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Disruptive Education: Integrating ChatGPT into an Active Methodology for Teaching Sciences and Mathematics

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ABSTRACT

Context: The integration of Artificial Intelligence (AI), marked by the advent of ChatGPT and other Large Language Models in December 2022, has demonstrated transformative potential in Science and Mathematics educational practices. This technology offers prospects to revolutionize conventional pedagogical methods and reduce socioeconomic disparities. A teaching model is proposed that employs Generative AI tools in flipped learning environments, allowing students to prepare at home through simulations that act as Sophotechnic Mediation. **Objectives:** An active methodology is presented where the use of ChatGPT at home precedes and prepares classroom learning, applying the Cognitive Networks Mediation Theory. **Design:** Hypercultural Mediation was utilized with simulations developed via ChatGPT, alongside mediations arising from students' previous experiences or integrated into classroom activities. **Environment and Participants:** Conducted with high school students, the research focused on the Physics curriculum, exploring concepts of Light and General Relativity Theory. **Data Collection and Analysis:** Following the ideas of Bachelard and Mortimer, the External Mediation Level Profile was created to visualize the most effective mediations for creating mental images. **Results:** A significant correlation was observed between the mental images formed and the students' gestures, suggesting a deepened understanding of the discussed concepts. **Conclusions:** Integrating AI with the Cognitive Networks Mediation Theory can help address traditional teaching limitations by considering individual student characteristics and fostering the development of modeling and problem-solving skills.

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Keywords: ChatGPT; Active Methodologies; Sophotechnic Mediation; Cognitive Mediation Theory in Network; Science and Mathematics Education.

Educação Disruptiva: Integrando o ChatGPT a uma Metodologia Ativa de Ensino de Ciências e Matemática

RESUMO

Contexto: Nesse Contexto: A integração da Inteligência Artificial (IA), exemplificada pelo advento do ChatGPT e outros Grandes Modelos de Linguagem em dezembro de 2022, tem demonstrado potencial transformador nas práticas educacionais em Ciências e Matemática. Essa tecnologia oferece perspectivas de revolucionar métodos pedagógicos convencionais e diminuir disparidades socioeconômicas. Propõe-se um modelo de ensino que emprega ferramentas de IA Generativa em ambientes de aprendizado invertidos, permitindo aos estudantes se prepararem em casa através de simulações que servem como Mediação Sofotécnica. **Objetivos:** Apresentar uma metodologia ativa, onde o uso do ChatGPT em casa antecede e prepara o aprendizado em sala, aplicando a Teoria da Mediação Cognitiva em Rede. **Design:** Utilizou-se a Mediação Hipercultural com simulações desenvolvidas via ChatGPT, além de mediações decorrentes de experiências prévias dos estudantes ou integradas às atividades em sala. **Ambiente e Participantes:** Desenvolvida com estudantes do ensino médio, a pesquisa concentrou-se no currículo de Física, explorando conceitos de Luz e Teoria da Relatividade Geral. **Coleta e Análise de Dados:** Seguindo as ideias de Bachelard e Mortimer, criou-se o Perfil de Nível de Mediação Externa para visualizar as mediações mais eficazes na criação de imagens mentais. **Resultados:** Observou-se uma correlação significativa entre as imagens mentais e os gestos dos estudantes, sugerindo uma compreensão aprofundada dos conceitos abordados. **Conclusões:** A integração da IA com a Teoria da Mediação de Redes Cognitivas pode ajudar a resolver as limitações do ensino tradicional, considerando as características individuais dos alunos e promovendo o desenvolvimento de habilidades de modelagem e resolução de problemas.

Palavras-chave: ChatGPT; Metodologias Ativas; Mediação Sofotécnica; Teoria da Mediação Cognitiva em Rede; Ensino de Ciências e Matemática.

INTRODUCTION

The journey of educational technology has been a continuous evolution, profoundly influencing teaching and learning methods and practices. The blackboard in the classroom, a tool that has been used for centuries, marked one of the first instances of technology facilitating interactive classroom environments. The introduction of the overhead projector in the 1880s further reinforced this interactive environment, enabling group learning and fostering a more dynamic pedagogical approach. The narrative of educational technology took a revolutionary turn in the 1960s and 1970s with the advent of the first computers. This marked the beginning of the digital era in education, paving the way for computer-assisted learning. The development and proliferation of microcomputers in the 1980s made this form of learning more accessible and affordable. The 1990s marked the transformative emergence of the internet, which facilitated the rapid dissemination of information, the development of online learning platforms, and enabled remote collaboration.

The emergence of learning management systems, such as Moodle, revolutionized the way educators created and managed courses, administered assessments, and tracked student progress. The internet also democratized access to education through the creation of Massive Open Online Courses (MOOCs), promoting a culture of lifelong learning. The 21st century opened an era of mobile devices, social media, and cloud computing, further revolutionizing the educational landscape. The growing ubiquity of smartphones and tablets allowed students and teachers to access learning resources anywhere, anytime. These devices facilitated the development of mobile learning (m-learning) and adaptive learning technologies, providing more personalized and engaging learning experiences (Crompton, 2013).

The use of social media in education not only transformed communication and collaboration among students, teachers, and institutions (Manca & Ranieri, 2016), but also paved the way for the technological revolution that has reshaped education in recent years. This refers to the advent of Artificial Intelligence (AI), with the creation of computational systems that can imitate and automate functions that typically require human intelligence, enabling these systems to learn from data, adapt to new situations, and make decisions based on available information. This includes the integration of machine learning (ML), which focuses on developing algorithms and computational models that allow systems to learn and improve from data.

