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Peirce's Semiotics: Use of Gestures as a Potential Semiotic Resource for Teaching Bohr's Atom Model

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ABSTRACT

Background: Gestures, seen through Peirce's semiotics as semiotic resources, have the potential to be revealed as cornerstones for the teaching of physics and, in particular, for the teaching of Bohr's atomic model. **Objective:** To investigate the contribution of gestures as a potential semiotic resource in teaching Bohr's atom model. **Design:** The principles of a qualitative study were observed. **Setting and participants:** Videos of a preparatory course for ENEM, in the subject of Physics, made by the secretary of education of the state of RS, Brazil, free of charge via the internet. **Data collection and analysis:** A total of seven hours of online classes of a preparatory course for ENEM are analysed. For the gestural microanalysis, episodes on Bohr's atom were chosen, with two distinct episodes: the first on the photon and the second on energy levels. **Results:** From the research analysis carried out on signs within the Peircean framework, it is possible to infer that gestures have the potential to be used as a semiotic resource in the classroom. **Conclusion:** We found that gestures can be a potential semiotic resource in teaching Bohr's atom model, as they can enable an articulation between different semiotic resources.

Keywords: Semiotics; Gestures; Bohr's atom; Science teaching.

Semiótica de Peirce: uso dos gestos como um potencial recurso semiótico para o ensino do modelo de átomo de Bohr

RESUMO

Contexto: os gestos, vistos por meio da semiótica de Peirce como recursos semióticos, têm o potencial de se revelarem fundamentais para o ensino de Física e, em especial, para o ensino do modelo atômico de Bohr. Será, inicialmente, abordada a

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perspectiva semiótica no processo de ensino e, subsequentemente, o papel dos gestos e da comunicação não verbal como um recurso semiótico. **Objetivo:** investigar a contribuição dos gestos como um potencial recurso semiótico no ensino do modelo do átomo de Bohr. **Design:** observou-se os princípios de um estudo qualitativo. **Cenário e participantes:** vídeos de um curso preparatório para o ENEM, da disciplina de Física, realizados pela Secretaria de Educação do Estado do RS, gratuitamente, via Internet. **Coleta e análise de dados:** analisa-se, então, um total de 7 horas de aulas, oferecidas de forma *on-line*, de um curso de preparação para o ENEM. Para a microanálise gestual, foram escolhidos os episódios sobre o átomo de Bohr, sendo dois episódios distintos: o primeiro, sobre o fóton, e, o segundo, sobre níveis de energia. **Resultados:** a partir da pesquisa realizada sobre os signos dentro da perspectiva Peirceana, é possível inferir que os gestos têm, de fato, o potencial de serem utilizados como um recurso semiótico na sala de aula. **Conclusão:** verificou-se que os gestos podem ser um potencial recurso semiótico no ensino do modelo do átomo de Bohr, pois podem possibilitar uma articulação entre distintos recursos semióticos.

Palavras-chave: semiótica; gestos; átomo de Bohr; ensino de ciências.

INTRODUCTION

The gestures of teachers and students can be a potential semiotic resource in the science education area. Therefore, this investigation sought to understand, analyse, and explore the gestures within a preparatory course for the ENEM, in the online modality, on Bohr's atomic model, a concept seen in the last year of elementary school (science) and high school (modern and contemporary physics).

Given the above, this research focused on the following problem: How do gestures contribute, as a potential semiotic resource, to teaching Bohr's atomic model? To answer this question and explore gestures as a semiotic resource, this investigation first discusses Charles Peirce's semiotics, exposing the concept and historicity. Subsequently, non-verbal communication – gestures – is discussed as a semiotic resource in science education. For the analysis and discussion of the results, we present episodes of online classes on Bohr's atom, using gestures as a semiotic resource in physics teaching. There will be two separate episodes: the first is about the photon, and the second is about energy levels.

The analysis of the videos took place through a microanalysis, i.e., the act of watching the videos exhaustively, minutely examining seconds of screening – with a wealth of details – and reading Arzarello's (2006) semiotic bundle to understand how gestures can be used as a semiotic resource in students' teaching-learning process.

THEORETICAL FRAMEWORK

Languages are present in the world, and people are in the language. So, it is natural to use semiotics as a reference for analysis in the classroom since it is the science that investigates all possible languages, i.e., that aims to examine the modes of the constitution of every fact as a phenomenon of production of meaning and sense (Santaella, 2012).

The fact is that, after the Industrial Revolution, the languages, codes, and messages of the means of reproduction were disseminated and, progressively, after the diffusion of information and messages, a “semiotic consciousness” emerged. Thus, following the Industrial Revolution, those three sources of study of semiotics, the languages, codes and messages, appeared (Santaella, 2012).

At the end of the 20th century, there was a significant growth in knowledge of linguistics, along with discourse analysis. As a result, several theories, methods, and discursive analyses were produced, among them, semiotics. The term semiotics originated from the Greek word *semêion*, which means *sema* or sign, thus representing the study of signs (Batista, 2003).

A sign (signifier), or *representamen*, as it is also called, is something that, under a specific aspect or form, represents something to someone (Peirce, 2015), i.e., it creates in a person’s mind a sign that is equivalent to or, perhaps, a better-developed sign. That said, it is known that the sign represents something for a specific thing, now called an object. The sign represents this object, not exactly in all its aspects, but as a specific reference to a type of idea that, for Peirce, would be a foundation of the *representamen* (Peirce, 2015).

Peirce’s manuscripts present several definitions of signs, some more extensive and elaborate and others more summarised. One of the best definitions of the concept of sign, according to Peirce, is the one that shows that the sign is a thing that represents its object.

