e absorção de luz. A ferramenta, uma instância de processamento cognitivo extracerebral, serviu para iluminar os mecanismos cognitivos internos que os estudantes empregaram para entender um novo conceito. Fundamentada na Teoria da Mediação Cognitiva, que enfatiza a importância das ferramentas externas na facilitação da cognição, e recorrendo ao Perfil Epistemológico de Bachelard e ao Perfil Conceitual de Mortimer, é proposto um novo 'Perfil de Nível de Mediação'. Este perfil representa o tipo preferido de mediação que cada aluno utilizou para elucidar suas observações e compreensões. A pesquisa utilizou o Protocolo *Report Aloud* para analisar o discurso verbal e gestual dos estudantes, revelando um padrão complexo de várias imagens mentais desenvolvidas através da interação com objetos externos via diferentes níveis de mediação. Notavelmente, os níveis de mediação psicofísica e hipercultural se destacaram entre os estudantes. As implicações desses achados para o Ensino de Física e as direções para pesquisas futuras são discutidas, destacando a utilidade dos aplicativos móveis como ferramenta suplementar em ambientes de laboratório e a complexidade e riqueza das imagens mentais na compreensão de fenômenos físicos.

Palavras-Chave: Espectroscopia Física; Ensino de Física; Teoria da Mediação em Redes Cognitivas; Perfil de Nível de Mediação.

INTRODUCTION

As Physics is often considered a distinct subject among high school and higher education students, and teaching it remains one of the most crucial and demanding tasks for educational systems worldwide, particularly in developing countries. The study of light and its interactions with matter is of significant importance, not only for physics but also for various other scientific disciplines. Interdisciplinary approaches are one effective way of addressing the challenges of teaching such topics.

The study of spectroscopy has played a prominent role in advancing scientific knowledge, beginning with the understanding of light itself and subsequently leading to the identification of chemical elements (Ivanjek, Shaffer, McDermott, Planinic, & Veza, 2015a). The term "spectrum" was first used by Sir Isaac Newton in the 17th century when he observed the decomposition of visible light, marking the beginning of spectroscopy. By the 19th century, the existence of infrared (IR) and ultraviolet (UV) radiation had already been acknowledged, leading to the development of optical equipment capable of recording some of those spectra through various means, such as different flame colors and radiation emitted from gases subjected to electrical discharges. Spectroscopy has played a fundamental role in physics, serving as the basis for investigations that facilitated the advancement of Atomic Theory and the emergence of Quantum Mechanics, which transformed the course of Physics during the 20th century. As such, spectroscopy is of great importance not only for the development and testing of theories but also has numerous practical applications, including the determination of the concentration of constituents in drugs and food, criminal investigation, identification of chemical elements in various contexts, and the production of new materials, among many others.

Due to its interdisciplinary nature, the study of spectroscopy has the potential to promote integration between the fields of natural science, including physics, chemistry, and biology. Additionally, it can facilitate the inclusion of experimental activities in formal teaching environments (Vanderveen, Martin & Ooms, 2013). However, the high cost of a spectrometer presents a significant obstacle for schools and universities, particularly those in developing countries like Brazil. One potential solution is the use of smartphone applications and less expensive materials. This raises the question of whether these cheaper, digitalized experiments are effective in building a more sophisticated conceptual framework in students' minds as they progress from being a novice to an expert.

There has been extensive research on the differences between novices and experts (Chi, Feltovich, & Glaser, 1981) and their cognitive processes (Clement, 2019, 2020; Tweney, 1985, 2010; Nersessian, 1995), particularly regarding the mental images they use to understand concepts or solve problems. Mental images are crucial for model building (Stephen & Clement, 2012, 2010), and it may be useful to identify the external objects from which these images are derived. These objects could include physical objects (psychophysical mediation), interactions with other people (social mediation), cultural objects such as books (cultural mediation), or even with computers and mobile phones (hypercultural mediation) (Souza *et al.*, 2012).

In this study, we report on the use of mental images derived from students' interactions with various extracerebral tools[1], both during didactic interventions and in their daily lives, to understand key concepts related to the use of low-cost optical equipment. Our objective was also to develop a "Mediation Level Profile," inspired by Bachelard's (1985) epistemological profile and Mortimer's (1995) conceptual profile, to qualitatively document the relative importance of each level of mediation expressed individually by expert and novice students when explaining concepts related to the nature of light following the use of a spectrometer.

LITERATURE REVIEW

First-year university students often rely on the scientific concepts they internalized during their high school education to build their understanding of complex topics. However, several studies have shown that students often struggle with developing a sufficient understanding of light due to the difficulty in comprehending the models they were previously exposed to in school (Sengören, 2010; Maurines, 2009; Colin & Viennot, 2001). While some research has been conducted on how students think about the properties of light and their relationship with the process of sight, relatively little has been done to address their understanding of light itself (Coelho & Borges, 2010; Uzun, Alev & Karal, 2013; Kesonen, Asikainen, & Hirvonen, 2017).

[1] Extracerebral tools is an expression derived from Cognitive Mediation Networks Theory, in which the use of extracerebral mechanisms (extracerebral tools or mediations) of information processing represent a cognitive advantage if they serve as 'auxiliary coprocessors' of the brain.

Uzun, Alev, and Karal (2013) investigated the understanding of light in 98 Turkish elementary, high school, and university students using open and multiple-choice questions, as well as a drawing exercise. Their results indicated the existence of a two-part process in describing light, first recognizing its structure and nature as a physical entity and then recognizing its interactions with the environment and effects. They also found that elementary school students were inclined to view light as "lighting, the possibility of life, and light sources," thereby interacting with different scientific disciplines, whereas middle school and university students understood light as a more abstract, undulating entity.

Kesonen, Asikainen and Hirvonen (2017) studied the comprehension of the "ray" and "wave" models of light in 60 freshman students enrolled in Basic Physics. They found that subjecting the students to experiments using different external objects, particularly lamps and lasers, triggered substantially different sets of ideas. This suggests that at least a portion of the difficulties often found in their understanding of light and its behavior may be due to their previous experiences with light sources or even with the specific devices commonly used in earlier levels of education.

Métioui (2023) conducted a study with 132 elementary school teacher trainees in Quebec, examining their alternative conceptions about the interaction of light with matter and the formation of shadows. The study, part of a four-year bachelor's program, revealed that the majority of participants face significant conceptual difficulties in explaining phenomena related to light, which are commonplace in their daily environment. A specific conceptual difficulty highlighted was the understanding of the concept of light absorption. Métioui (2023) emphasizes the need for assistance to students in developing concepts of light absorption and diffusion. This study underlines the importance of effective teaching methods, including more interactive and visual approaches, to overcome difficulties in understanding the complex aspects of light.

The perception of light as a physical phenomenon and its complex interactions with other objects seems to progress as individuals advance through childhood, adolescence, and adulthood, as well as through increasing levels of education. However, there remains a palpable lack of knowledge regarding luminous phenomena, with a significant portion unable to explain the concept scientifically. Students appear to build their concept of light through psychophysical mediation (interaction with different objects and light sources), social mediation (interaction with teachers and colleagues), and cultural mediation (books and organized curricula concepts). Therefore, the use of more sophisticated devices to interact with light in educational settings could lead to a valuable gain in understanding its complexities.

The research by Puspitaningtyas *et al.* (2021) demonstrates that the implementation of virtual laboratories and structured teaching methods leads to significant improvements in students' understanding of the theory of light waves. This finding supports the thesis that didactic approaches incorporating technologies and interactive practices are effective in teaching abstract physical concepts. The study further highlights that high school students tend to limit themselves to geometric optics in studying wave phenomena, a tendency that persists into higher education, as evidenced by a university student referring to light as a "ray" during the analysis phase of the article's results.

Additionally, Assem *et al*. (2023) point out that common misconceptions about physical concepts can negatively impact students' academic performance and understanding. This issue is also addressed in the study by Aykutlu, Ensar and Bayrak (2022), which examines erroneous conceptions of light polarization among future physics teachers. Using a qualitative case study approach, the authors administered a questionnaire with five open-ended questions to 20 university students, followed by semi-structured interviews with 11 participants. The results indicated that the participants had an incorrect or insufficient conceptual understanding of light polarization, linked to a deficient understanding of the nature of light. As a recommendation, they suggest the use of simulations to enhance understanding of the electromagnetic nature of light.

Another factor affecting student performance is the lack of contextualization in their studies (Dogru & Kurnaz, 2023). Dogru and Kurnaz (2023) investigated how tenth-grade students in Turkey applied optical principles, finding that most had difficulty associating optical events such as reflection, refraction, and mirage with real-life contexts. The research revealed a significant gap in students' ability to contextualize optical concepts, pointing to the need for more effective teaching strategies in physics, especially in optics.

Based on the literature, there is an opportunity for better teaching of the concept of light and its properties through the use of more sophisticated devices, if economically viable. Such a device has been developed by a group at the Universidad Privada Boliviana in Colcapirhua, Bolivia: a low-cost spectrometer that can be easily set up by teachers and students at practically all levels of education. The system utilizes a smartphone with a diffraction grid (made from a CD or DVD) attached to its camera, controlled through an application called SpectraUPB[2], which displays the visible light spectrum graph in real-time, given in terms of the wavelength of the light, for a sample under analysis.

Malisorn *et al.* (2019) demonstrated the viability of using smartphones as both sources and detectors of light in a sequence of activities performed in Thailand. They measured the scattering of light as it passed through a sample using the Beer-Lambert Law and did not require any specialized equipment. Silva *et al.* (2014) had already proposed the use of LEDs in educational optical experiments, given their advantages of intensity, efficiency, low voltage, and low cost. Grasse, Torcasio and Smith (2016) also previously suggested the use of food dyes to perform absorption experiments. They made a strong argument for introducing spectroscopy studies using low-cost equipment, commonly found kitchen ingredients, and smartphone applications at the beginning of undergraduate education. Taken together, these references indicate the viability and effectiveness of using low-cost spectrophotometers, different light sources such as lamps and LEDs, and food dyes diluted in water to perform educational activities that can familiarize students with the use of these materials for scientific experiments and the phenomena involved in them. This promotes a better understanding of the underlying concepts.

The study by Tumanggor *et al.* (2019) focuses on the profile and learning difficulties of high school students regarding optical instruments. Employing a survey research methodology with 65 students, it was found that the average problem-solving ability score was 1.78, placing the majority of the students in the novice category (69.23%). The expert students (30.76%) approached optical problems using appropriate concepts, principles, and laws, while the novices were limited to inserting values into equations without proper interpretation. The authors suggest the need for teaching strategies to enhance students' problem-solving skills in optical instruments.