These advances led to the development of intelligent tutoring systems and virtual assistants, which can support personalized learning and improve educational outcomes (Woolf, 2009). However, the world was not prepared for the paradigm shift that occurred in December 2022. The launch of ChatGPT marked the beginning of the era of Large Language Models (LLMs). This development was surprising, demonstrating the transformative potential of AI in education and setting the stage for a new chapter in the evolution of educational technology. These high-complexity models possess the remarkable ability to interpret and respond accurately to complex linguistic prompts, a capability that contributed to the rapid increase in popularity of ChatGPT, which became a powerhouse in the field of natural language processing by January 2023.

Although ChatGPT is not the first or only AI-powered chatbot capable of natural language processing accessible via a web browser (Garg, 2023), its adoption and rapid expansion were notable (Hu, 2023). A significant part of this success can be attributed to its ability to generate high-quality text, similar to human writing (OpenAI, 2022). This capability is so advanced that the model has passed professional-level exams in medicine (Kung et al., 2022), law (Choi et al., 2023), and business (Terwiesch, 2023). Furthermore, it has demonstrated the ability to perform certain cognitive tasks as well as, or even better than, human participants (Binz & Shulz, 2023), even scoring high on IQ tests (Rozado, 2022; Webb et al., 2022).

However, the history of Educational Technology (EdTech) is not without conflicts. Despite the multiple potential benefits offered by the continuous integration of Information Technology (IT) in education, there are dangers and potential negative consequences that must be recognized. One of the most pressing concerns is the growing digital divide between rich and disadvantaged countries and communities (Mattos & Chagas, 2008). Limited access to modern technology, infrastructure, and training can exacerbate existing educational disparities, as students in disadvantaged regions cannot fully benefit from the latest EdTech advancements. This inequality can perpetuate a cycle of poverty and hinder social mobility, further deepening the socioeconomic gap.

In fact, the integration of IT in education has been a constant theme of debate and analysis, with the potential to revolutionize conventional pedagogical approaches and help overcome socioeconomic disparities, if we discover how to do so. In this context, this article aims to propose a teaching model that effectively incorporates Generative AI tools in classroom environments, with an emphasis on Science and Mathematics education. As well as explaining the benefits of using these tools in teaching and learning..

COGNITIVE NETWORKS MEDIATION THEORY (CNMT)

The TMC (Souza et al., 2012) is a contextualist and constructivist theory that aims to provide a broad approach to human cognition, based on a set of five basic assumptions about human cognition and data processing:

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

The TMC proposes that cognition is an information processing phenomenon and that digital technologies have an impact on human thought. This is due to the inherent limitations of the brain in processing all available information, resulting in a significant part of the processing occurring outside the brain. This theory elucidates how cognitive operations interact with aspects such as the physical environment, social collectives, cultures, equipment, machines, and more, thereby increasing their own information processing capabilities.

For example, when a computer or cell phone is used to process information or perform more complex calculations, it is employed as an external Mediation mechanism. In order to use such devices effectively, it becomes necessary to establish internal mechanisms that enable the manipulation of these devices and the understanding not only of their operation (providing inputs), but also of the information they provide (comprehending outputs). These internal mechanisms enable the use of the aforementioned external mechanisms and act, from a cognitive perspective, as virtual machines (or drivers, establishing an analogy with computing), which develop through the interaction between the individual and external structures, aiming to complement information processing. In other words, for Mediation to occur, it is crucial that the person has internalized the operational patterns and movements of the external structures used.

Thus, students create drivers both when learning to handle a program's interface and during the development of activities or even in their daily or previous school experiences. Moreover, they offer new cognitive functionalities that transcend information processing support, introducing logical ideas, schemes, and universally applicable skills based on the internalized operational patterns. As a result, a person's environment is not just an inactive collection of components, but rather physical and sociocultural structures that form dynamically interactive cognitive ecosystems.

The TMC theorizes that humans have undergone cognitive evolution, with different forms of Mediation emerging in a layered sequence, with each new layer incorporating the previous ones. Table 1 describes the first four stages:

Table 1

The evolution of four forms of Mediation in the order of their emergence

Mediation Form	External Mechanisms	Internal Mechanisms
Psychophysical	Physics of the objects and the environment	Sensory and motor schemes, knowledge of the behavior of everyday physical systems
Social	Group behavior	Rules and standards of collective behaviors and interactions
Cultural	Tools, symbolic systems, rituals, traditions, and practices	Formal and informal knowledge of sociocultural content and functioning
Hypercultural	Computers, digital devices, and their software	Analogical representations, drivers

Finally, the CNMT defines that cognition and learning through extracerebral processing are carried out at different levels of Mediation, interacting with different external processing tools, which can be grouped into four different levels of Mediation, as shown in Table 1. Each of these levels of Mediation marks a specific historical period in the development of humanity and, from an evolutionary perspective, represents progressive cognitive gains that naturally reflect in learning. It is through the use of external mechanisms present in these different Mediations that students will develop differentiated mental representations and drivers, which can facilitate learning, which for us translates into the construction of specific representations that enhance the student's problem-solving ability, as well as gaining insights into a particular concept. Previous investigations suggest the theoretical contribution of the CNMT by 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).

WHAT IS EXPECTED TO HAPPEN WITH THE EMERGENCE OF GENERATIVE AI?

Generative Artificial Intelligence, or Generative AI, is a subfield of Artificial Intelligence (AI) that focuses on creating systems capable of generating data, content, or outputs that resemble what a human could produce. Instead of merely processing information or making decisions based on existing data, generative AI is designed to autonomously create data or resources through natural language, as exemplified by ChatGPT (OpenAI, 2022, 2023a).

Referring to Table 1, we currently have four different levels of mediation. With the emergence of Generative AI, it is proposed that a new level of Mediation will emerge, and the reasons why this encompasses a new Mediation and is not simply a continuation of Hypercultural Mediation are discussed in Souza, Andrade Neto, and Roazzi (2023). Sophotechnic mediation requires the development of internal mechanisms that include mastering the technical elements of interaction with technology, the logical schemes and concepts that reflect the basic functioning of AI, awareness of the biases, assumptions, and logical fallacies of the AI-generated content, and understanding the structure and dynamics of communities, markets, and other sociocultural structures built around AIs.