A sign intends to represent, at least in part, an object which is, therefore, in a sense, the cause or determinant of the sign, even if the sign falsely represents its object. But to say that it represents its object implies that it affects a mind in such a way that, in a way, it determines in that mind something that is immediately due to the object. This determination of which the immediate or determining cause is the sign, and of which the mediate cause is the object, can be called the interpretant (Santaella, 2012, p. 90).

If the sign has the power to represent or replace something distinct from it, then yes, it will function as a sign. The sign is not an object, but it is in its place, so it will only represent this object in a particular way and a particular capacity (Santaella, 2012). If you are going to think of a painting of a car, a photograph of a car, a sketch of a car, a toy in the shape of a car, or even the look at a particular car, all these will be signs of the object 'car'; never the car itself. Likewise, visual representations of physical models are intended to be signs of those models, in general, mathematically defined.

Only an interpreter can understand the sign is allusive to its object, as the sign represents its object when it provides something in the interpreter's mind (a specific sign or quasi-sign) that is also correlated to the object, not directly, but through the mediation of the sign (Santaella, 2012). So, signs teachers use to represent a physical model, for example, may not have the same meaning for them as they would for their students, as they are different interpreters.

The concept of interpretant is not attributed to the fact of the interpreter of the sign; however, there is a particular relational process that is conceived in the mind of the interpreter (Peirce, 2015). The moment there is a relationship of representation that the sign perpetuates with its proper object, another sign is generated in the interpreting mind that translates the meaning of the first, that is, the interpretant of the first. Some physical models, such as Bohr's model of an atom, are articulable, dynamic, and, therefore, manipulative. In this way, it is possible that when manipulating those models during an explanatory class, teachers gesticulate, adding more signs conceived in their minds as interpreters that must be interpreted by the students.

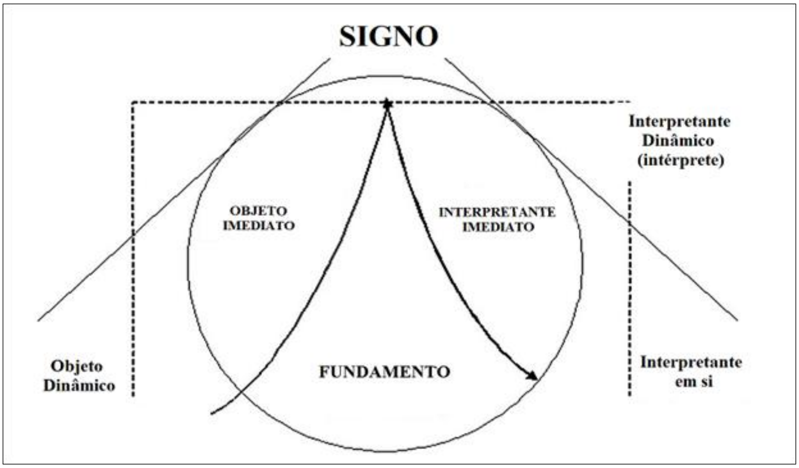
Consequently, the meaning of a sign (whether a physical model or gestures used by the teacher when explaining a model) is another sign (it may be a mental, perceptible image, some gestural action or reaction, or even an idea), because, in other words, what is worked out in the mind by the sign results in another sign (a version of the first). To better determine and understand the definition of a sign, it is important to make it clear that the sign has two objects and three interpretants (Figure 1).

In the following figure, we can observe how the sign is composed of its objects and interpretants. The first of them, the immediate object (inside the circle, i.e., inside the sign), corresponds to how the dynamic object (to the left of the figure inside the circle and that is nothing more than what the sign replaces) is being represented in the sign. As emblematic as this image may be, the immediate object is the appearance of the drawing in which its strives to best portray its shape (a car, as used as an example earlier).

The immediate interpretant (inside the circle and in front of the immediate object) is composed of what the sign will perform in the interpreting mind. It is not about what the sign actually produces in my or your mind, but what, depending on its nature, it can produce (Santaella, 2012). This is because some signs can be interpreted through a person's experience, in a concrete way or action, those that are interpretable by the quality of feelings and, perhaps, others are still susceptible to interpretation through an immeasurable succession of thoughts.

Figure 1

Image representing the concept of sign.



This production will conform to the nature of the sign and its particular potential as a sign. That said, for example, when listening to a song, if the person is not a connoisseur and enthusiast of this art form made up of sounds and rhythms, it will not produce in the individual a sequence of impression characteristics, i.e., auditory, visceral and, perhaps visual perceptions (Santaella, 2012).

Gestures as a potential semiotic resource in teaching Bohr's model of an atom

Currently, the way one lives and expresses oneself in the social environment is strongly related to signs. It is, in fact, one of the factors that boosted, in recent years, the surprisingly fast growth of studies related to semiotics. This search for semiotics leads to a growing awareness that we live in a society of signs and artefacts (Radford, Schubring, & Seeger, 2008).

However, what exactly does semiotics have to contribute to education and the teaching process, especially physics? For Radford, Schubring, and Seeger (2008), the answer is both simple and complex. It is simple insofar as mathematics, their central research topic, is an intrinsic symbolic activity; that is, mathematics happens through written, oral, and bodily signs, among others.

Therefore, semiotics, with its set of concepts and trichotomies of concepts, seems to be convenient to help us understand and follow the processes of thinking, symbolising and communicating mathematics, as well as physics, chemistry, and biology. However, semiotics can be complex because, for thinking processes, symbolisation and communication are subsumed under broader symbolic systems.

How we think and communicate does not make those symbolic systems merely personal matters but something already intertwined with society and its culture. Therefore, semiotics is also considered (Radford, Schubring, & Seeger, 2008) something advantageous, being a fissure of the symbolic, a disturbance of the familiar, a grouping of everyday life – from where it is possible to investigate, resist, and transform signs and systems of signs by which one breathes and lives.