The current study emphasizes the use of mental images derived from interactions with extracerebral tools, such as mobile apps, for understanding optical concepts. This approach could be effective in developing deeper and more conceptual problem-solving skills, in contrast to the procedural mathematical approach observed in the study by Tumanggor *et al.* (2019). Additionally, the use of low-cost optical equipment, such as spectrophotometers built with smartphones, is suggested to make the teaching of optics more accessible.

This article proposes a "Mediation Level Profile" to qualitatively document the relative importance of each mediation level expressed by expert and novice students in explaining concepts related to the nature of light. This could assist in identifying and addressing specific difficulties faced by students.

Özcan (2015) provides insight into the understanding and interpretation of the nature of light by future physics teachers, emphasizing the use of different mental models in various contexts. These mental models are cognitive representations used to interpret phenomena and are essential for comprehending abstract concepts such as the nature of light. Students employ a range of models, including beam ray models, hybrid models, and particle models, reflecting their mental images of light. The study identifies a state of mixed model in some students, indicating flexibility and continuous development in their mental representations.

Özcan's (2015) findings highlight the importance of didactic approaches that aid in building and refining students' mental images. Understanding and addressing the mental models of students is crucial for effectively teaching complex concepts such as the nature of light, corroborating the significance of research on the interaction between mental imagery and the level of mediation in students to understand their difficulties.

There is a solid theoretical framework that supports the notion that understanding complex concepts, such as those related to the physics of light, is a cognitive process involving the building of mental images through interactions mediated by objects and images, as well as sociocultural mechanisms. This provides additional evidence for the efficacy of the didactic approach addressed in this paper and an explanation of how it works.

THEORETICAL FRAMEWORK

The present research used as a theoretical referential Cognitive Mediation Networks Theory (CMNT) originally proposed by Souza (2004; 2012) which is a cognitive theory that tries to understand the cognitive changes associated with the emergence and dissemination of information and communication technologies over the past decades. CMNT is a contextualist, constructivist theory that aims to provide a broad approach

[2] Available at: https://www.upb.edu/en/contenido/spectrometry-software-for-android

to human cognition and is founded upon a set of five basic assumptions regarding human cognition and data processing:

> *[…] 1) The human species has as its most important evolutionary advantage the ability to generate, store, retrieve, manipulate, and apply knowledge in various ways; 2) Human cognition is effectively the result of some form of information-processing; 3) Alone, the human brain constitutes a finite and, ultimately, unsatisfactory, information-processing resource; 4) Practically any organized physical system is capable of executing logical operations to some degree; 5) Human beings complement their cerebral information processing by interacting with external organized physical systems. (Souza et al., 2012, p.2).*

The CMNT proposes that cognition is an information-processing phenomenon and that digital technologies have an impact on human thinking. This is due to the brain's inherent limitations to process all available information, which results in much of the processing occurring outside of the brain. The brain compensates for this by utilizing external processing through its interaction with environmental structures, thereby increasing its own information processing capabilities.

For example, when we use a computer or cell phone to process information, or even perform a more complex calculation, we are using it as an external mediation mechanism. To effectively use any device, we need to create some internal mechanisms that allow us to handle this device and understand not only how to operate it (provide inputs), but also the information that it is offering us (understand outputs). These internal mechanisms allow the use of said external mechanisms and function, cognitively, as virtual machines (or drivers, building an analogy with computation), which develop from the interaction between the individual and the external structures in order to complement the information processing.

Thus, students create drivers both when learning to handle the SpectraUPB interface, and during the development of activities or even in their previous daily or school experiences. Finally, CMNT sets that cognition and learning through extracerebral processing is performed at different levels of mediation, by interacting with different external processing tools, present in what can be grouped into four different levels of mediation:

- Psychophysical (physics of objects in the environment),
- Social (other more capable individuals),
- Cultural (cultural objects, like books or television),
- Hypercultural (programmable machines, like computer or cell phone) tools.

Each of these levels of mediation mark a specific historical period in the development of humankind and from an evolutionary perspective they represent progressive cognitive gains that are reflected naturally in learning. It is through the use of external mechanisms present in these different mediations that students will develop mental representations and differentiated drivers, which can facilitate learning, which for us takes the form of building specific representations that enhance the student's problem-solving capabilities as well as gaining insights on a particular concept. Previous work suggests the theoretical contribution of CMNT for presenting Mediation and Extracerebral Information Processing as mechanisms that assist in cognitive processing when developing activities with the Bohr atom (Freitas, 2019) or in understanding fundamental concepts of Quantum Mechanics (Trevisan, 2018).

It is natural that everyone, when solving any problem, uses not just one, but several different external mediations that intertwine and compose the repertoire of mental images and drivers that the individual uses to solve the problem. As discussed in Meggiolaro's (2019) contribution, in which the author suggests that students use various levels of mediation when reporting a single concept, for example:

In the discussion of the resultant electric field vector, where the student must sum all vectors of the individual electric field produced by all changes, we conclude that the five students pointed out that the combined use of the external mechanism of social, cultural and hypercultural mediation provides subsidies for the representations and drivers acquired referring to the notebooks, exercises, classes, and computer simulation in GeoGebra of the concepts covered. (Meggiolaro, 2019, p.153).

Borrowing from Vergnaud (1982) that argued that "one situation isn't solely with a since concept as well as a concept isn't formed by solving a single class of problem", it seems that a single situation or concept is often cognitively processed by representations from multiple levels of mediation. The mental images that populate the student's cognitive structure may therefore come from different levels of mediation. When observing the diversity of mental images from the different external processing mechanisms employed by each student in this research, we conjecture that it is possible to draw a Mediation Level Profile for each student, for a given concept, which would indicate which mediation levels are preferably used by the student, when using a concept to solve a specific problem. The idea of creating a Mediation Level Profile was inspired originally both from the constructions of Bachelard (1985) and Mortimer (1995), who study the problematic of solving scientific problems with the Epistemological and Conceptual Profiles, respectively.

Gaston Bachelard (1979) argues in some of his works, as "The New Scientific Spirit (Le Nouvel Esprit Scientifique)" (1934) and "The Philosophy of No (La Philosophie du Non)" (1966) the need to accept that different philosophies can be present in the same sense of a concept, even though some of them are consciously considered inadequate to characterize a certain notion of scientific knowledge. Bachelard (1966) exposes ideas linked to the term he calls “epistemological profile (profil épistémologique)”, with the proposal that the concepts are, in their development course, somewhat attached to some philosophical points of view (animistic, realistic, empiricist and rationalist) depending on the student’s stage of maturity. In other words, a student can present different representations or ways of seeing a scientific concept. Therefore, the philosophical currents, for each student, are drawn according to the evidence of the degree of importance when expressing the frequency of effective use of the notion of the concepts worked on.

Trevisan and Serrano (2016) examine the relationship between Cognitive Mediation Theory (CMT) and the ideas of philosopher Bachelard, with a focus on the study of scientific knowledge production. The authors utilize CMT as a theoretical framework to analyze the impact of mediation through hypercultural tools, such as software simulations of quantum mechanics experiments, on students' cognitive structure and epistemological profiles. Additionally, they employ Bachelard's conception of epistemological obstacles to investigate students' conceptions of wave-particle duality, a fundamental concept in quantum mechanics. Thus, the article explores the impact of cognitive mediation through hypercultural tools on students' cognitive structure, while investigating students' conceptions of wave-particle duality. It establishes connections between these conceptions and the main interpretations of quantum mechanics, as well as maps the philosophies that influence their understanding.

From Bachelard's ideas, Mortimer created the notion of conceptual profile (1995, 2000), in which a single concept can be dispersed in different zones that correspond to the different ways of seeing, representing, and meaning the world, so that, anyone can have more than one way of understanding reality, which can be used in appropriate contexts. According to Mortimer (1995, p.274) “taking the notion of Conceptual Profile (CP) into account, the problem of learning and teaching science may be considered in a new way”. From it, obstacles to the learning of concepts can be identified and worked on in the classroom in a vision of science learning as a change in conceptual profiles, where the student does not necessarily need to abandon his conceptions when learning new scientific ideas but become aware of these different zones and the relationship between them. For the author “the students' previous ideas play a fundamental role in the learning process” (Mortimer, 2000).

Mortimer (1995) applied the notion of conceptual profile to two concepts related to the theory of matter: atomistic conception and physical states. In these works, the author analyzed the obstacles arising from each zone of the profile that was established, which allows describing the concept formation process, in science classrooms, in a way that is consistent with the idea that different points of view can be complementary. Each zone in a conceptual profile offers a way of looking at the world that is unique and different from other zones, which corresponds to different forms of mediation, to different theories and languages, which translate the world into its own forms. Reality itself cannot be understood entirely from a single perspective because only a complementary view can produce a complete picture.

Using the aforementioned profile ideas, the Mediation Level Profile is drawn up, based on the CMNT’s four different levels of mediation described above, for each of the concepts presented by the students. This profile seems to be useful to visualize the most relevant mediations (psychophysical, social, cultural and hypercultural) to offer the student specific mental images that helped them to understand the concept, as well as the transitions between external mechanisms.

The notion of conceptual profile shares some characteristics with the epistemological profile, such as the hierarchy between different zones of the profile, with each zone being successive, the epistemological profile starts from naive philosophy to scientific thinking and the conceptual profile from the oldest to the modern. This is also proposed and organized in the research presented, since the Mediation Level Profile is part of the psychophysical mechanism, being the first to emerge through interactions with the environment, and finally reaching, chronologically, at the hypercultural that arises from the Digital Revolution. Mortimer's understanding of his conceptual profile also indicates that Reality can only be grasped by a complementary view of the different conceptual profile zones, each being developed by the student. Likewise, the Mediation Level Profile naturally shows how the understanding of a particular concept by a student is made by a mosaic of different mediation levels representation and drivers, from different external processing objects. If said mediation level profile of a particular student's concept is relatively populated with representations from the psychophysical level of mediation, it may reveal poor interaction with the teachers (social mediation), cultural artifacts as books or even sophisticated simulations that could offer empowering representations of the phenomena pertinent to the concept.

RESEARCH PROBLEM AND METHODOLOGY

Our research problem is: What is the Mediation Level Profile emerging from each student when answering questions about spectroscopy?

To answer this question, we also made use of two auxiliary question: Which different mental images are used by students to explain the absorption and emission of light after using a cell phone application that analyzes emission and absorption spectra? And from which different levels of mediations do novice and expert students mental images originate to explain the nature of Light after doing a mobile-based spectroscopy experiment?