This new level of mediation, sophotechnic mediation, will lead to potential new cognitive impacts, including:

- **Improved Problem-Solving Skills**: Gaining an understanding of how AI works can enhance general problem-solving abilities, encouraging an organized approach to thinking and the ability to decompose complex problems.
- **Enhanced Digital Literacy**: Becoming proficient in the technical aspects of interacting with AI can transfer to other digital tools, strengthening overall digital literacy and the ability to interact with various software and systems.
- **Critical Thinking and Evaluation**: Being aware of biases in content curation, hidden assumptions, and logical inaccuracies can cultivate a critical mindset relevant to various sources of information and situations, encouraging individuals to examine and evaluate the authenticity and reliability of the information they encounter.
- **Adaptability and Flexibility**: As individuals cultivate Internal Mechanisms to interact with a variety of AI systems and tools, they can become more versatile and adaptable when faced with new technologies or systems, empowering them to learn and adapt quickly in unfamiliar situations.
- **Communication and Collaboration**: Understanding the fundamental structure and dynamics of AI-centered communities, markets, and sociocultural constructs can enhance communication and collaboration skills within and outside these AI-related contexts. This could improve networking capabilities and the ability to work effectively in diverse groups or teams.
- **Creativity**: Interaction with natural language AIs has the potential to boost creativity by removing interface barriers, both by offering new perspectives through random generation ("Temperature") and because systems that produce the most direct logical responses exert pressure to explore more unique possibilities, as previously observed in the context of the Japanese game Go by Shin et al. (2023).

Given the impact on cognition caused by interaction with sophotechnic mediation, this can be a valuable tool to enhance student learning and make the classroom more interactive and collaborative. However, it is necessary to explore further how this technology can be effectively integrated into the classroom and how teachers can be trained to use it appropriately. One possibility is its combined use with active methodologies discussed in the next section.

ACTIVE METHODOLOGIES FOR THE INTEGRATION OF TECHNOLOGIES IN SCIENCE TEACHING

The contemporary school scenario presents a contrast between traditional teaching and the constant transformations of society. Despite economic, cultural, and technological changes, content-based lessons using traditional methodologies are still observed. Specifically, regarding science teaching, it should facilitate the construction of scientific knowledge, going beyond the understanding of transformations and processes. To achieve this, it must actively interact with the student's environment, requiring an up-to-date teaching profile. In this context, active methodologies have stood out as an effective approach to promote active student participation in the construction of their own knowledge. According to Johnson (2014), active methodologies consist of various techniques aimed at promoting student engagement, achieving meaningful learning.

Unlike the traditional teaching model, where the teacher plays a central role in the transmission of information, active methodologies place the student as the protagonist of their own learning. To create a more favorable learning environment, the use of active methodologies enables the construction of knowledge so that students become active subjects in the classroom, and the teaching practice is re-signified (Berdel, 2011). In a context involving active methodologies, there must be a teacher with an investigative stance, recognizing problems and proposing solutions.

It is essential for students to reflect on the activities developed, rather than just following the teacher's instructions, as critical thinking can stimulate and qualify the formation of future professionals. Adopting a teaching model that employs active methodologies changes the educational process, where the teacher acts as a learning facilitator (Mazur, 2015). Additionally, active methodologies can be seen as reinterpretations of models present in various theories, seeking ways to enhance knowledge acquisition.

Active methodologies encourage students to explore, investigate, question, and build knowledge through practical activities such as case studies, simulations, experiments, group discussions, and projects. Furthermore, active methodologies promote collaboration among students, developing social skills and preparing them for teamwork. An important characteristic of active methodologies is the contextualization of learning. This means relating the studied content to real-world situations and student experiences. Through case studies, practical projects, and the application of knowledge in concrete situations, students are motivated to understand the relevance and applicability of the concepts (Inayah et al., 2023).

Capone (2022) highlights another fundamental aspect of active methodologies: continuous and formative feedback. Students receive guidance and evaluation from both teachers and peers, allowing them to reflect on their own learning process, identify areas for improvement, and enhance their performance. Furthermore, practical and reflective activities promote the development of complex cognitive skills, such as critical thinking, analysis, synthesis, and problem-solving. Meaningful learning is facilitated as students are encouraged to relate theoretical knowledge to practice and apply it in real-world contexts, leading to better retention and transfer of knowledge to future situations.

For teachers, adopting active methodologies means playing the role of learning facilitators, promoting a partnership relationship with students. This approach allows for the exploration of creative and innovative actions, as well as obtaining immediate feedback on students' progress and performance. However, the effective implementation of active methodologies can face challenges, such as resistance to change, the need for adequate time and resources, curricular adaptation, and the assessment of achieved results. Overcoming these challenges requires institutional support, investment in teacher training and capacity building, the creation of appropriate spaces, and an educational culture that values innovation and continuous improvement (Capone, 2022).

In this perspective, many resources can foster the usability of active methodologies, such as Digital Information and Communication Technologies (DICT). Computational simulations can be used in the classroom to reproduce phenomena, for example, to solve issues present in everyday situations. Additionally, digital games like Kahoot can be used in an effective gamification approach to the learning process, making teaching more engaging and interactive through interactive challenges and educational competitions. The integration of digital technologies in Science teaching is discussed next, highlighting some relevant pedagogical approaches.

DIGITAL INFORMATION AND COMMUNICATION TECHNOLOGIES (DICT) IN SCIENCE TEACHING

The advancement of Digital Information and Communication Technologies (DICT) has played a significant role in education, including Science teaching. DICT provides students with access to interactive educational resources such as videos, simulations, animations, and games, making the learning of abstract scientific concepts more tangible and engaging. Additionally, these technologies facilitate communication and collaboration among students, teachers, and other education professionals through discussion forums, blogs, wikis, and other collaborative tools (Freitas, Silva, & Cardoso, 2020).