When teaching classes, particularly physics classes, teachers face apprehensive students, having as factors students' fear and the often complex development of the curriculum units. Learning and teaching concepts within this area require finding new and varied didactic resources that agree with the reality of the students' context.

Recently, however, several studies have focused on the body and considered that corporal means of expression could be used as a semiotic resource in teaching-learning. Along those lines, this research emphasises gestures as a semiotic resource.

We pay attention to gestures as a semiotic resource because we know people spontaneously gesticulate when they speak. Gesturing is nothing more than a natural and universal body action. Regardless of culture and nation, people gesture when speaking and use specific gestures to express themselves, even if they have different or opposite cultural meanings. Ergo, gestures are present in people's universal communication.

A good review of publications that indicate the universality and spontaneity of gestural production, published in *Physical Review Physics Education Research* (Stephens & Clement, 2010), reminds us that it is already known that blind-born individuals produce spontaneous gestures even when they talk to other blind-born people, even though they both know they are blind, a fact that was documented and published in *Nature* magazine (Iverson & Goldin-Meadow, 1998). The most important factor as to whether subjects are blind or sighted seems to be the nature of the internal representation underlying communication; therefore, some gestures reflect more the way one thinks about the world than the need for communication (Iverson & Goldin-Meadow, 1998).

Gestures accompany speech and various types of actions that have a symbolic or semiotic function, or as gesture systems, alternative sign languages or idioms. Nevertheless, it is possible to identify and distinguish them from other body movements through particular characteristics. Gestures usually begin in a resting position, move away from the initial position, and later return to rest. However, a difference may occur depending on the culture and age (McNeill, 2000).

The act of gesturing reveals not only what is going on in one's mind, one's mental image, but a point of view of the individual towards the gesture, giving the notion that the meaning of the gesture is usually global and synthetic, never hierarchical. Thus, through the gesture typologies categorised by McNeill, we can state whether the gesture is relevant and its relationship at the time of speech, and perhaps understand what happens in one's mind. In view of this, it is worth mentioning how fundamental this can be in teaching modern and contemporary physics (MCP) in high school.

Some researchers have already carried out studies (Oliveira, Vianna, & Gerbassi, 2007; Monteiro, Nardi, & Bastos Filho, 2009; Magalhães Júnior & Pietrocola, 2011; Melo, Campos, & Almeida, 2015; Massoni Barp & Dantas, 2018) to understand the difficulties encountered in inserting and carrying out the MCP teaching in high school. For Silva, Reis, and Rego (2019), one of the main obstacles is related to physical phenomena that are not easily perceptible in the students' daily lives. Furthermore, its representations are abstract, and it is often necessary to use mathematical formalism, among other additional resources.

Therefore, given the difficulty encountered in developing concepts related to the MCP, either through teacher education courses, in which few resources are available to teachers or because of the complexity involved in explaining concepts, such as the photon, energy levels, relativity, photoelectric effect, black body, among many other concepts that have been part of physics after the 20th century, it is important that, besides pointing out the difficulties, we seek solutions for the problem of physics teaching. According to Santos, Nascimento, and Souza (2016), the insertion of the MCP in high school can arouse in students some curiosity and interest in physics from its relationship with the objects that are present in their lives, such as, for example, the smartphones, notebooks, tablets, among others.

According to Karam and Pietrocola (2008), no matter how many obstacles and adversities we find in the way of physics teaching in high school and especially of physical phenomena of tiny scales, such as atomic and subatomic scales, it is possible to find mechanisms to transpose modern themes for this school level.

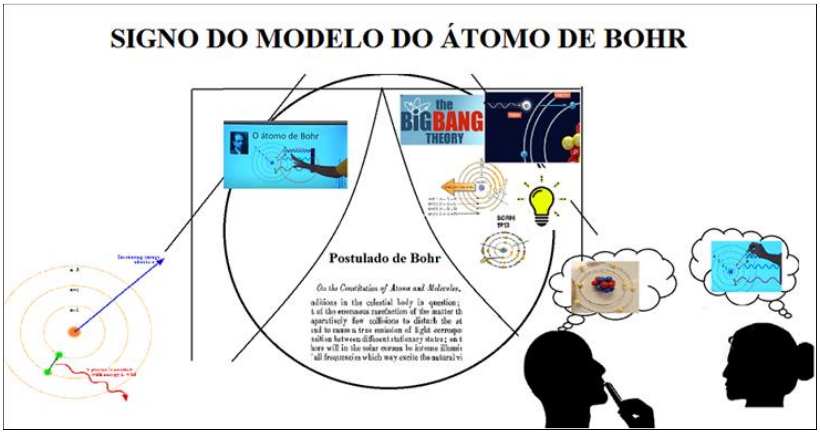
The use of didactic sequences, approaches to the conceptual dimension of modern physics (without renouncing the use of mathematics), representations through different materials, computer simulations, creation of models, and illustrations, among others, have been used with excellent results since elementary school (Freitas, 2019). Finally, why not use the conscious use of gestures produced by teachers as a resource?

To properly analyse the function of gestures as a semiotic resource in class, we must introduce them from a semiotic approach, which allows for a better definition of "signs". So, Peirce's theory discussed earlier in this article contemplates the objective of this research and articulates it better (Sabena, 2008). Assuming Peircean semiotics, everything that enters a semiotic process is a sign; thus, a greater variety of phenomena containing body movements and gestures can be seen as semiotic resources in the classroom.