When explaining or clarifying an issue, a person typically forms a mental image. As postulated by the theory discussed in this article, this mental image can arise from various forms of mediation, including psychophysical, social, cultural, and hypercultural mediations. Psychophysical mediation, for example, suggests that the mental images generated are related to everyday situations and interactions with environmental objects, such as preparing food using specific utensils. In the realm of social mediation, the mental image focuses on interaction with other people or groups. In cultural mediation, the emphasis is on the use of symbols and cultural artifacts, exemplified by engagement with signage or reading a book. Finally, in the context of hypercultural mediation, mental images involve the use of advanced technologies, such as interacting with mobile devices to perform a variety of tasks.

Therefore, our research goal is to use a cell phone application and low-cost materials for the study of emission and absorption spectroscopy – that could be used in the classroom. Thus, we are employing different mediations, throughout the activities described below, for the process of building knowledge on the concepts of light and color (emission or reflection). It is also understood that the students' previous experiences will also be recalled during their reasoning, from different levels of mediation and, therefore, for the analysis of which external processing mechanisms are most present in the student's reasoning, we draw the Mediation Level Profile trying to identify the predominant level of mediations used by each student.

The research was developed with a sample of 6 students who were studying between the second (sophomore) and last year (expert) of the Physics Education Undegraduation course of a private educational institution, in the year 2018. The procedures were previously scheduled with the students.

The activities that were planned for the applications employed a cell phone, a CD (used as a diffraction grating), a tube made of cardboard and electrical tape, light sources (incandescent lamp and LED's) and colored substances (water containing food dyes). Those low-cost materials are easy to find in most developing countries. The SpectraUBP application, has a simple and intuitive interface, just opening it is already possible to view the spectrum of the sample under analysis. It is necessary to calibrate the measurement, but the app guides the user in the whole process.

Through the analysis of each student, we aim to identify which mental images (and from what mediation they were developed) are used by the students to answer questions about light phenomena experienced by the student with the use of the spectrometer. And, with that, build the Mediation Level Profile of the students. Essentially, the didactic implementation of this experiment can be divided in in four stages:

STAGE I: In the initial stage, we explained the students the research proposal and asked their consent to participate in the study. Questions were asked about the content, in the form of a conversation, to assess the students' individual previous knowledge.

STAGE II: A pre-test was prepared by the authors and applied to students, before they had contact with the application, or the materials arranged in the activities. Each student answered the pre-test individually. The pre-test questions were in the line of “Explain, in your words, how different sources of light emission are seen in different colors: For example, a red LED and a blue LED (or when light is incident on a red/blue shirt)”. After the pre-test, an expository class was given, addressing the concepts related to spectrophotometry, with the aid of a slide presentation.

STAGE III: The students were asked to download the SpectraUPB application to their cell phones and the materials for the application of the activities were made available. Stage III was divided into two tasks and developed based on two guides (scripts), given to students, who used the application and the experimental arrangement by themselves. The script was used according to the POE (Predict-Observe-Explain) strategy, in which students are asked to predict the behavior of a problem-situation or an experiment, observe it and, after these steps, explain possible differences between their predictions and what was observed (Tao & Gunstone, 1999).

Script I - Light emission: In the cell phone's camera, a small part of a CD-ROM was placed without the reflective film, which serves as a diffraction grating, and a tube containing an opening (slit) in the front, through which the light passes and reaches the mobile camera, to create the low-cost spectrometers. Each student was able to measure the emission spectrum of an incandescent lamp and colored LEDs, following the guide.

Script II - Absorption: The second stage was related to the absorption of white light, the spectrum seen after the light source falls on water containing blue or red dye (Figure 1).

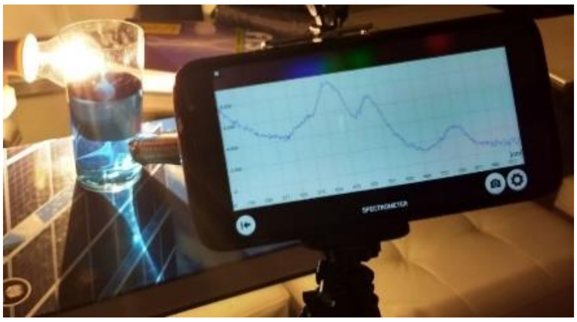


Figure 1 - *Demonstration of the absorption experiment with a blue dye.*

STAGE IV: After the activities using the application, a post-test was applied individually to the students, containing similar questions and related to the content covered in the pre-test, emission and light absorption (light sources or objects that reflect a certain color). At the end of the evaluation, the interviews were made. The interviews were semi-structured and conducted individually with each participant, focusing on his/her post-test questions’ answers. The interviews were conducted according to the Report Aloud protocol (Trevisan, 2019), adapted from the Think Aloud technique (Van-Someren, Barnard, & Sandberg, 1994). The most striking difference between both methods is that in the former the interview is made after the students answer the post-test, without interventions. In other words, during the interview, students are requested to describe their process of conducting the tests, including aspects such as their perceptions and thoughts at the time of execution, for example. The interviews were recorded (on video) and transcribed, for later analysis.

The verbal language, present in the interview transcripts, and the written language, present in the data collection instruments, were then analyzed. In turn, the non-verbal language, characterized by the depictive gestures (gestures used to describe something imagined) performed by the students during the interviews was analyzed based on the methodology used in Monaghan's and Clement (1999) line of work. By analyzing the combined verbal and written language, we could infer the relationship between mental images present in the student's cognitive structure and gestures performed by the student.

By asking them, during the interview, where those images came from, it was possible to identify the source of the mental images, in a specific mediation with an external processing mechanism. Whereas the Report Aloud protocol focuses on collecting verbal descriptions from students about their cognitive processes during test execution, Monaghan and Clement's analysis is directed towards non-verbal language, examining the students' representative gestures to infer the connection between their mental images and physical actions, as well as to determine the origin of these images.

For example, the sequence of images, discussed later, in Figure 2 (a) illustrates a gestural speech made by a student participating in the research and this speech is directly connected to a static mental image. The student, when reporting the concept, makes a gesture describing what he is imagining. This image can be interpreted by the nature of the gestural speech combined with the transcribed verbal speech. During the analysis, we realized that the representation corresponds to a mental image produced during a social mediation (with a teacher), which we label “#TM”. In this way we proceed to all other instances of coded gestural analysis, always labelling them according to what is being described by the student and asking where the image comes from exactly when the student started to produce the specific gesture. This was made for all interviews and transcripts.

ANALYSIS AND RESULTS

In this part of the work, we present the detailed results of the analysis for two exemplary students. One is a senior (A1) and the other is a sophomore (A2) student. A1 has already studied the disciplines of Modern Optics and Quantum Mechanics and A2 did not participate in these disciplines. The subject of light is not treated in any other discipline in the course.

The results are split by the post-test questions used during the interview. During the analysis, we noticed that students used complex patterns of mental images to describe their thinking, coming from different mediations, so that in each answer several different mental images were generated, from not only one, but several different mediations that happened during the subject’s life experiences. In the interviews, the researchers read again the post-test question (that was already answered by the student and written in the test) and question what the student was imagining at the time of answering the question, thus assessing his thinking process.

“Let’s supposed that an open window allows sunlight to pass through and hit a wall. Explain in your own words what is light?”

The first question inquires the nature of light, and a situation is used as a context in which the student may or may not support himself to answer. This question was inspired by the results of Uzun, Alev and Karal (2013), that novice students’ mental representations of light is connected to the psychophysical mediation level, while experts to socio-cultural mediation level, as discussed in the literature review. When explaining what is requested, A1 (senior) begins to express its conception regarding the behavior of light. He starts his reasoning by stating that he imagines the “wave motion of the photons”: "I *can imagine a wave motion of the photons, coming from outside and reaching the wall*" (A1). This resonates with what was found by Uzun, Alev and, Karal (2013), and Kesonen, Asikainen, and Hirvonen (2017) that students finish high school with a light model using rays instead of waves, that is developed during undergraduate courses. The interviewer asks the student whether he had any mental image when answering the question on the test. Continuing his explanation and already answering the question, A1 reports, while gesturing that: “(the photon) *has no color and the size is tiny [#TM] and they have sinusoidal movement*”. (Figure 2).

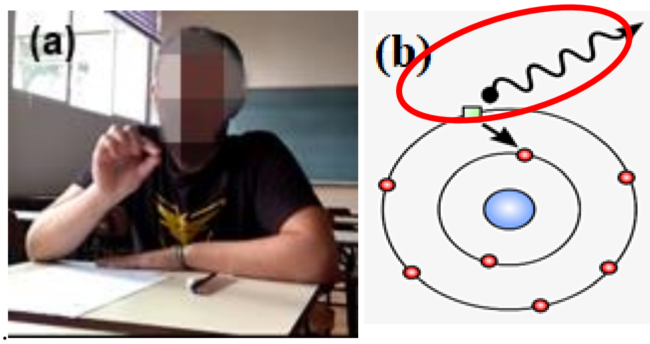


Figure 2 - (a) The image above illustrates a gesture with the fingers of the right hand tighten close, representing the size (small) of a photon. Static image. (b) Figure that most closely resembles the student’s image.

After being asked where that mental image comes from, the student reports that the image comes from a picture draw by a teacher on the chalkboard in a class (social mediations) and give more details allowing the researchers to draw a picture of his mental image (Figure 2). The mental image itself is static (Clement, 1999), but the student, when answering the question uses the static image as it was moving and gestures (Figure 3).

Figure 3 - The sequence of images above, illustrates a movement with the right hand, forward, indicating a trajectory, in this case, the trajectory of a wave carrying photons. This sequence of images received the hashtag #SE. Dynamic image.

Again, the idea of light as an undulating entity was also described being used by middle-school's students in Turkey by Uzun, Alev, and Karal (2013), and just like our exemplary case A1, emerging from social mediations with teachers.

Following the conversation, the student is asked to detail how he 'sees' in his mind's eye the movement that he attributed to the photon, if he can imagine it and he states: "*I know that they exist and that they have movement, but I cannot 'imagine' or 'see'. I see the whole package in the form of light [#LZ]. The package would be a set of waves of different frequencies (Figure 4 (b)) that travel together from the Sun and hit the wall*" (A1). Moreover, when A1 is asked about the color of this "tiny" object, in the student's own words, he says that: "*There are particles, they have a frequency, but, for example, sunlight striking a wall, I cannot imagine a color but white, because there are all the colors there. I would end up seeing only the color of the wall itself. There is a light coming in, but I don't see color like red, just white*" (A1).