DICT also allows for virtual experimentation through simulations and virtual labs, enabling students to conduct experiments, explore scientific phenomena, and analyze data without the need for specialized physical equipment (Akpan & Andre, 2020). This provides greater flexibility and access to practical experiences in controlled environments. Furthermore, DICT can be used to personalize learning, catering to individual student needs. Through adaptive learning platforms, students receive activities and materials that match their knowledge level and learning pace, providing a more individualized educational experience.

The use of DICT in Science teaching also increases student engagement and motivation. Multimedia resources, gamification, and interactive elements make learning more attractive and engaging, encouraging students to explore scientific concepts actively and autonomously. Various pedagogical approaches stand out in the use of DICT in Science teaching. Problem-Based Learning (PBL) involves solving real-world problems as the central point of the teaching-learning process (Chistyakov et al., 2023). DICT is used in this methodology to provide relevant information, facilitate research and collaboration, and help create solutions for complex scientific problems.

The Mobile Learning approach involves the use of mobile devices, such as smartphones and tablets, to provide access to educational resources and learning activities. This allows students to access educational materials anywhere and anytime, promoting learning outside the classroom (So & Kim, 2018). Virtual Reality (VR) and Augmented Reality (AR) technologies offer immersive opportunities for Science teaching. Using VR devices or AR applications on smartphones, students can explore virtual environments or overlay virtual information on the real environment, allowing the visualization of complex scientific phenomena, such as the effects of the

Theory of Relativity and aspects of Quantum Mechanics and Chemistry, and interact with virtual objects in real-time.

In the approach known as Instructional Design, the needs and interests of students are the focus when designing learning activities. Here, DICT can be incorporated to allow students to create personalized scientific projects, explore topics of their interest, and share their results with a broad audience, encouraging critical thinking and creativity (Valente, Almeida, & Geraldini, 2018).

Given the various teaching possibilities, Veiga (2006) asserts that the teacher can no longer present static didactics but must become a mentor and facilitator, intermediating the student's access to information. Thus, for teachers to enhance their pedagogical practice and meet students' needs, a solid teacher training is necessary.

METHODOLOGY

Hypercultural Mediation was applied through simulations built with the support of ChatGPT, while the other Mediations were used either in the classroom or derived from the students' previous experiences.

The following are examples of applying the External Mediation Level Profile, focusing on the implications for Physics Teaching. The underlying purpose of the investigations was to identify the modalities of external mediation capable of fostering a broad spectrum of mental images in students concerning the concepts of light (Anjos, 2022) and special relativity (Souza, 2021).

In both investigations, after the data collection phase, semi-structured interviews were conducted, recorded following the Report Aloud protocol (Trevisan et al., 2019). Subsequently, these interviews were subjected to the Descriptive Gesture Analysis technique, as proposed by Clement and Steinberg (2002), Monaghan and Clement (1999), and Stephens and Clement (2010, 2015). This qualitative analysis aims to identify descriptive gestures manifested by students.

Both verbal and gestural manifestations were analyzed together. In this sense, the goal was to identify the external mechanisms employed to explain specific phenomena through the production of mental images.

RESULTS

In the context of Physics teaching, the use of different levels of Mediation can facilitate the learning of complex concepts in Modern and Contemporary Physics, such as the Relativity Theory. While for some students, using only one type of Mediation may be sufficient for understanding a concept, for others, more variations are necessary. Moreover, based on previous results (de Souza & Serrano, 2020; de Souza, 2021), it is known that the combined use of different levels of Mediation can facilitate the learning process of Relativity.

In this regard, some educational resources for approaching the General Relativity Theory (GRT) through different levels of mediation will be presented here. All resources were used with high school students but can be adapted for elementary education. The focus here is on the representation of the Equivalence Principle (EP) through the four Mediations. This principle, which gave rise to GRT by Einstein, aims to include gravity in his theory. It states that, locally, it is impossible to differentiate a gravitational field from an accelerated reference frame. Therefore, an inertial reference frame would be equivalent to free fall.

Psychophysical Mediation

A very simple psychophysical resource consists of demonstrating the Equivalence Principle using a PET bottle. To do this, make a small hole in the lower side of a 500 ml PET bottle. This bottle is filled with water, which can be colored with dye, and its cap is closed. Climb a ladder, and upon opening the cap, the water starts to flow through the hole. When dropping this bottle, the water jet stops during the fall (Figure 1), demonstrating that free fall is equivalent to the absence of gravity.

This simple experiment is a psychophysical resource with significant potential for classroom use. In addition to using low-cost materials, it utilizes elements from the students' everyday lives, with which they are familiar, to demonstrate a fundamental principle of GRT.

Figure 1

Experiment with PET bottle to demonstrate the Equivalence Principle (EP)

A widely used analogy for approaching GRT is the spacetime mesh model, providing another example of a psychophysical resource. Postiglione and Angelis (2021) describe the assembly process of a structure for this demonstration. In an adaptation, a hula hoop with six PVC pipes (around 1m each) fixed to it can be used. Using the pipes to keep the structure upright, a mesh can be fixed to the hula hoop with paper clips. To represent objects of different masses, marbles can be used to observe the trajectory of objects moving near massive objects (Figure 2).

GRT introduced a new interpretation of gravity as a deformation in spacetime caused by massive objects. With this model, it is possible to visualize the deformation caused in a mesh by the marbles and how this deformation increases with the number of marbles used, i.e., the mass. It is worth noting that the mesh must be very tight, requiring many marbles to cause significant deformation, similar to the rigidity of spacetime. It is also important to emphasize this information to students.

After using several marbles to cause a large deformation in the mesh, other marbles can be thrown around it, demonstrating how their trajectories are curved due to the deformation. A single marble can also be thrown on the mesh, comparing its linear trajectory to the curved trajectories in the other situation.