Applying Peirce's semiotic classification to the case in question, Bohr's atomic model, the foundation (Figure 2) would be the postulates he created in the 1913 article (Bohr, 1913). The dynamic object would be Bohr's model, commonly used in several publications, such as textbooks, very well illustrated in the simulation, where a central nucleus is surrounded by small spheres representing electrons that can "jump" from one layer to another and thus emit or absorb light (represented in a corpuscular form or as a wave).

Figure 2

Image representing the sign of Bohr's model.



The immediate object – from the standpoint of the observer, a student who attends the online class – consists of the conceptual triplet of the static representation of the dynamic object, the teacher's speech, and the gestures the teacher performs. The dynamic interpretant would be all the possible representations that the immediate object evokes in the interpreter's mind, including several visual, tactile, auditory representations, etc., which refer to the phenomenon of emission of a light signal. The interpretant itself depends on how each student relates the immediate object to his or her previous experience individually.

Students learn simple models of atoms in elementary school and gradually integrate more complex ideas into these simple models throughout their academic careers. The study of atoms is a content-rich area, providing a solid foundation for understanding everything, from the fundamental building blocks of nature to the foundation of modern technology (Mckagan, Perkins, & Wieman, 2008). In Brazil, the first contact with physics and chemistry is in the Science curriculum unit, in the last grade of elementary school. It is considered a challenge for teachers and students, given its complexity and the different obstacles the subjects present.

Students resist and even feel repulsion by physics contents, often due to the unattractive way they were presented to the students since elementary school or during the first grade of high school (Leal & Oliveira, 2019). So, why not seek to carry out research that contributes to science teaching and shows the beauty and relevance of teaching physics? (Cipolla & Ferrari, 2016).

Corroborating this idea, Bohr's model can be a gateway to the world of the internal structure of matter. A prime motive for studying atomic models is the adventure that can draw students into a complex web of reasoning about how new models are built and old models discarded based on experimental observations.

Studying Bohr's atom is essential and of great value in high school. Therefore, it must occur in a constructivist way (historically), which implies specific teaching strategies. The historicity of the concepts is one of the most critical strategies because, from the explanation of the entire process, evolution, and construction of atomic models, the students can grasp and reflect on the process of knowledge construction over time (Peduzzi & Basso, 2005).

Therefore, Bohr's atom allows students to assimilate important implications for understanding progress and scientific practice by reconstructing events that led Bohr to postulate his atomic model. Thus, teaching Bohr's and other atomic models fosters in students and teachers a moment of understanding and reflection in the search for assimilating, articulating, feeling, and perceiving the entire historical process from the first atomic model to that of Bohr (Rodriguez & Niaz, 2004).

METHODOLOGY

The Covid-19 pandemic in Brazil brought a need for teachers and students to hastily adapt to the new way of teaching, employing new techniques, digital platforms, and teaching methodologies. According to this reality, many projects were developed to support teaching and, particularly, to prepare students for the National High School Exam (ENEM). Therefore, we chose a course that included classes in all high school subjects, which took place through a public channel on the YouTube platform.

The physics subject, the focus of this research as it addresses the topic of Bohr's atomic model, had an average of 40 videos covering all the contents proposed for high school. For this research, we chose to analyse the classes on Bohr's atomic model. Therefore, these online classes constitute the object of this investigation.

The methodology includes the selection of significant episodes, which undergo a detailed analysis divided into levels of seconds (microanalysis).

After viewing the videos, this microanalysis was performed by observing the teacher's speech and gestures.

In the online ENEM preparation course, the classes taught by the physics teacher bring the beginning of the elaboration of modern physics, its impact on society over the years, and its main concepts. Several resources were utilised, such as a whiteboard, slides, computer simulations and verbal and non-verbal (gestural) communication, which is the focus of this research.

That said, we present as follows some fragments taken from classes 7 (Modern Physics 07 – FM07) and 8 (Modern Physics 08 – FM08) of the preparatory course for the ENEM, in which the central subject was Bohr's atomic model. For a better understanding and explanation of the selected excerpts, two different moments will be exposed: Episode I (addressing the concept of a photon) and Episode II (addressing the concept of energy levels).

The small number of cases analysed is justified because the gestural and verbal analysis – both of students and teachers – requires deeper analysis, a thorough examination of a few cases rather than a more superficial analysis of a large number of cases (Monaghan & Clement, 1999).

Thus, we analysed approximately seven hours of recorded classes (only the Modern Physics classes) and made them available online, to find episodes that were used as the focus of gestural speech microanalysis. Using the framework of the semiotic bundle (Arzarello, 2006), we analysed two classes (Modern Physics 07 and Modern Physics 08) out of the eight related to the theme of Modern Physics in this online course for preparation for the ENEM. A semiotic bundle is characterised by three distinct features, presented below (Arzarello, 2006):

> a) a set of signs that can be produced through different actions, such as uttering, speaking, writing, drawing, gesturing, and handling an artefact;
>
> b) a set of modes of production and transformation of those signs. Such modes may be rules or algorithms, but also more flexible actions or modes used by the individual;
>
> c) a set of relationships between signs and their underlying meaning structure.

The idea of the semiotic bundle is formed by the signs that are performed by the students (or by a class) at the moment they solve a problem, situation, or an issue in the course of some teaching activity. For Arzarello et al. (2009), the teacher also ends up participating in this production, so the semiotic bundle can also include the signs performed by the teacher.

For Paiva (2019, p. 39), semiotic bundles

> [...] are semiotic resources in a unified way in the learning process, within the joint effort. Those resources or semiotic means are orchestrated during the activity, establishing meanings between the processes of objectification and subjectivation, pointing out that the meanings that appear in this process are multimodal, considering the various semiotic means involved (gesture, speech, expressions, drawings, rhythm) and that cannot be analysed separately.