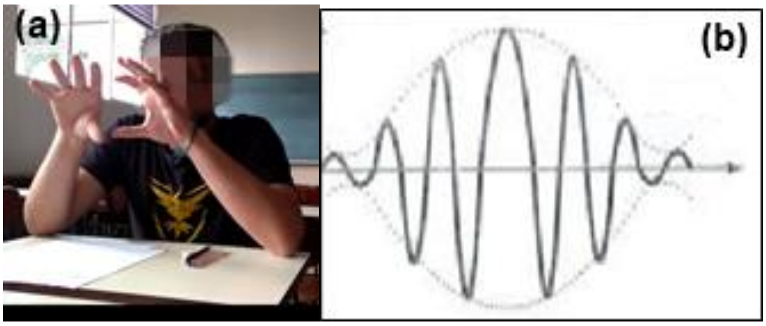


Figure 4 - (a) The image above illustrates a gesture with the fingers of the hands spread and open, representing a wave packet. This image received the hashtag #LZ. Static image. (b) Representation of a photon wave packet, with a sinusoidal shape, as described by A1

After A1 explains his mental image of the nature of light, he is asked about the origin of the mental image: "*In the optics class and in carrying out scientific research and projects. In modern physics and quantum mechanics too*" (A1). Therefore, A1 used different mediations to report his idea of light. Still following in the dialogue: "*The sine wave I saw in books and the photons in the quantum mechanics class. The only image that I can attribute to the photon is spherical (a ball)"* (A1).

From the mental image identified by the analysis of verbal and gestural discourse during the interview, we can uncover the mediations that originated the drivers (or mental simulations) used when reporting their thinking. We understand that the image of a photon alone is "spherical", as seen in classes, with a "sinusoidal" movement that was visualized by A1 in books, as shown in Figure 2 (b). Therefore, we infer that A1 first recalled a psychophysical mediation to obtain a general image of what was being proposed (the wall), based on the image produced and supported by social mediations, such as classes, and then complemented his idea with cultural mediations, books. A total of three different levels of mediations were used to compose the mental image he used to answer this question and build the concept studied in the student’s mind.

Now let’s compare to the mediations used by student A2 (sophomore) to answer the same question. The students elaborate a reasoning around the sun's rays passing through the window to answer the question: “*I imagined the open glass and the light from the incidence of the sun's rays*” (A2). It is noticed that A2 adds a “glass” to the image to represent what was being asked. She continues her speech with the mentioned “sun rays”: “*That if the wall was white, if not, it would be something else. It would have an object that would absorb the light from the sun's rays [#RS] and reflect the object's own light, the color itself, not the light* ”(A2).

Figure 5 - (a) The sequence of images above illustrates hand movement, from right to left, indicating a trajectory, in this case, of the sun's rays. This sequence of images received the hashtag #RS. Dynamic image. (b) Solar rays

The mental image built by the sophomore student to answer the question relies on psychophysical objects seen in the environment (window with glass and sun rays crashing into a wall. As the conversation continues, A2 is asked to dig more into the “sun rays” she described. She replies that “It has all colors” (A2). In the next moment, A2 reports that within these luminous rays there are atoms moving: “*I imagine atoms there, moving. A classic atom [#AC], with a nucleus, protons, neutrons, the electrosphere and electrons*” (A2).

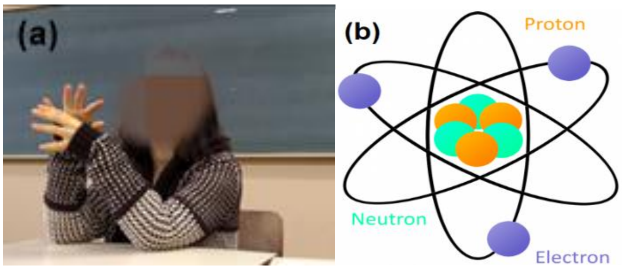


Figure 6 - (a) The image above illustrates a gesture with open hands, representing a classic atom. This image received the hashtag #AC. (b) Representation of an atom

Soon after, A2 describes that she changed her mind and starts to call the “atom” a “photon”: “*Actually, my answer is wrong. I imagine a photon, which is an electron of light, sort of, then that photon comes along with the wave to make the effect, it would be as if it were moving sinusoidally. Several photons that leave a trail”* (A2). The image that the student explains the interviewer is that of a particle that moves “in a sinusoidal way”, that is, that has the behavior of a wave, as already shown in Figure 2 (b), and similar to A1. In the interview, there are indications of a potential conceptual shift occurring in the student's mind. This is evidenced as she corrects herself and discards her previous mental image of light as 'atoms', transitioning instead to a mental image of light as 'light electrons', which she refers to as photons. The authors interpret this change due to the fact that the student is a sophomore, and the process of concept evolution of light between a high-school student and a expert was captured during the interview.

We also ask A2 to go further and remember when she had previously viewed the “sun ray” representation, citing that the image comes “From a rainbow” (A2). Nonetheless, the students also make use of a “textbook” photon image in her description, and the interviewer dig further, “as we can’t see photons in rainbows”: “*No, you do not see. They are very micro. And then there would be the various sinusoidal movements*” (A2). It is asked whether A2 has other different images in her head, as she talked about colors of the photons: “*The photons I imagine moving have different frequencies, which would form different colors*” (A2). We infer, therefore that there is a possibility that A2 is using in her explanation both a psychophysical with a socio-cultural mediation when talking about different frequencies and colors.

So, we then seek to understand whether these reported concepts were imagined or if A2 had already seen them in some other activity, commenting that: "*I imagined when I did the experiment. This came up in my head when I performed the experiment, when I did the experiment, I had no idea about the color issue*." (A2). Analyzing the reasoning of A2 before the answers to the questions, using verbal and gestural speeches, there are two mediations that gave rise to the images used to explain the phenomena involved when narrating her thought process. As mentioned, we can firmly identify the role of the psychophysical mediation, when she mentions the incidence of sunlight and even the idea of the rainbow, and it is not clear from which mediation the photon representation of a particle imbued with movement arose, as she can't recall the origin, but as she mentions the classes and the book, we imagine that her explanations are of a sociocultural mediation.

"Explain, in your words, what happens so that different sources of emmited light appear to us in different colors: For example, a red LED and a blue LED":

When explaining what was his first thought to elaborate the answer, A1 starts to express his idea regarding the electromagnetic spectrum and the different emission frequencies that are processed by the human eye, identifying different colors (the color of the object depends on the emission frequency): "*I remembered the electromagnetic spectrum [#ES], with the radiation bands and then there is a blue LED, with higher frequency and a red one with lower frequency and the human eye captures these values characterized by the frequencies and are interpreted in different ways*" (A1).

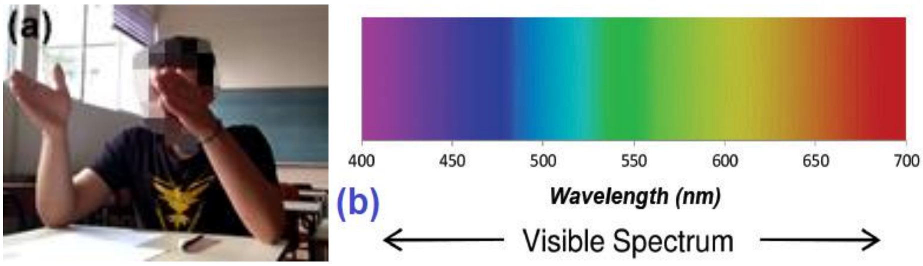
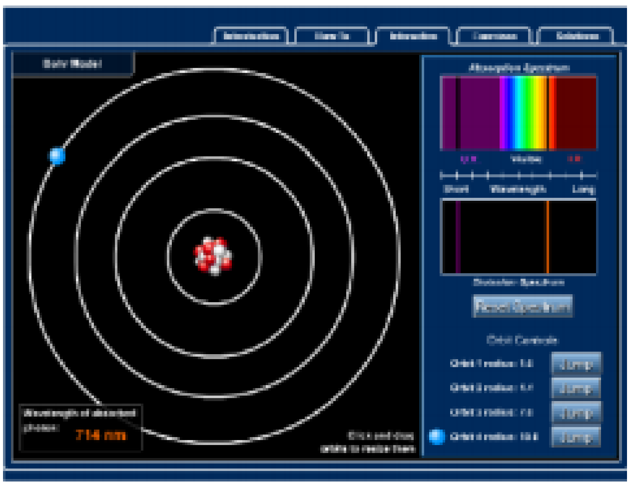


Figure 7 - (a) The image above illustrates a gesture with hands spread and open, representing the space where the electromagnetic spectrum was imagined. This image received the hashtag #ES. Static image. (b) Representation of the electromagnetic spectrum[3]

During the interview, we identified the presence of verbal speech intertwined with instances of gestural speech as reported by A1, evidence of the presence of mental images. Readily during the interview, the student is asked if he was thinking about any images at the moment, and reports that: "*I saw (in my mind's eye) the electromagnetic spectrum (that I previously have seen) in readings, on the computer and many similar images in books*" (A1). It is important to note that A1 reports that he used didactic activities about the Bohr Atom in the classroom, working with a specific simulation during his pre-service teacher training (Figure 8) for teaching middle school students. Up to this moment, there are two different mediations, cultural (readings) and hypercultural (computer), which give rise to the mental images previously mentioned.



[3] The image was viewed in the activity guides.

Figure 8 - The Bohr Atom Simulation screen. Source: The Bohr Atom (Mheducation)[4]

After, A1 talks about the spectroscopy experiment used in the research presented here: "*In the experiment you could see the* [#EX] *spectrum that formed there. We were using a white light, it had an entire spectrum and with the colors separately I saw that with red only red appeared, with blue only blue. On the cellphone."* (A1). The student talks about the use of a white lamp, with which it is possible to view the entire electromagnetic spectrum (Figure 9 (b)) and LED's with different colors, with different frequencies and relative intensity peaks positions for each color on the cell phone screen (Figure 10 (b)).

Figure 9 - (a) The sequence of images above, illustrates a movement with the hands, moving them as if drawing an imaginary line, in this case, the drawing on the cell phone screen of the spectral band. This sequence of images received the hashtag #EX. Dynamic image. (b) Range of visible spectrum analyzed in the experiment through the cell phone camera from a white light Source: the research

When questioned about "the separate colors" he mentioned previously, A1 answers: *"I was imagining the LED [#LD]. Therefore, a monochrome light emission"* (A1). In this excerpt when reporting to the activity displayed on the cell phone screen, to answer the question, A1 also recalls the idea of a single light source. Therefore, we infer those A1 complements the hypercultural mediation, with psychophysical mediation to describe what it was imagining.

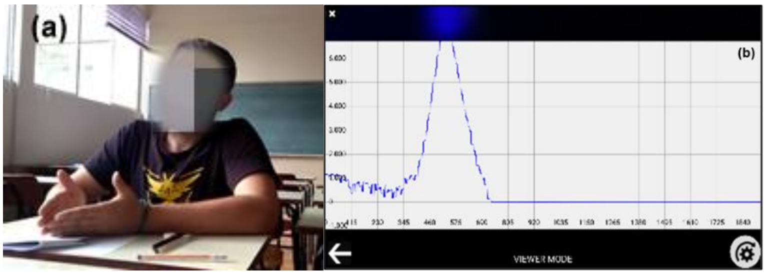


Figure 10 - (a) The image above shows a hand gesture, indicating the spectrum concentrated in a certain region. This image received the hashtag #LD. Static image. (b) Representation of the cell phone screen after capturing the emission spectrum of one blue LED. Source: the research.