Figure 2

Structure of the mesh model (left) and students interacting with the model (right)

The presented model is a relatively simple and inexpensive psychophysical resource, with potential for classroom use, provided its limitations are explicitly discussed with students—representation of a four-dimensional Universe in only two dimensions. The visualization of objects deforming the mesh representing spacetime is a psychophysical resource of external processing that can help students build drivers to aid in understanding General Relativity.

Social Mediation

Social Mediation is present in all activities utilizing other Mediations through interactions among students and with teachers. However, it is important to promote activities that focus on student collaboration. Therefore, the development of small group activities, especially problem-solving, is highlighted. Exercise lists involving conceptual questions can be used to stimulate peer discussion to find answers.

Regarding the Equivalence Principle, a question that could foster good discussions among students might be: "A group of people was placed in a spacecraft with acceleration a = g. Suppose they do not know they are on a spacecraft. Would it be possible for them to identify (through some experiment or test) that they are in accelerated motion without having contact with the outside of the spacecraft? Explain." It is important to encourage students to reflect and share their opinions on the proposed situation. In small groups, and with teacher Mediation, they can discuss questions in this format and reflect on GTR through Social Mediation (Figure 3).

Various questions can be used in this type of activity. It can involve spacetime deformation, establishing a connection with the mesh analogy mentioned earlier, through the question: "Consider the star Sirius, with a mass more than twice the mass of the Sun. Why would objects near it describe curved trajectories? Would a light beam passing near it be curved? Explain (you can use text, drawings, diagrams)." In this way, students can discuss their answers and relate them to other resources used to address the same phenomenon.

Figure 3

Students discussing conceptual questions in small groups

Cultural Mediation

Through Cultural Mediation, elements of culture with which students have likely had some contact are used, whether through television or social media. Regarding GTR, the widely known film "Interstellar" can be utilized. In this context, excerpts and scenes from the film can be used to address topics of the theory.

A notable scene in the film is when the characters visit a planet near a black hole, Gargantua. While only a few hours pass for the crew members who descend to the planet, several years pass for the one waiting for them on the ship and on Earth. This scene can highlight the phenomenon of gravitational time dilation and how its effects can only be observed in the presence of extremely massive objects, such as the black hole in question.

Additionally, videos and images, such as recent photos of black holes circulating in the media, can be used to discuss how they corroborate GTR. Another option involves using scientific dissemination articles, which can be read in small groups and discussed, incorporating Social Mediation.

Figure 4

Parabolic flight (left) and Hawking's experience (right)(NE10, 2015; BBC News, 2018).

Regarding the equivalence principle, videos of parabolic flights that simulate the absence of gravity, like the Zero-G Experience, can be used. A famous video involves the experience of physicist Stephen Hawking during this flight (Figure 4). It is important to discuss how these simulations work, where during the plane's descent, a situation close to free fall is achieved, in which, according to the EP, the effects of a gravitational field are not perceived. Using these cultural elements, with which students interact daily, can help them process information during the learning of new concepts, establishing connections between them.

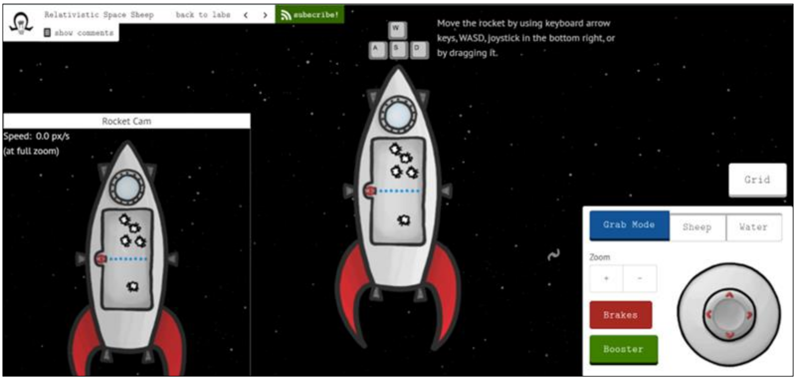
Hypercultural Mediation

Regarding Hypercultural Mediation, there are various easy-to-use computational simulations freely accessible online. For a productive interaction with the simulations, it is beneficial to use guides that direct the students. A technique that has yielded good results is the POE (predict-observe-explain) method (Tao & Gunstone, 1999), where situations are proposed in which students first predict what will happen, then observe it in the simulation, and finally reflect on what they imagined and observed.

Obviously, for a greater enhancement of students' cognitive processing, it is recommended that they interact directly with the simulations. However, given the reality of many Brazilian schools, it is possible to adapt the activities by using simulations collectively through a projector. Even in this case, the POE technique can be used to conduct the activity.

Figure 5

Simulation "Relativistic Space Sheep." (MinuteLabs, 2014)



For demonstrating the equivalence principle, an easy-to-use simulation is "Relativistic Space Sheep," developed by MinuteLabs.io (Figure 5). It features a spaceship with sheep floating inside it. There is also a water pump ejecting droplets horizontally across the ship. Using the keyboard or the controls in the lower right corner of the screen, it is possible to accelerate the ship up, down, right, or left. With acceleration, it can be observed that its effects on the sheep inside the ship are the same as those of a gravitational field, demonstrating the Equivalence Principle.

Sophotechnic Mediation

Contemplating the use of Generative Artificial Intelligence, sophotechnic mediation in the classroom proposes an activity using Bing AI and ChatGPT together. It is highlighted that the direct and individual interaction of students with these resources provides a more productive external processing of information. However, it is possible to adapt the activity according to available resources, dividing students into pairs or trios.

Regarding the equivalence principle, through direct interaction with ChatGPT, students can ask about this principle, requesting explanations and examples. The teacher can suggest some guiding questions, but students are free to formulate questions based on their individual doubts.