Therefore, a semiotic bundle corresponds to the set of semiotic means that teachers and students mobilise during the activity and that act in a coordinated and unified way.

Teachers in the areas of natural sciences, technology, and mathematics use various resources in the classroom, such as projections on the screen, physical models, computer simulations, drawings on the board, and others, in addition to speech and gestures (Moro et al., 2015).

Thus, those resources influence the way teachers gesture and articulate their speech, along with the gesture. Consequently, it is known that, just like other resources help in learning, gestures are also semiotic resources that support and activate the teaching-learning process.

It is fundamental to consider the way each semiotic resource, through small differences, expresses the same meaning; therefore, gestures can contribute to obtaining an additional, complementary, broader understanding of what is proposed to students (Silva & Gobara, 2020).

RESULTS AND ANALYSES

Episode I – Photon

Before starting to teach Bohr's atomic model, the teacher reports the evolution and history of atomic models, discussing and showing their differences and, consequently, their evolution. Upon arriving at Bohr's model, the professor begins by explaining that Bohr, using the theory of quantum physics, formulated the theory of the hydrogen atom1.

> ***Teacher [40'17" – FM07]:*** *Niels Bohr, using quantum theory, using Max Planck's concepts, formulated the theory of the hydrogen atom, or Bohr's atomic theory, in which: the electrons that were actually circling the nucleus, were negative, were circling the positive nucleus, but they could only be in specific places, some energy levels.*

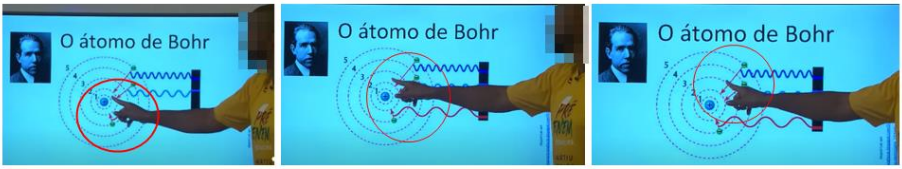
Then, when discussing how electrons can move from one orbit to another, he explains that the electron must receive or emit photons. To explain the photon, at the same time that the teacher exposes it, he elaborates on this abstract concept. Therefore, when mentioning the concept of photons, the teacher gestures to show the students the concept and movement of the photon, as shown in the excerpts below.

In the first section, the teacher reports that the electron can be in any of the "energy layers"; however, for it to leave the first layer and go to the second, for example, the teacher says that the electron must receive energy and that would be receiving photons (3).

> ***Teacher: [42'50" – FM07]*** *So, it receives photons, it can jump to another layer.*

Figure 3

Gesture performed by the teacher indicating the transition from one layer to another, after receiving the photons. The red arrow indicates the direction.



The teacher, to better explain this "jumping to another layer", uses the image in the slides (Figure 3) at the same time that he uses his right hand to

[1] Naturally, this is not the place to analyse the precision of the teacher's speech and classes, and we are only responsible for the semiotic analysis of the proposed gestures.

point and show what the movement of the electron "jumping from one layer to another".

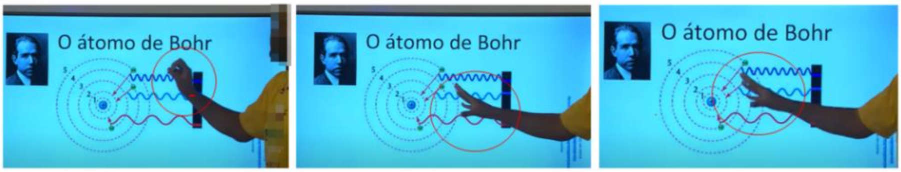
According to Almeida and Goulart (2020), the semiotic bundles (Arzarello, 2006) allow for the articulation of semiotic resources, in this case, gestures, verbal communication, and slides. Through those resources, we can increase the teacher's actions during their activity. Soon, the gestures served as a way to articulate the teacher's speech with the image.

In the second fragment of this episode, the teacher explains that at the moment the electron returns to the lowest energy level, it must release this photon; thus, the teacher makes a gesture with his right hand, opening and closing, representing the release of a photon, as in the following fragment (4).

> ***Teacher: [43'35" – FM07]*** *It must release this photon, that light.*

Figure 4

The gesture performed by the teacher to represent the photon movement.



This gesture is similar to what elementary school students performed when explaining the photon in another recent survey (Figure 5).

When performing this gesture (Figure 5), the girl explains as follows: "*And when it approaches the nucleus, it emits a photon. [...] I see it jumping and... [01'56"], and emitting a photon [01'59"].*" Even if this student did not observe this gesture being produced by the teacher under analysis, the gesture is the same, possibly a universally exchanged gesture between educators and students. Thus, we observe that student A1's interpretant is most likely composed – consciously or not – of physics teachers' gestural elements similar to the immediate object shown in Figure 4 of the teacher's gesture.

Figure 5

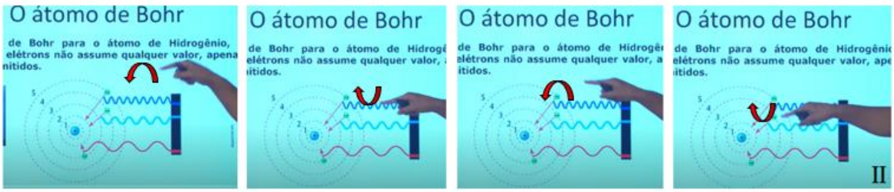
The sequence of images of student A1's gesture about the photon in 2018. (Freitas, 2019)

According to Arzarello (2006), semiotic resources refer to the identification of different resources the individuals –in this context, the student– voluntarily or involuntarily choose. The photon gesture occurred similarly between people and in different situations.