Following, A1 is asked whether he associates his previous didactic use of the simulation Bohr Atom (Figure 8), with the light emission activity proposed in the research: "*I can think for one color, referring to exchanges of energy and photon emission from the electron changing orbits. The light will be emitted by the LED from the decay of these electrons. It will decay to a previous shell and emit a photon. This photon will have an energy that is related to its frequency"* (A1). He is asked to describe from which previous experience he is able to produce the images, since coupled with the verbal speech A1 performs gestures: *"I combined. The atom and electrons I imagine from my previous didactic experience"* (A1).

With the analysis of the last stretch, we realize that A1 uses different mental images, coming from different external processing mechanisms (mediations) and internalizes them, reflecting an integrated view, in which the hypercultural external processing mechanism mental images communicates with mental images from the cultural mediations and/or psychophysical mediations simultaneously when reporting the studied phenomenon. So, again, A1 combines three different types of mediation to describe the thought process used at the time he was answering the question.

[4] The simulation was used by the student during another project. Simulation reference: https://highered.mheducation.com/olcweb/cgi/pluginpop.cgi?it=swf::800::600::/sites/dl/free/0072482621/59229/Bohr_Nav.swf::The%20Bohr%20Atom.

Now on to A2, we observe that she uses the idea of frequency for different colors, used to report what she reasoned during the description of the answer: "*The frequency determines the color. The higher the frequency, a color band you will see. Lower frequency red, higher the color blue. And it has the wavelength"* (A2). After asked where does this concept of frequency comes from*: "I imagine that color disk [#DC] that when it spins it turn white, has all primary colors and that had a relationship with the frequency"* (A2). When asked for details, A2 described the "color disk", as a Newton disk, often used in high school during optics classes in Brazil.

Figure 11 - (a) The sequence of images above illustrates a movement with the right index finger, in a circular shape, representing Newton's disk. This sequence of images received the hashtag #DC. (b) Representation of the cartoon "Where does it comes from?" and Newton's disk image Source: the research and TV Futura[5]

The interviewer imagined, at the moment of the interview, that the image of the Newton's Disk originally came from a psychophysical mediation (classroom experiment). But when further asked where she saw this "color disk", A2 explains that*: "I saw it at "Kika, De onde vem?"*. A2 refers to a Brazilian TV children animated cartoon about a curious girl that learns science, as shown in Figure 11 (b). This answer indicates the use of cultural mediation, since the drawing was watched by means of a TV show (cultural artifact), even being in fact a physical object. Therefore, the mental image comes from an external cultural processing mechanism.

Continuing with the investigation, A2 is asked if there was any other image source (mediation) used in her reasoning of different colors, reporting that: *"In the (spectrometer) app it has colors (Figure 10 (b)). Whenever it had blue, even on its own, it stayed in the blue color band. The red one in the red color range. All colors remain in their locations, at their respective wavelengths"* (A2). The bands referred by A2 are the spectral bands that could be viewed on the cell phone screen. After the report, it is asked what she was imagining when she answered about the "bands": *"I'm imagining a graph, I saw it in the experiment app"* (A2), just as described for the student A1 (Figure 9 (b)). All students have developed the same mental image when working with the spectrometer app.

To answer question two (2) of the post-test, student A2, even though using less gestures than A1, first used a cultural mediation, originating from the "Newton's disk" mental image, complementing her idea of colors with hypercultural mediation, which enabled the production of mental images coming from the mobile application. In the latter, A2 can visualize the relationship between colors and frequencies or wavelengths, as shown in the mentioned graph.

"Explain, in your words, what happens so that different objects appear, to us, in different colors: For example, a red shirt and a blue cup":

In this last question of the post-test, A1 is asked to explain his concept of light absorption and reflection, and the question itself offers some examples. Métioui (2023) already detected that those concepts are hardly developed by students. To start the report A1 says: *"When we have white light in an environment that has these objects, such as a blue cup, it will absorb the spectrum and emit only the blue that would be its color, the color we see. The reason I can't explain. I remember the experiment with* [#AC] *the dyes. We had the red dye and a white light source, when it passed, it showed all the colors on the cell phone and when adding the dye in front of the white lamp, it "filtered", barred* [#BL] *only allowed the red to pass"* (A1). A1 acquires the image of the glasses with dyes, an image from a psychophysical mediation, to demonstrate the trajectory of white light until reaching the cell phone screen. There is the clear the interaction of the psychophysical mediation with the hypercultural mediation (cell phone screen), combined in A1's mind.

[5] Futura is a Brazilian television channel.

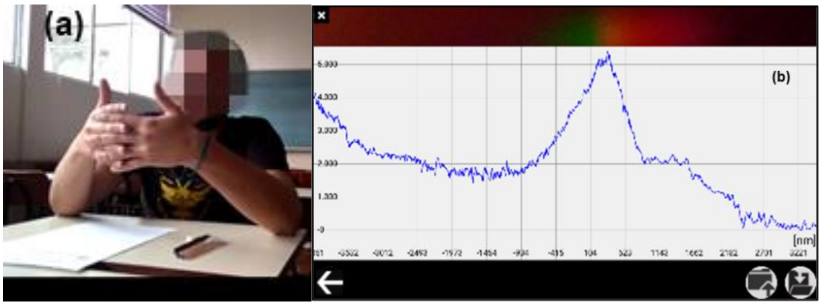


Figure 12 - (a): The image above illustrates a gesture with the hands "crossing" in front of the body, indicating blocking of the luminous spectrum coming from white light. This image received the hashtag #BL. Static image. (b) Spectrum obtained after white light passes through a sample with red dye

When asked about the gesture of "blocking the spectrum", since the glasses with dyes were positioned in front of the (white) light source, A1 explains that: "*I imagine the object in front of the light, the white light goes hit it and only red light came out* (Figure 12 (b)) *emitting the frequency only close to red. The white light hits the bottle with dye, it is contained and only red leaves*" (A1). The student has mental images of the physical objects in a location and is able to explain the trajectory traveled by white light, which is absorbed when passing through colored materials. When describing that the light coming from the glass with a dye has just the color (frequency) of the dye, it leads him to imagine the cell phone screen showing this positioning of colors, that is, he uses hypercultural mediation.

To answer this last question, A1 combined mental images of two different mediations. First, he imagines the lamp and the glass with dyes (psychophysical) and then he starts to visualize the cell phone (hypercultural), forming his mental image of the phenomenon.

Analyzing the explanation of A2 to the same question, we can see a similar explanation of A1, using daily objects to contextualize her answer*: "It (a shirt) absorbs and then emits. The color of the shirt is red, we see red because it has an absorption and at the same time it emits the color, it would happen to any object* "(A2). This mental image comes from a psychophysical mediation imagined from the very context of the question. When asked about what she remembered to justify her answer when arguing about absorption, A2 reports that: *"I saw it in chemistry, first, and in the experiment (app), on the slides (class) too. When we place the object there will be an absorption of bands of that white light. And it sends it back* [#RC]"(A2). The student mentions the chemistry class, highlighting that there is a mental image of social mediation coupled with what she visualized in the experiment and on slides, hypercultural/cultural tools (Figure 13 (b)).

Figure 13 - (a): The sequence of images above, illustrates a movement with the direct arm, forward and upward, representing the reflection of the colors, after passing through a substance that absorbs it. This sequence of images received the hashtag #RC. (b) Representation of one of the images that were on the presented slides.

A2 is then asked, about where she acquired the images to explain the phenomenon of absorbed light, pointing out that most of her ideas came from our didactic intervention: "*I saw very little about that. I remember the application and the slides more"* (A2) (Figure12 (b) and Figure 13 (b)). Despite having mentioned the class, her conceptions were mostly constructed with the help of the proposed activities, usually images originating from a hypercultural mediation.

Outlining the Mediation level Profile of students A1 and A2 for the concepts of light and color:

As already discussed, based on the ideas of Bachelard (1979), regarding the subject's epistemological profile and Mortimer (2000), with his proposal of a conceptual profile, we propose the building of a Mediation level Profile of students in relation to the light concepts used in the didactic experiment. To build each profile, we attribute a weight to each different mediation level in much like the same way done originally by Bachelard.

A1 Mediation Level Profile

The outline of the Mediation level Profile will start with the analysis of student A1 for the concepts of light (as it reflects on a wall), color of emitted light and color of absorbed light, respectively, up to the general profile of the student. The same will be done for student A2. In the abscissa axis, successive mediations are indicated and, in the ordinate axis, a value that corresponds to the relative frequency (as perceived by the authors) with which such mediation is expressed by the student regarding his notion of each concept. One author raised each profile while the other author analyzed comparatively each profile to the others, especially the relative size of each mediation profile. Both authors then discussed each profile until a final profile was realized.

The mediation that is most representative for the formation of the concept of light, is the social mediation, followed by cultural and, finally, psychophysical, without mention to the hypercultural mediation, as shown in Figure 14.

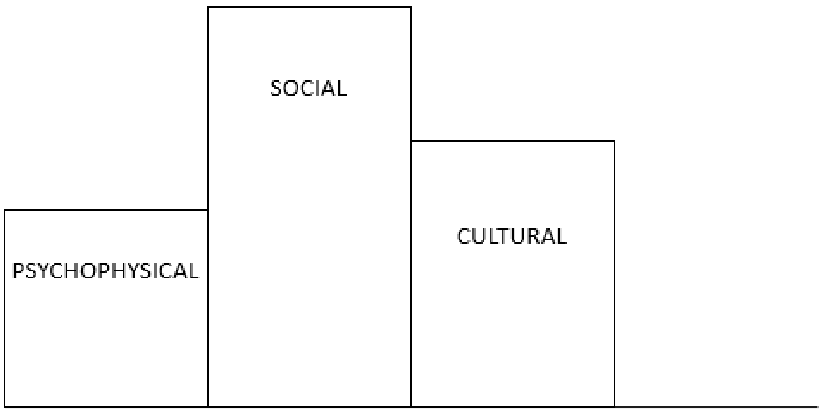


Figure 14 - A1's (Senior) Mediation level Profile of the concept of light (hitting a wall)

Social mediation excels in the various explanations in which the student uses terms or expressions often found in physics classes, even reporting three different courses on which he relied to explain the phenomenon, showing the establishment of mental images from social mediations. The spherical photon mental image itself, which is evident in his speech comes from a class, as well as the "light package", "sinusoidal" and the idea of "frequency"; all intertwined with gesture production expressing imagery.