Figure 6

Example of images generated by students

After interacting with ChatGPT, students can be prompted to generate images using Bing AI (Figure 6). Based on their conclusions from the previous activity, they can create a description of what they imagine when thinking about the equivalence principle and ask Bing AI to generate an image from it. After generating the images, students can present them, explaining which concepts they sought to represent in their construction.

It is interesting for students to interact with Bing AI, suggesting modifications and improvements to the generated images to obtain an image closer to what they imagined. Clearly, familiarity with the tool makes its use more productive; in this case, it is up to the teacher to assist and guide the students during the activity. Furthermore, the activity can be performed on computers or smartphones, depending on resource availability.

The Need to Use Mediations in an Integrated Manner

The construction of concepts occurs in an integrated manner among various Mediations, within the perspective of CNMT (Souza et al., 2012), such as personal experiences, social interactions, education style, culture, language, and technological advances. It is the dynamic and multifaceted interaction of these elements that allows the construction and expansion of the understanding of the world around them.

In an educational environment, it is noted that the same student may present multiple approaches to solving or explaining issues related to a particular concept, which can vary depending on the context they are in. These different approaches are not always clearly defined. The creation of distinct meanings for a specific concept in the classroom is closely linked to the interpretations resulting from the relationships between the presented content and the student. Similarly, the diverse life experiences of the students will also contribute to a variety of perspectives, thus influencing the Mediations adopted.

It is natural for everyone, when solving any problem, to use not just one, but several different external Mediations that intertwine and compose the repertoire of mental images and drivers the individual uses to solve the problem. As discussed in Meggiolaro's (2019) contribution, 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 the individual electric field vectors produced by all the charges, we concluded that the five

> students pointed out that the combined use of the external mechanism of Social, Cultural, and Hypercultural Mediation provides support for the acquired representations and drivers related to notebooks, exercises, classes, and computer simulation in GeoGebra of the addressed concepts (Meggiolaro, 2019, p.153, our translation).

As in the study conducted by Meggiolaro (2019), during the analyses of other research within Physics teaching (Souza, 2021; Anjos, 2022), it is perceived that the mental images that populate the cognitive structure of the student originate from different levels of Mediation (Psychophysical, Social, Cultural, and/or Hypercultural). Borrowing from Vergnaud (1982), who argued that "a situation is not just with a concept, just as a concept is not 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.

By observing the diversity of mental images from the different external processing mechanisms employed by each student when studying different physical concepts, the analysis tool titled "External Mediation Level Profile" can be traced individually for a given concept. This tool would indicate which levels of Mediation are preferentially accessed by the student when using a concept to solve a specific problem. The idea of creating an External Mediation Level Profile was originally inspired by the constructions of Bachelard (1985) and Mortimer (1995), who study the problem of solving scientific problems with the Epistemological and Conceptual Profiles, respectively. According to Bachelard (1991):

> Various philosophical schools and epistemological stances are adopted by individuals when constructing the concept of specific content. A single philosophical conduct would not be sufficient to express the different ways of thinking when attempting to present and explain a simple concept (Bachelard, 1991).

In the analysis of the investigation studying the concept of light (Anjos, 2022), it was also noted that students' previous experiences interfered with the level of Mediation used. According to Mortimer (2000), "students' prior ideas play a fundamental role in the learning process" (Mortimer, 2000).

In his works "The New Scientific Spirit" (1985) and "The Philosophy of No" (1991), Bachelard presents the need to demonstrate that different philosophies can be present in the same understanding of a concept, even if some of them are consciously considered inadequate to characterize a certain notion of scientific knowledge. Bachelard (1966) expounds on ideas related to the term he called "epistemological profile," which characterizes the various philosophical schools and epistemological stances of individuals. This plurality represents different ways of seeing and representing reality, both for an individual concerning a scientific concept and for the same concept in different historical contexts.

Bachelard proposes that concepts, in their course of development, are to some extent linked to certain philosophical points of view (animist, realist, empiricist, rationalist), depending on their stage of maturity. In other words, a student can present various representations or ways of perceiving reality in relation to a scientific concept. The philosophical currents for each student are traced based on the evidence of the importance expressed by the frequency of effective use of the concepts worked on. Based on this profile, inferences can be made to identify the philosophies that stand out in the process of defining a specific concept. This epistemological profile, according to Bachelard (1991, p.25), "must always refer to a designated concept, being valid only for a particular individual who is being examined at a specific stage of their culture."

In the book "The Philosophy of No" (1991), Bachelard presents his ideas that culminate in the term coined as "epistemological profile," using two examples constituted by graphical constructions. These examples allow the author to trace and analyze his own personal epistemological profile in relation to the definitions of the concepts of mass (Figure 7) and energy (Figure 8).

When presenting the graphs for his epistemological profile concerning the concept of mass and energy, Bachelard does not explain how he obtained the values for the frequency of personal use of each notion. He merely points out the difficulty of establishing these values, stating:

> [...] we will then try to roughly highlight its relative importance by placing the successive philosophies on the abscissas and a value on the ordinates which - if it could be exact - would measure the frequency of effective use of the notion, the relative importance of our convictions. With some reservation regarding this very rough measure, we then obtain our epistemological profile (Bachelard, 1991, p. 25).