According to Radford (2003), gestures, for example, in the social process, facilitate the exposition of the intentions and thoughts of the individuals; therefore, gestures – and all bodily and verbal actions of human beings – are attempts to allow us to make the meaning of abstract concepts tangible. Therefore, even though people performed the photon gesture at different times, the performed gesture seeks to provide the viewer with a closer look at what is going on in the subject's mind.

In the third excerpt of this episode (Modern Physics – 08), the teacher argues that, to change layers, the electron must "deliver something", i.e., it must receive or emit a photon.

Then, the teacher points out the screen with the slides and, with his hand, mimics the movement that must occur for the electron to go from the fundamental level to the most excited level (



6). Moreover, when mentioning "receiving a light", the teacher performs a "wave" gesture, in which he represents exactly the illustration that appears in the slides used by the same teacher.

> ***Teacher: [10'29" – FM08]*** *For that level, to leave the fundamental and go to an excited level (I), it must receive a light (II), a photon.*

Figure 6

Sequences of images in relation to the gesture performed by the teacher (I).

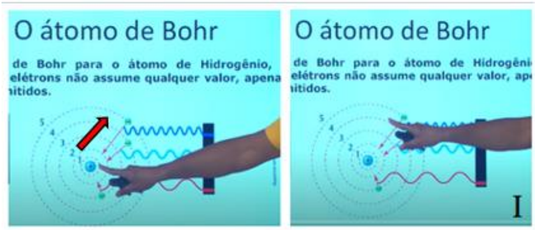
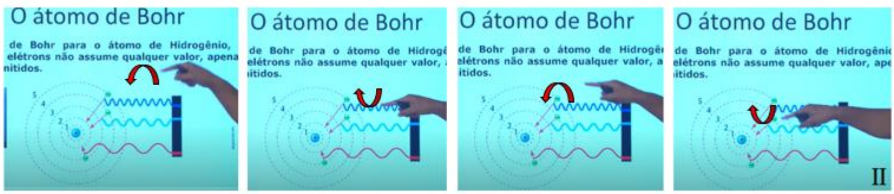


Figure 7

Sequences of images in relation to the gesture performed by the teacher (II).



In the fourth fragment (Figures 8, 9, 10, and 11), the teacher resumes his explanations, giving more emphasis and in greater detail, and explains that it is necessary to "throw" a photon so that the electron can move from one energy level to another.

> ***Teacher: [43'57"]*** *I throw one photon (I) in it, it wins that photon and goes that way (II), but it becomes unstable (III) and, at a given moment, it loses, it releases this photon (IV) and returns to the layer.*

As it is possible to observe in the images in Figures 8, 9, 10, and 11, when mentioning the photon, the teacher performs the same gesture previously made, which, as already discussed, is the same gesture also performed by other students in recent research works (Freitas, 2019). At the second moment of this fragment, the teacher exposes, with his index finger, the action that the electron would perform when gaining a photon. With the index finger and in the "come and go" movement, quickly, the teacher emphasises the unstable level.

Finally, this fragment ends again with the teacher's speech about photons and performs the same photon gesture he had performed earlier. We can see that the dynamic object for the photon contains the opening and closing hand and waving gestures (Figure 7).

Figure 8

Gesture related to the concept of photon (I).

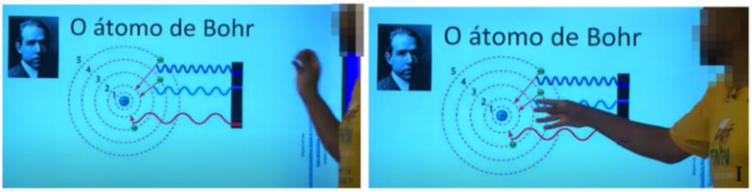


Figure 9

Gestures related to the moment it gains a photon (II).

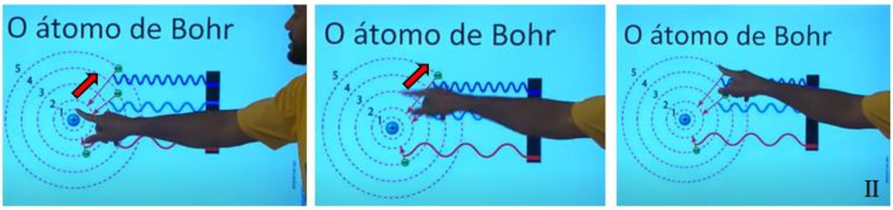


Figure 10

Gesture related to the moment the electron becomes unstable (III).

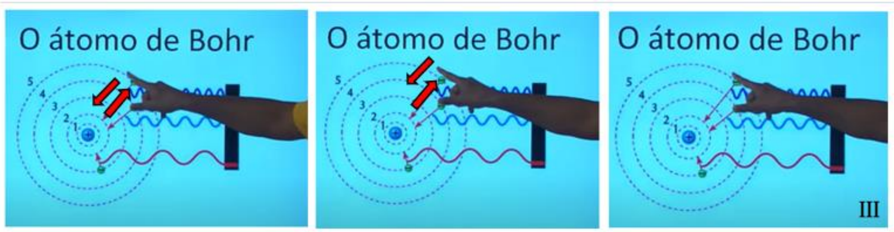
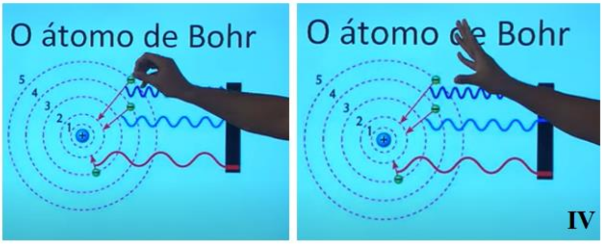


Figure 11

Gesture again related to photon (IV) (Authors, 2022).