Cultural mediation mental images are present in his thinking from interacting with books and teacher-training activities carried out by A1, with which he manages to build the specific mental image that gives rise to the photon movement. This mental image is used to support the main idea that light is composed of particles (social mediation), with the wave movement, seen originated from a cultural mediation. However, the student mentions a wall hit by sunlight, as the question suggests, and for this image the different mediations with the explanations proposed by the student arise. The idea of the wall itself comes from a psychophysical mediation, but to form an idea of the concept of light it is the mediation that stands out least in the discourse.

Therefore, to draw this mediation level profile (Figure 14) the social mediation level is higher, followed by the cultural mediation level and then the psychophysical level. Outlining the A1 Student's Mediation level Profile for the concept of emitted light, it is noticed that the external processing mechanism highlighted in his speech is the hypercultural one that is associated to (or combined with) two other mediations (cultural and psychophysical) in certain moments to exemplify specific concepts of the activities exposed. Most of the representations come from hypercultural mediations, as is the case with the spectra visualized in the application, the simulation and in research (using the computer).

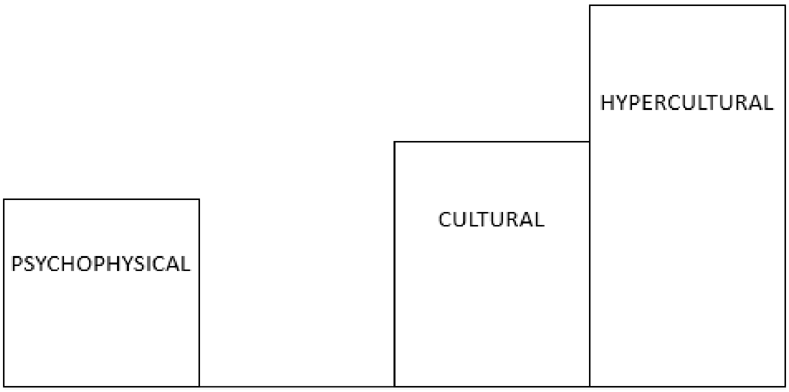


Figure 15 - A1's (Senior) Mediation Level Profile of the concept of color of an emitted light

Even though cultural and psychophysical mediations showed up equally at different times, cultural mediation seems to be more important to him. The images of the electromagnetic spectrum and the Bohr Atom, representations that are more frequently mentioned, come from books. The basis for understanding the concept, not counting using computers (for study/simulation) and the application, is in the cultural mediation, which comes from mental images that are often mentioned and that are part of the color concept, such as the "electromagnetic spectrum", "the atom" and frequency". Psychophysical mediation is only included in his profile due to the evidence of an image of the LEDs, used in the experiment and manipulated by A1, a mental image from the psychophysical mediation, as shown in Figure 15.

Regarding the question about absorbed light, although the use of two mediations gave rise to the mental images mentioned by A1, the hypercultural mediation, after the didactic activity, proved to be more determinant for the creation of mental images. Figure 16 illustrates the outline of A1 mediation level Profile for question 3.

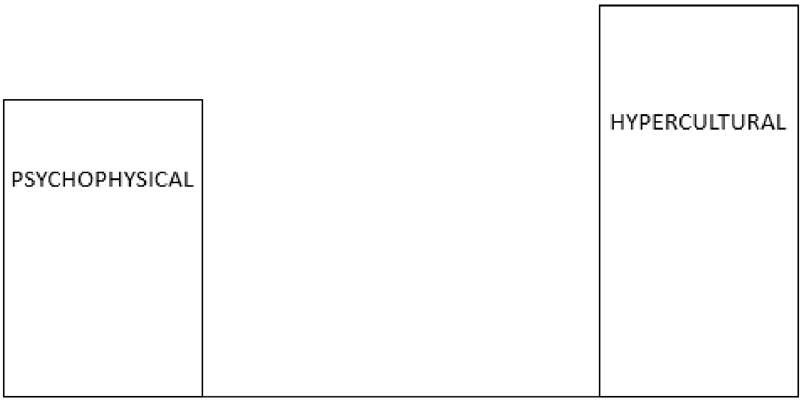


Figure 16. A1's (Senior)Mediation level Profile of the concept of color of reflected light (after passing through a dye).

The images from psychophysical mediation are limited to the context of the experiment, to the manipulation of "cups" and "dyes" as the student was setting up the experiment. It is important, in the author's view, that the student can see for himself the trajectory of the light leaving the source, hitting the dye, and finally arriving at the screen (the cell phone screen) (without being sure that the light being measured by the app comes from the dye, the student can't ascertain that he is measuring the absorption spectrum). But it is in the app (a hypercultural external mechanism) that A1 can visualize the spectrum and, therefore, create most of the mental images mentioned, which is evident in the gestures produced.

As each specific profile, for each question, has already been detailed, the general profile of student A1, for the concept or light, is raised below (Figure 17). When analyzing the Mediation level Profile for the questions elaborated, it is noticed that the mediation present in the three questions is psychophysical, that is, the interaction with the environment and parts of the experiment. The second most important mediation level is the hypercultural mediation, with higher relevance in two of the three questions and which allows the visualization of the experiment.

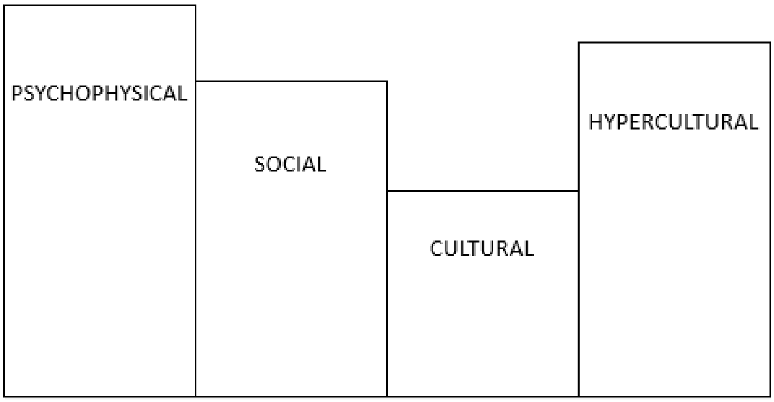


Figure 17 - Consolidated Mediation level Profile of student A1 (senior)

The social mediation, despite showing up in only one of the questions, was the basis of light knowledge for student A1, who participated in several classes on the topic – what we could see as his original conceptions prior to the experiment. Finally, cultural mediation is the least prominent and is present at a certain time when A1 mentions the use of books.

A2 Mediation Level Profile

Student A2 throughout the first interview used mental images from psychophysical mediations, followed by a hypercultural mechanism. Therefore, to raise her Mediation level Profile for the first question (Figure 18) we placed the psychophysical mediation above others, followed by the hypercultural mediation.

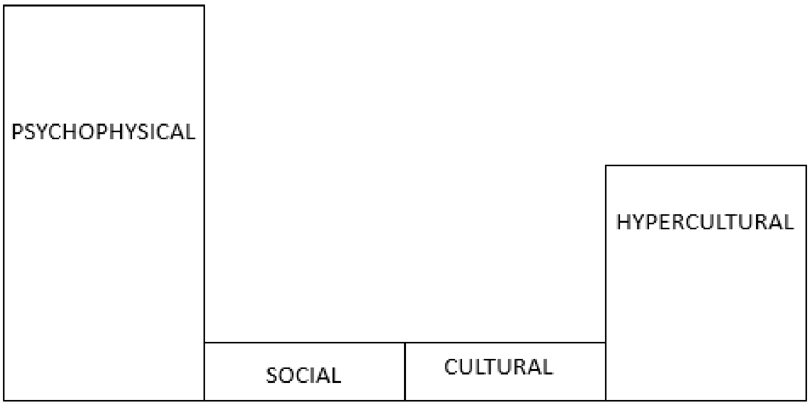


Figure 18 - A2's (sophomore) Mediation level Profile of the concept of light (hitting a wall)

To draw her profile above, one must keep in mind that she uses images acquired from interacting with psychophysical mediations, such as the "wall", the "glass", the "sun rays" and the "rainbow" to contextualize her explanation and uses these images to construct her understanding of light. When A2 talks about "frequencies" and "different colors", she offers evidence of a mixture of socio-cultural mediations, since the representations are very similar to those of A1 for the same concepts. As much as the actual origin of the evidence couldn't be recalled by the student, as discussed before, differently to A1, we assumed the source of those mental images a combination of social and cultural mediations, despise having weak evidence here. Finally, hypercultural mediation is cited in a way that integrates A2's understanding of the concept of light.

Analyzing the mediations that gave rise to the mental images internalized by A2, for the concept of emitted light (question 2), it is identified that the most used mediation level is the cultural one, followed by the hypercultural one. As the "disk" mentioned by the student comes from a TV series – a cultural artifact - and not a real physical object, no mental images from the psychophysical mediation itself was used by the student, as well as no social mediation (Figure 19).

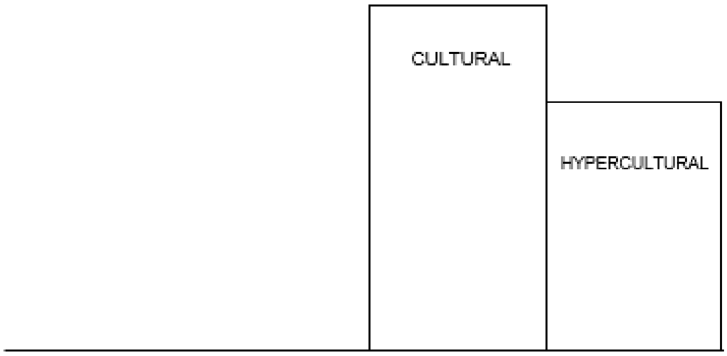


Figure 19 - A2's (sophomore) Mediation Level Profile of the concept of color of an emitted light

The images acquired from cultural mediation stands out in the reports brought by A2, which justifies the notion of colors with the "Newton's disk", from an animated cartoon. It is interpreted that the basis for the construction of A2 notion lies in the cultural mediation, with psychophysical images, complemented by the hypercultural mediation that made possible the images of "frequency", "spectrum" and the "graphic", all coming from the cell phone app used in the research, as previously mentioned. The probable hypothesis as to why there are no reports of social mediations for the concept of emission of light is that the student is still a sophomore.

Figure 20 shows the outline of the A2 Mediation level Profile of the concept of absorbed light (after passing through a dye). It is noticed that A2 builds her knowledge of reflection based on concepts that she remembers having seen in a chemistry class and interaction with the class provided by the researchers before the activities with the cell phone, that is, social and hypercultural mediations (the latter with a bit more relevance).