Figure 7

Epistemological profile of the personal notion of mass (Bachelard, 1991, p. 25)

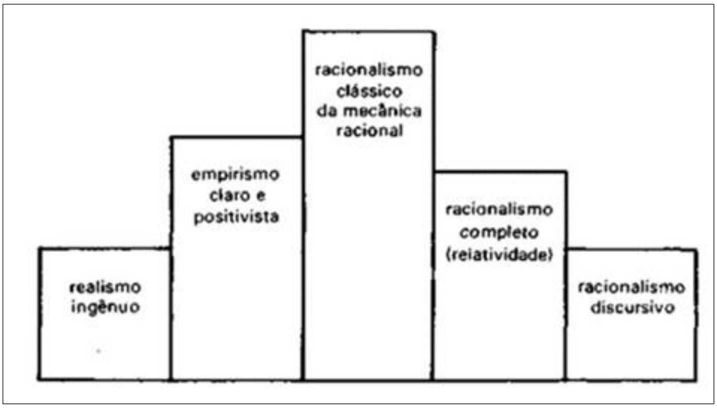
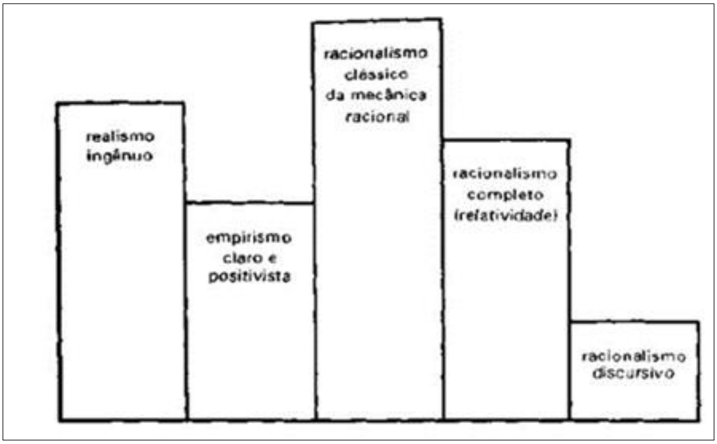


Figure 8

Epistemological profile of the personal notion of energy (Bachelard, 1991, p. 27)



Trevisan and Serrano (2016) examine the relationship between the Cognitive Mediation Theory (CNMT) and the ideas of philosopher Bachelard, focusing on the study of scientific knowledge production. The authors use CNMT as a theoretical framework to analyze the impact of Mediation through hypercultural tools, such as quantum mechanics experiment simulations, on students' cognitive structures 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 structures while investigating students' conceptions of wave-particle duality. It establishes connections between these conceptions and the main interpretations of quantum mechanics, and maps the philosophies that influence students' understanding.

Based on Bachelard's ideas, Mortimer (1995, 2000) developed the notion of a conceptual profile, in which a single concept can be fragmented into different zones that correspond to different ways of seeing, representing, and giving meaning to the world. This means that any individual can have more than one way of understanding reality, which can be used in appropriate contexts. According to Mortimer (1995, p.274), "considering the notion of Conceptual Profile (CP), the problem of learning and teaching science can be viewed in a new way." From this perspective, obstacles in learning concepts can be identified and addressed in the classroom, viewing science learning as a change in conceptual profiles. This implies that students do not necessarily need to abandon their conceptions when learning new scientific ideas but rather become aware of the different zones and the relationships between them. For the author, "students' prior ideas play a fundamental role in the learning process" (Mortimer, 2000).

Mortimer (1995) applied the notion of a 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 established profile, which allows describing the concept formation process in science classes coherently with the idea that different points of view can be complementary. Each zone in a conceptual profile offers a unique way of seeing the world, differing from other zones and corresponding to different forms of Mediation, theories, and languages that translate the world in their own ways. Reality itself cannot be fully understood from a single perspective, as only a complementary view can produce a complete image.

Using the ideas of authors Bachelard and Mortimer, the External Mediation Level Profile was constructed exploratorily, following CNMT, for each concept presented by students. This enabled the visualization of the Mediations (Psychophysical, Social, Cultural, and Hypercultural) most relevant for creating the mental images that helped understand the topics, as well as the transitions between external mechanisms.

The notion of a conceptual profile shares some characteristics with the epistemological profile, such as the hierarchy between different zones of the profile. Each successive zone in the epistemological profile starts from naive philosophy and advances towards scientific thinking, while in the conceptual profile, the zones are organized from the oldest to the modern. This proposition and organization are also applied in the construction presented here, where the External Mediation Level Profile ranges from the psychophysical mechanism, as the first emergent stage through interactions with the environment, to the hypercultural level, which arises chronologically from the Digital Revolution.

Mortimer's understanding of the conceptual profile indicates that reality can only be understood through a complementary view of the different zones of the conceptual profile, each being developed by the student. Similarly, the External Mediation Level Profile naturally reveals how a student's understanding of a particular concept is formed by a mosaic of representations and influences from different levels of Mediation, stemming from different external processing objects. If the External Mediation Level Profile of a specific concept, for a student, is predominantly filled with representations from the Psychophysical Mediation level, this may indicate little interaction with teachers (Social Mediation) and cultural artifacts, such as books or even sophisticated simulations that could offer better representations of the phenomena related to the concept.

The External Mediation Level Profile is individually traced for each concept, indicating the transitions between Mediations and the frequency of each. This analysis allows determining the degree of importance of each extracerebral mechanism in understanding the studied concepts, following a historical progression from the psychophysical to the hypercultural level. On the abscissa axis, the successive Mediations are represented, while on the ordinate axis, a value corresponding to the effective frequency with which each Mediation is expressed by the participant in relation to each concept is assigned. This representation will be demonstrated in the applications of the Profile below.

Application of the External Mediation Level Profile

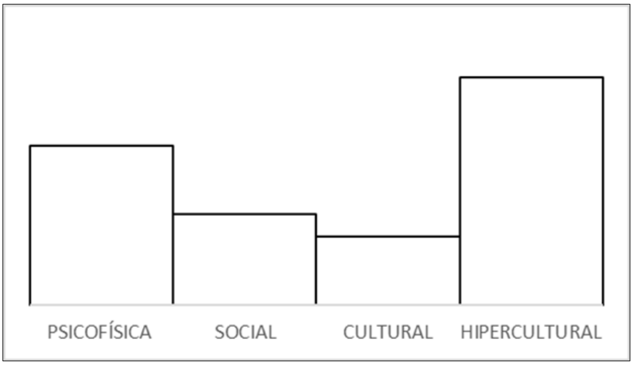
Here, we present some examples of the use of the External Mediation Level Profile with applications in Physics Teaching. The investigations aimed to identify which external Mediations provided a broader repertoire of mental images to students concerning the concepts of light (Anjos, 2022) and relativity (de Souza, 2021).