In harmony with Arzarello (2006), this first episode brought some semiotic resources that composed what he calls a semiotic package, such as speech, gestures, slides with images, and illustrative representations.

Through these resources and especially gestures, the teacher articulated resources to promote learning in his students, thus increasing actions and development in the teaching-learning process, as mentioned by him (Almeida & Goulart, 2020).

Thus, the first episode on the concept of photons shows that, while explaining the concept, the teacher "opens and closes" his hand quickly, allowing the student to listen about the concept and, through non-verbal communication, understand the action of this particle.

Episode II – Layer levels and transitions

In the second episode, the guiding concept is energy levels. In the first analysed fragment, the teacher gestures with his index finger in a movement in which he circles the positive nucleus counterclockwise, showing the electron's trajectory (Figure 12).

> ***Teacher: [40'35" – FM07]*** *The electrons, they were actually circling the nucleus, they were negative, and they were circling the positive nucleus, but they could only be in a few places.*

In the second fragment, the teacher gestures over the slides and, exactly on each of the energy levels represented in the illustration, the position of each of Bohr's energy levels. That is, when he talks about the composition of Bohr's atomic model with seven layers, or orbits, as he mentions, he gestures on the screen, exposing each of the energy levels (Figure 13).

> ***Teacher: [40'57" – FM07]*** *The seven layers are Bohr's energy levels.*

Figure 12

Gesture on the slides when the teacher explains the electrons surrounding the nucleus.

Figure 13

Gesture that demonstrates the location of Bohr's energy levels.

In the third fragment, the teacher points out that the electron can be in each of the energy levels and, when mentioning it again, he gestures over the illustration that appears in the slides, at the same time that he explains energy levels, as seen in Figure 14.

> ***Teacher: [42'36" – FM07]*** *But this electron, it can be in any of these energy layers.*

Figure 14

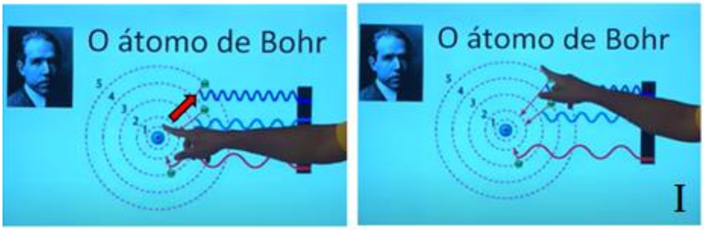
Gesture in which the teacher shows the layers of energy.

Separated into two sequences, the fourth fragment exposes when there is an electron leaving a layer (Figure 14), an energy level and, thus, going to another layer (Figure 15). The teacher, as already seen in the other fragments, when using verbal communication, also uses non-verbal communication, i.e., with his index finger, he points and shows in the slides the movement that occurs in the transition of an electron to another layer.

> ***Teacher: [43'40" – FM07]*** *When I have the electron leaving one layer and going to another (I), it is absorbing, it is receiving light, they are giving light to it (II).*

Figure 15

Gesture demonstrates the electron going from one layer to another.



In the penultimate fragment of this episode, the teacher addresses the colours that appear, which are related to the amount of energy (Figure 16). Next, it is possible to see that the teacher explains and makes movements, seeking to give more information and clarify better to the students that the amount of energy is related to the change of colour that the students can visualise on the screen (Figure 17).

> ***Teacher: [9'44" – FM08]*** *So here, depending on the energy, the amount of energy (I), the colour (II) will change.*

Figure 16

Gesture related to the moment when the electron receives light. Once again, the gesture for the photon is produced.

Figure 17

Gesture that indicates changes in energy levels.

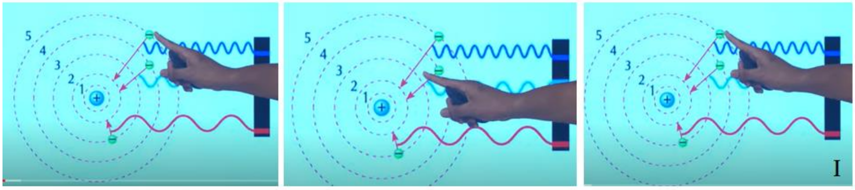
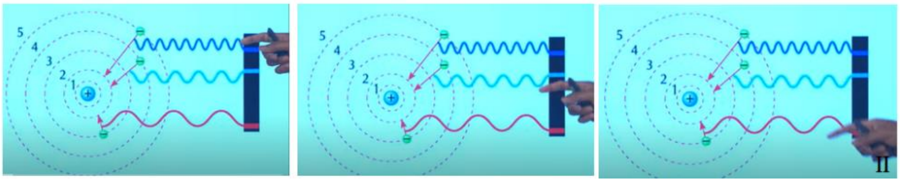


Figure 18

Gesture that points out the change of colours in the spectrum, according to energy levels (Authors, 2022).



In the last fragment, the teacher reviews the content to start the lesson and, at that moment, recalls that when the frequency increases, the energy increases and the higher the frequency, the "more towards violet" the colour becomes (Figure 18), as the teacher mentions in his class. Also, the lower the frequency, the "more towards red" the colour becomes (Figure 19).

> ***Teacher: [9'50" – FM08]*** *So, when it jumps here (I), depending on the level it is in, the fundamental level, the first, and the excited levels, the farther from the nucleus, the more energy, the greater energy it will have, this electron circling its atom (II).*

Figure 19

Gesture demonstrating the moment the electron jumps from one layer to another.