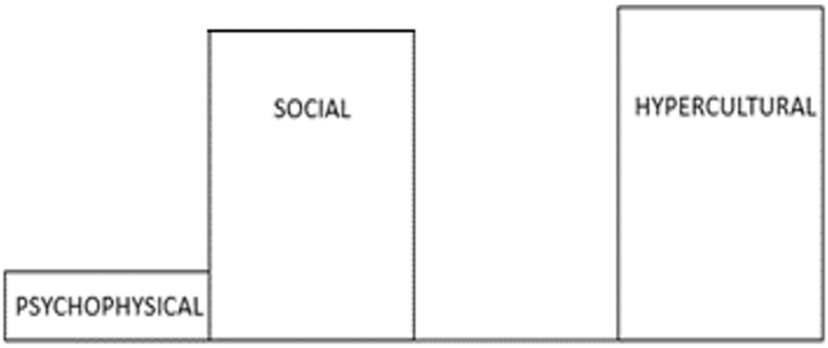


Figure 20 - A2's (sophomore) Mediation level Profile of the concept of color of reflected light (after passing through a dye). Source: the research.

The aforementioned images from social and hypercultural mediations are intertwined with images acquired from psychophysical mediation to explain the absorbed light in a "red shirt". What allows the visualization of the learned concept is the app (hypercultural mediation), since the student had not had contact (visual) with the phenomenon previously, except images and conversations in the classroom.

The consolidated mediation level profile of A2 is then raised. The external hypercultural processing mechanism is the most prominent mediation in A2's understanding (Figure 21) of the concepts involved (light and color). The importance of psychophysical mediation is also represented below, which is evident in two of the three questions, but with few mental images arising from this mediation, only in more than half of them, standing out only in the concept of light.

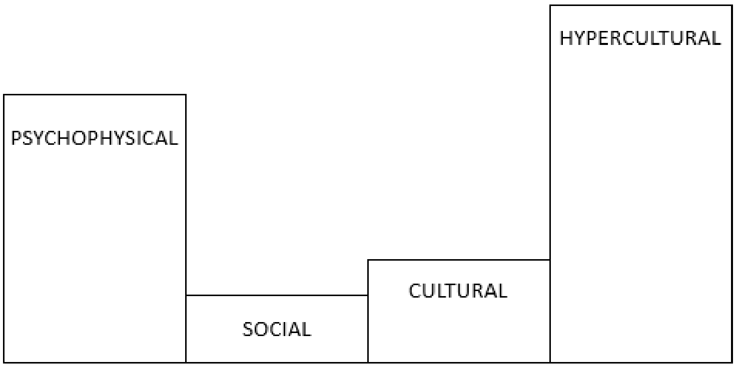


Figure 21 - Consolidated Mediation level Profile of student A2 (sophomore)

Cultural mediation was the basis for constructing the concept of emission, and the mechanism is mentioned immediately when A2 explains his reasoning about the phenomenon. The mediation with the lowest occurrence of mentions is social, which is justified by the fact that she is a second-year student, having not already attended the subject, only indicating a social mediation when reporting that she remembers a chemistry class (for question three).

Student A2 uses representations of previous experiences, physical objects, and interactions with the environment (the research materials themselves) to build her knowledge about the concepts of light. The mediation most often used is the hypercultural mediation that involves the use of the app mainly to visualize the spectrum. A1, on the other hand, can navigate more easily among all profile areas, with two being more evident, as psychophysical and hypercultural, both linked to the activities proposed in the research. The external social and cultural mechanisms are reported by A1 as being part of practices experienced before applications, such as classes and participation in projects.

With the final analysis of the consolidated mediation profile for both students it's possible to see that the process of acquiring and assimilating mental images related to a specific concept is different from the same process within the epistemological or conceptual profile; while those profiles evolve beginning with the development of the initial zones and progressively advancing to incorporate the later and more evolved zones, the mediation level profiles is heavily dependent on the specific environment where the concepts are constructed by the students and later zones (hypercultural more specifically) can be developed earlier on giving the student the opportunity to have rich static and dynamic mental images if said student interact with hypercultural devices. Apparently, from our results, while the hypercultural zone of the mediation level profile can be developed faster, the social and cultural levels are developed as the student progress in his/her course. This resonates with outhers researchers (Aykutlu, Ensar, & Bayrak, 2022; Puspitaningtyas *et al.*, 2021) defending the use of virtual laboratories and other methods (Dogru & Kurnaz, 2023). Additionally, our study highlights that by using hypercultural tools, the student will develop mental imagery related to those tools, that may include microscopic models of light emission and absorption that can help foster a deeper conceptual model of light.

We constructed a figure (Figure 22) that sums up the results presented in the article. The experienced student (A1) can navigate more easily in all areas of the profile, while the novice student (A2) uses representations of her previous experiences, as already reported.

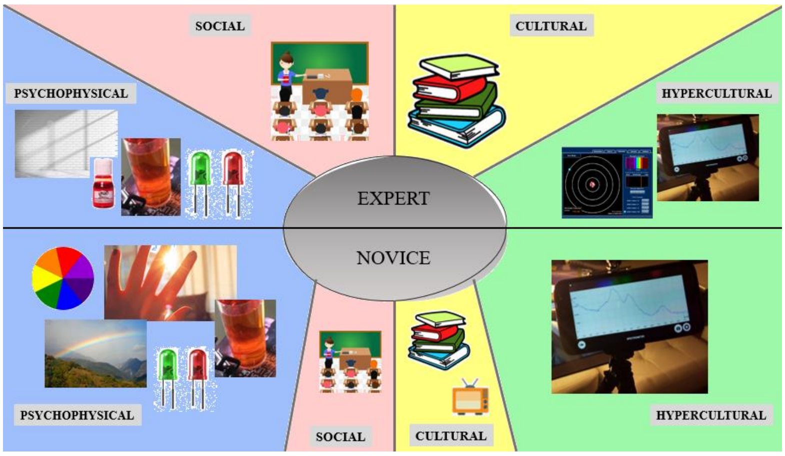


Figure 22 - Diagram of the results of the mediation levels of each student (A1 and A2), according to the reported descriptions.

FINAL CONSIDERATIONS

The increasing availability and use of portable devices have had a profound influence on people's behavior, modifying various sectors of society. Education is no exception, as it has brought about new alternatives for the development of teaching activities in the classroom. Accordingly, we conducted research using an experimental, low-cost alternative spectrophotometer to teach light absorption, reflection, and emission, which are fundamental in various spectroscopic techniques. The application serves as an external information processing mechanism, providing students with visualization and analysis of phenomena related to spectroscopy through an activity guide. It is worth noting that the use of materials such as lamps, LEDs, or food coloring glasses also acted as mediation tools for students to explain concepts. Additionally, the clear description of the light path made by A1 for the absorption of light by a die further grounded the formulation of concepts in empirical evidence, which is the cornerstone of experimental physics teaching.

During our analysis, we observed that students used imagery and mental images acquired from at least two different levels of mediation to answer each question, indicating that their interaction with the content resulted in complex patterns of images from various external mechanisms. The post-test questions were all related to concepts such as light itself, emitted light color, and absorbed light color. Using the Report Aloud technique, we tracked the transition of mediations that the students underwent while reporting their thought process. Ultimately, we created a Mediation Level Profile that outlined the most relevant external mechanisms for creating mental images that the student used to answer the questions. Both the expert (A1) and novice (A2) students used images that were acquired after interacting with various external mechanisms to understand each concept. However, upon analyzing the students' general framework while answering questions about spectroscopy using the SpectraUBP app, we found that the mediations that most influenced the origin of mental images were psychophysical and hypercultural, especially for the sophomore student. This can be attributed to the empirical nature of the experiment where the students interacted with physical objects and a hypercultural device used to process data.

When it came to the image of light on a microscopic level, there were differences between the expert and novice students. The expert student had a textbook image of a photon, whereas the novice student initially imagined a classical atom for light. However, the novice student quickly realized her mistake and adjusted her mental image to something similar to that of the expert student. This demonstrated a transition from a naïve image of microscopic objects being solely atom-like to recognizing the need for a different mental image for light.

After constructing our proposed Mediation Level Profile, we are now able to visualize the intrinsic and complex patterns of mental imagery from different external mechanisms more clearly. This profile highlights the predominant mediations used by students to build their concepts, which were also the most utilized in our didactic experiment involving laboratory objects and a mobile app. We have also found evidence that different mediations are influenced by each student's previous experiences. For instance, student A1 is able to create mental images more easily using and connecting all mediations, while A2 mainly relies on the mediations present in the experiment as she is still at the beginning of her undergraduate studies.

We anticipate that as A2 progresses through her course and gains experience with social (teachers and colleagues) and cultural mediations (books, videos, etc), it will enrich her mental imagery and help bridge the gap between the two mediations and the hypercultural and psychophysical mediations in building the concept of light. It appears that having multiple mental images from different levels of mediation is crucial in constructing richer mental images and mental simulations, enabling students to comprehend more complex facets of the concepts involved.

The Mediation Level Profile is constructed by considering the relative importance of each level of mediation to demonstrate the degree of importance of different extracerebral mechanisms in constructing the concepts of light and color, ordered progressively from the most basic level of mediation (psychophysical) to the most recent (hypercultural). In a teaching situation, it is observed that the same student may present more than one way to solve or explain questions about the concept of light and color, depending on the context.

In addition, our didactic proposal, which focuses on the use of low-cost spectrometers, has demonstrated the expected notions of analysis and visualization, making it a viable option for teaching spectroscopy in third-world countries. Its integration into a learning environment has the potential to enhance the teaching of Physics and other scientific disciplines, as evidenced by the powerful mental images acquired through the experiment, utilizing both psychophysical and hypercultural mediations. However, it is important to note that while hypercultural tools can enhance learning by providing dynamic and static images that aid in building a wider range of mediations, they should not be seen as a replacement for social interaction and reading, which are essential components in advancing the student's mediation level profile as a whole. As such, we believe that all levels of mediation should be utilized in teaching, and caution students accordingly.

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REFERENCES

Assem, H. D., Nartey, L., Appiah, E., & Aidoo, J. K. (2023). A Review of Students' Academic Performance in Physics: Attitude, Instructional Methods, Misconceptions and Teachers Qualification. *European Journal of Education and Pedagogy*, *4*(1), 84-92. https://doi.org/10.24018/ejedu.2023.4.1.551

Aykutlu, I., Ensari, Ö., & Bayrak, C. (2022). Prospective teachers' conceptual understanding of the polarization of light. *European Journal of Physics*, *44*(1), 015701. https://doi.org/10.1088/1361-6404/ac93cc

Bachelard, G. (1985). *El compromiso racionalista.* Tucumán, Argentina: Siglo XXI.