In both studies, after the data collection period, semi-structured recorded interviews were conducted following the Report Aloud protocol (Trevisan et al., 2019). Subsequently, these interviews were analyzed using the Descriptive Gesture Analysis technique (Clement & Steinberg, 2002; Monaghan & Clement, 1999; Stephens & Clement, 2010, 2015). This qualitative analysis seeks to identify descriptive gestures made by students. The studies suggest a relationship between the mental images present in students' cognitive structures and the gestures they make.

The verbal and gestural discourses were analyzed together. In this way, we sought to identify the external mechanisms used to explain certain phenomena through the production of mental images. Through this approach, it was possible to develop the individual analysis tool presented here.

Figure 9

External Mediation Level Profile of student A11



An External Mediation Level Profile was developed for each concept studied during the investigation (Anjos, 2022). At the end, a general profile was constructed for each student. For example, Figure 9 below presents the

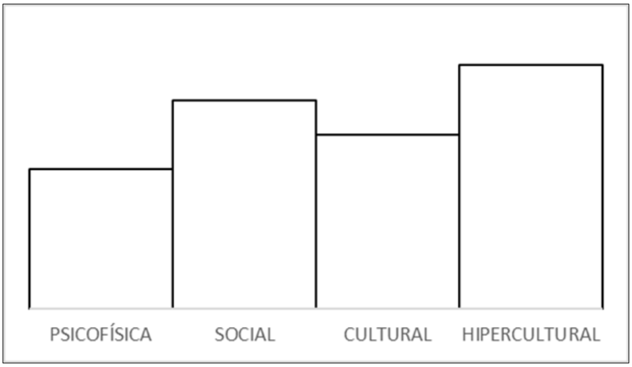
External Mediation Level Profile of student A11 (nomenclature used in the research) regarding the concept of light:

For the construction of the External Mediation Level Profile based on questions related to concepts involving the idea of light, it was observed that Hypercultural Mediation was the most relevant in creating the drivers that generate the mental simulations of student A11. In other words, this mechanism was the most mentioned by the student and the one that most enabled the construction of mental images. Following this, we have Psychophysical, Social, and Cultural Mediations, respectively.

To investigate the degree of relevance of each Mediation for questions related to the concepts of special relativity and their transitions between different external processing mechanisms, Figure 10 presents the External Mediation Level Profile of student A18:

Figure 10

External Mediation Level Profile of student A18



As previously mentioned, an individual External Mediation Level Profile was constructed for each concept addressed in the research questions, followed by a general profile. When analyzing student A18, it is observed that, once again, the most cited mechanism by the student, which enables the construction of mental images, is Hypercultural Mediation. Following this, we have Social, Cultural, and Psychophysical Mediations, respectively.

The presented research was conducted in different ways. The first study, which addressed the concept of light, was conducted remotely and prioritized the construction of an experimental apparatus, involving stages such as reading, viewing videos, simulations, and a recorded lesson. The second investigation, related to the concepts of special relativity, took place in a classroom setting, where the teacher developed various activities involving the four Mediations. It is noted that the examined students transition through all forms of External Mediation, with varying degrees of relevance, which were important in the construction of physical concepts.

It is common for students to use more than one Mediation when imagining a situation while answering a question. In other words, mental images originate from the interaction between Mediations, as exemplified earlier. One relevant consideration regarding the construction of the External Mediation Level Profile in the two presented studies is that for each question, at least two Mediations are reported, evidencing that concept construction requires different Mediations that complement each other, dialoguing and composing the concept in the student's mind. The addition of sophotechnic Mediation will bring new elements that will enrich the student's conceptual learning through active methodologies.

CONCLUSIONS

The present research proposed using artificial intelligence (AI) with Cognitive Networks Mediation Theory (CNMT) for science teaching. The proposal involves using an AI system that generates personalized conceptual models for each student, based on their prior knowledge, interests, and learning objectives. This research also discussed the advantages and challenges of this approach and presented an illustrative case study of its application in a high school class.

The presented proposal is innovative and relevant to the field of science teaching, as it seeks to integrate AI with CNMT to promote more meaningful, contextualized, and autonomous student learning. Using AI with CNMT can help overcome some limitations of traditional teaching methods, which often do not consider individual student characteristics or stimulate the development of modeling and problem-solving skills.

However, the proposal also presents some challenges and limitations that need to be considered and overcome. For example, the AI system requires a robust and updated database to generate appropriate conceptual models for each student. It is also necessary to ensure the quality and reliability of the feedback and suggestions provided by the system, which must be consistent with the teacher's pedagogical objectives.

Therefore, it is suggested that more empirical research be conducted to evaluate the effectiveness and feasibility of the proposal in different educational contexts. It is also recommended that mechanisms for assessing student understanding be developed that are compatible with the AI and CNMT approach, such as portfolios, concept maps, self-assessments, and peer reviews, allowing for tracking student progress and verifying whether they are building consistent and coherent conceptual models with scientific concepts.

In summary, this article proposed an innovative way to use AI with CNMT for science teaching, which can bring benefits to students and teachers. However, more studies and experiments are needed to validate and improve the proposal and to develop appropriate ways to assess student understanding. It is hoped that this proposal can inspire other researchers and educators to explore the possibilities of AI with CNMT for teaching other areas of knowledge.

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AUTHOR CONTRIBUITION STATEMENT

JA utilized her own case study to analyze the mediation level profile. MGS authored the majority of the results section, detailing the different mediation level activities for classroom application. TSB examined the use of active methodologies and contributed significantly to the organization of the paper. AS conceived the original idea for the paper and conducted the bibliographic review.

DATA AVAILABILITY STATEMENT

The data supporting the findings of this study will be available from the corresponding author, AS, upon reasonable request.

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