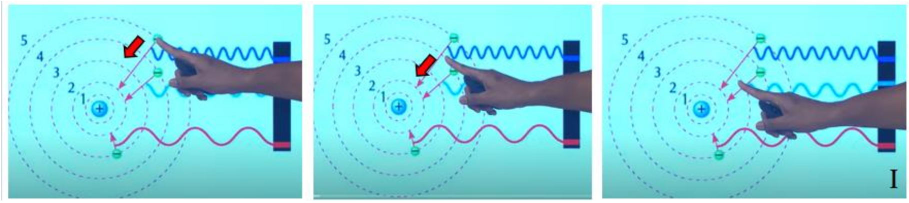
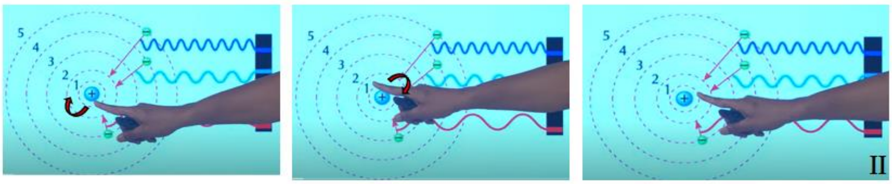


Figure 20

Gesture in relation to the electron circling its nucleus.



This second episode brought a fragment of Modern Physics classes 07 and 08, showing the energy levels concept and the actions and changes that occur when an electron changes its energy level. By observing all the fragments, we can observe that in addition to verbal communication and the aid of computer simulations and illustrations on the screen, the teacher needs and performs non-verbal communication through gestures to detail and help his explanation about Bohr's atom.

Arzarello (2006, p. 292) states that,

> New semiotic resources appear on the scene in different semiotic sets that are becoming more and more integrated, not by juxtaposition or translation, but by the integration of their elements: they all continue to be active within the semiotic bundle (p. 292, our translation).

According to the author, the various semiotic resources the teacher used do not come forward to translate or to juxtapose but to integrate all the elements. More specifically, the gesture enters this integration with the other resources of the semiotic package of the episode.

Moreover, it seems that this fruitful gesticulation indicates the representation of a sequence of internal images, or “mental simulations” (Stephens & Clement, 2010), that must occur in the teacher’s mind, possibly his particular dynamic object of Bohr’s atom. These gestures contribute to the students’ apprehension of the dynamic character of the model; in this case, gestures providentially captured by the positioning of the camera.

In the course of the online classes of the ENEM preparation project, more specifically the last two Modern Physics classes (07 and 08), the gestures, the focus of this analysis, emerge as a supplier of specific ways of carrying out the semiotic process. The analysis also showed that these forms differ from those provided by semiotic systems, such as languages, symbolic systems, images, and others.

According to Sabena (2008), as a semiotic resource inherently linked to the body, the gesture allows the display of such characteristics in a very direct way. Gestures provide a peculiar way of substantiating the knowledge process, the way the teacher imagines and explains things, and the way the students imagine things and which, through gestures, they can show.

From the gestures exposed by the teacher, we can state that, according to Peirce’s work, this non-verbal communication (gesture) is considered as a set of signs for those who observe, even though it is a spontaneous production of the subject without necessarily representing a link with the need for communication (Stephens & Clement, 2010; Iverson & Goldin-Meadow, 1998). These signs manage to be endowed with structures of underlying meanings, being, in this way, linked to the context, i.e., the online classes on Bohr’s atom, reproduced by bodily representations.

Therefore, the gestures performed by the teacher are *representamen* of the movement with the possible intention of representing the object (immediate interpretant) of the dynamic model, since the slides are static (they are also signs of the model) and are understood to provide a dynamic sign of Bohr’s atomic model.

FINAL CONSIDERATIONS

This research sought to present and discuss how the gestures of teachers and students can be a potential semiotic resource in the area of science education. Therefore, our purpose was to understand, analyse, and explore the gestures in a class about Bohr's atomic model in an online preparatory course for ENEM. Through the exposition on semiotics – as a language of humankind – and on gestures as a potential semiotic resource, we can better understand and discuss the episodes selected for analysis.

From all the above, we found that gestures – and other semiotic resources – can be potential tools in Bohr's atomic model teaching because, as other mechanisms (speech, images, drawings, sounds, etc.), gestures can enable articulation between these different semiotic resources and better develop the teachers' and students' activities.

Therefore, from this investigation, the gestures are a potential method for Bohr's atomic model teaching, from the moment that it is used not only to "translate" or to be an "apposition" at some point in the class or educational activity, but as an articulator of ideas and integrator of semiotic resources, being able to enhance communication or organise thinking at the moment of exposure. Thus, we believe that analysing the semiotics of gestures can be essential in understanding the bodily action of the subjects (the gestures) in the teaching process.

Therefore, by bringing light to the analysis of teachers' and students' gestures, this study can be a new and adequate source of reference to understand, reflect, and debate the question. This can help teachers and students in their communication and in understanding the teaching-learning process better, bringing relevant and unprecedented contributions to the area. However, we believe that further research should be carried out for greater clarity and more experiences in the educational environment so as to allow the assessment of its effective contribution to the teaching of science.

AUTHORSHIP CONTRIBUTION STATEMENT

All authors contributed to the research and writing of the article. SAFD was responsible for preparing the theoretical contributions, such as the methodology and data analysis. ASAN guided and supervised the research and the final revision of the article.

DATA AVAILABILITY STATEMENT

Data supporting the results of this study are openly available. These data are derived from the following resources available in the public domain: https://www.youtube.com/c/TVSeducRS/playlists

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