Bachelard, G. (1966). *La philosophie du non.* Paris, France: Presses universitaires de France.

Bachelard, G., & Pessanha, J. A. M. (1979). "*A filosofia do não: O novo espírito científico: A poética do espaço*". São Paulo, SP: Abril Cultural.

Clement, J. (2019). Imagistic simulation and physical intuition in expert problem solving. In *Proceedings of the Sixteenth Annual Conference of the Cognitive Science Society: Atlanta, Georgia, 1994* (p. 201). Routledge. Retrieved from https://people.umass.edu/~clement/pdf/imagistic_simulation.pdf

Clement, J. J. (2020). Reasoning Patterns in Galileo's Analysis of Machines and in Expert Protocols: Roles for Analogy, Imagery, and Mental Simulation. *Topoi, 39*, 973-985. https://doi.org/10.1007/s11245-018-9545-5

Chi, M. T., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive science*, *5*(2), 121-152. https://doi.org/10.1207/s15516709cog0502_2

Coelho, G. R., & Borges, O. (2010). The understanding of the students about the nature of light in recursive curriculum. *Caderno Brasileiro de Ensino de Física, 27(*1), 63-87. https://doi.org/10.5007/2175-7941.2010v27n1p63

Colin, P., & Viennot, L. (2001). Using two models in optics: Students' difficulties and suggestions for teaching. *American Journal of Physics, 69*, S36-S44. https://doi.org/10.1119/1.1371256

Doğru, M. S., & Kurnaz, M. A. (2023). Students’ contextualizing knowledge on the mirage incident, reflection and refraction: a case study. *Physics Education*, *58*(6), 065004. https://doi.org/10.1088/1361-6552/ace874

Freitas, S. A. (2019). Use of different external mediating mechanisms of the Bohr atom model: Evidence of Meaningful Learning through verbal-gestural analysis in elementary school students. *Acta Scientiae, 21*(4), 133-148. https://doi.org/10.17648/acta.scientiae.v21iss4id5253

Grasse, E. K., Torcasio, M. H., & Smith, A. W. (2016). Teaching UV–Vis spectroscopy with a 3D-printable smartphone spectrophotometer. *Journal of Chemical Education*, *93*(1), 146-151. https://doi.org/10.1021/acs.jchemed.5b00654

Ivanjek, L., Shaffer, P. S., McDermott, L. C., Planinic, M., & Veza, D. (2015). Research as a guide for curriculum development: An example from introductory spectroscopy. I. Identifying student difficulties with atomic emission spectra. *American Journal of Physics*, *83*(1), 85-90. https://doi.org/10.1119/1.4901977

Kesonen, M. H. P., Asikainen, M. A., & Hirvonen, P. E. (2017). Light Source Matters–Students’ Explanations about the Behavior of Light When Different Light Sources are used in Task Assignments of Optics. *Eurasia Journal of Mathematics, Science and Technology Education*, *13*(6), 2777-2803. https://doi.org/10.12973/eurasia.2017.01253a

Malisorn, K., Wicharn, S., Plaipichit, S., Pipatpanukul, C., Houngkamhang, N., & Puttharugsa, C. (2019). Demonstration of light absorption and light scattering using smartphones. *Physics Education, 55*(1), 015012. https://doi.org/10.1088/1361-6552/ab51ea

Maurines, L. (2009). Geometrical Reasoning in Wave Situations: The case of light diffraction and coherent illumination optical imaging. *International Journal of Science Education*, *32,* 1-32. https://doi.org/10.1080/09500690903271389

Meggiolaro, G. P. (2019). *An investigation between external mediation mechanisms and electrostatic problem situations, in a general physics discipline at the university level*. (*Uma investigação entre os mecanismos externos de mediação e situações-problema de eletrostática, em uma disciplina de física geral em nível universitário).* (Tese de doutorado), Universidade Luterana do Brasil – Programa de Pós-Graduação em Ensino de Ciências e Matemática, Canoas, Rio Grande do Sul, Brasil. Retrieved from http://www.ppgecim.ulbra.br/teses/index.php/ppgecim/article/view/341/336

Métioui, A. (2023). Primary School Preservice Teachers’ Alternative Conceptions about Light Interaction with Matter (Reflection, Refraction, and Absorption) and Shadow Size Changes on Earth and Sun. *Education Sciences*, *13*(5), 462. https://doi.org/10.3390/educsci13050462

Monaghan, J. M., & Clement, J. (1999). Use of a computer simulation to develop mental simulations for understanding relative motion concepts. *International Journal of Science Education*, *21(9),* 921-944. https://doi.org/10.1080/095006999290237

Mortimer, E. F. (1995). Conceptual change or conceptual profile change? *Science & Education, 4(3),* 267-285. https://doi.org/10.1007/BF00486624

Mortimer, E. F. (2000). *Linguagem e formação de conceitos no ensino de ciências*. Belo Horizonte, MG: UFMG.

Nersessian, N. J. (1995). Should physicists preach what they practice? Constructive modeling in doing and learning physics. *Science & Education, 4,* 203-226. https://doi.org/10.1007/BF00486621

Özcan, Ö. (2015). Investigating students’ mental models about the nature of light in different contexts. European Journal of Physics, *36*(6), 065042. https://doi.org/10.1088/0143-0807/36/6/065042

Puspitaningtyas, E., Putri, E. F. N., Umrotul, U., & Sutopo, S. (2021). Analysis of high school student’s concept mastery in light wave using structured inquiry learning assisted by a virtual laboratory. *Revista Mexicana de Física*, *18*(1 Jan-Jun), 10-22. https://doi.org/10.31349/RevMexFisE.18.10

Sengören, S. K. (2010). How do Turkish high school graduates use the wave theory of light explain optics phenomena? *Physics Education*, *45*, 253-263. https://doi.org/10.1088/0031-9120/45/3/005

Silva, L. P. C., Da Via, C., Freitas, A. M., & Santiago, A. J. (2014). Use of the power Led in Optics laboratories. *Caderno Brasileiro de Ensino de Física*, *31*(1), 60-77. https://doi.org/10.5007/2175-7941.2014v31n1p60

Souza, B. C. (2004). *The Cognitive Mediation Theory: The cognitive impacts of the Hyperculture and of the Digital Mediation.* Tese de doutorado, Curso de Psicologia, Universidade Federal de Pernambuco, Recife, Brasil. Retrieved from https://www.researchgate.net/profile/Bruno-Campello-De-Souza/publication/267232585_A_Teoria_da_Mediacao_Cognitiva_Os_impactos_cognitivos_da_Hipercultura_e_da_Mediacao_Digital/links/545feb750cf295b56161caf6/A-Teoria-da-Mediacao-Cognitiva-Os-impactos-cognitivos-da-Hipercultura-e-da-Mediacao-Digital.pdf

Souza, B. C., Da Silva, A. S., Da Silva, A. M., Roazzi, A., & Carrilho, S. L. (2012). Putting the Cognitive Mediation Networks Theory to the test: Evaluation of a framework for understanding the digital age. *Computers in Human Behavior*, *28*(6), 2320-2330. https://doi.org/10.1016/j.chb.2012.07.002

Stephen, A. L., & Clement, J. J. (2010). Documenting the use of expert scientific reasoning processes by high school physics students. Physical Review Special Topics-*Physics Education Research, 6(2),* 020122. https://doi.org/10.1103/PhysRevSTPER.6.020122

Stephen, A. L., & Clement, J. J. (2012). The role of thought experiments in science and science learning. In *Second international handbook of science education* (pp. 157-175). Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-9041-7_13

Tao, P.-K., & Gunstone, R. F. (1999). The process of conceptual change in force and motion during computer-supported physics instruction. *Journal of Research in Science Teaching*, *36*(7), 859-882. https://doi.org/10.1002/(SICI)1098-2736(199909)36:7<859::AID-TEA7>3.0.CO;2-J

Trevisan, R., & Serrano, A. (2016). Uma construção do Perfil Epistemológico de licenciandos em Física acerca da dualidade onda-partícula em Mecânica Quântica, após o uso de bancadas virtuais: um estudo a partir do discurso gestual e verbal. *RENOTE*, *14*(1). https://doi.org/10.22456/1679-1916.67375

Trevisan, R. (2018). Investigating the Drivers and Mental Representations of the Private Interpretations of Students of Quantum Mechanics. *Acta Scientiae*, *20(4).* https://doi.org/10.17648/acta.scientiae.v20iss4id4670

Trevisan, R., Serrano, A., Wolff, J., & Ramos, A. (2019). Peeking into students' mental imagery: The Report Aloud technique in Science Education research. *Ciência & Educação (Bauru), 25*(3), 647-664. https://doi.org/10.1590/1516-731320190030004

Tumanggor, A. M. R., Jumadi, J., Wilujeng, I., & Ringo, E. S. (2019). The profile of students' physics problem solving ability in optical instruments. *Jurnal Penelitian & Pengembangan Pendidikan Fisika, 5*(1), 29-40. https://doi.org/10.21009/1.05104

Tweney, R. D. (1985). Faraday's discovery of induction: A cognitive approach. In D. Goodling & F. James (Eds.), *Faraday rediscovered: Essays on the life and work of Michael Faraday, 1791-1867* (pp. 189-209). New York, United Sates of America: Stockton Press. https://doi.org/10.1007/978-1-349-11139-8_11

Tweney, R. D. (2010). Representing the Electromagnetic Field: How Maxwell's Mathematics Empowered Faraday's Field Theory. *Science & Education, 20*(7-8), 687-700. https://doi.org/10.1007/s11191-010-9256-9.

Uzun, S., Alev, N., & Karal, I. S. (2013). A cross-age study of an understanding of light and sight concepts in physics. *Science Education International, 24*(2), 129-149. Retrieved from https://files.eric.ed.gov/fulltext/EJ1015829.pdf

Vanderveen, J. R.; Martin, B.; Ooms, K. J. (2013). Developing Tools for Undergraduate Spectroscopy: An Inexpensive Visible Light Spectrometer. *Journal of Chemical Education,* *90*(7), 894-899. https://doi.org/10.1021/ed300396x

Van Someren, M. W., Barnard, Y. F., & Sandberg, J. A. C. (1994). *The think aloud method: a practical approach to modelling cognitive*. London, England: Academic Press. Retrieved from https://pure.uva.nl/ws/files/716505/149552_Think_aloud_method.pdf

Vergnaud, G. (1982). A classification of cognitive tasks and operations of thought involved in addition and subtraction problems. *A cognitive perspective*(pp. 39-59). Hillsdale, United States of America. Retrieved from https://www.gerard-vergnaud.org/texts/gvergnaud_1982_cognitive-tasks-operation_addition-subtraction.pdf

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