Narration and multimodality: The role of the human body and material objects in science teaching

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ABSTRACT

This article seeks to shed light on the semiotic approach to science teaching and learning. Essentially, the mental representations of learners are also affected by the sign vehicles employed to communicate ideas in the material world. Thus, any learning object also appears as a material representation, consisting of acoustic and visual forms, which affect its content. The human body's kinetic modalities, spatial configurations (i.e., graphs, images), material objects, prosody, as well as the written and spoken word constitute the perceptual data that encode the concepts. This particular paper deals with the possibility that the more emphatic signifiers, i.e., the human body and material objects, can create narrative spaces and produce meaning during science teaching. It also discusses alternative uses of material objects along with the multiple interpretations their visual images can evoke. As regards the human body, iconic, deictic, and ergotic gestures are analyzed as forms that produce meaning and are autonomous and dynamic when working with the other semiotic systems. Both material objects and the human body rely upon the ability of the learners' imagination to transport them to narrative worlds located outside the classroom.

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1. INTRODUCTION

Research in science education has shown that cognitive processes are the product of the continuous interaction of signs produced by the teacher and the students [1]–[4]. The representation of a scientific concept through the different semiotic systems (spoken word, gestures, spatial compositions) is not a rendition of the same thing in different ways; rather it gives knowledge shape [5]. In short, it appears that any conceptualization of scientific entities derives not only from within the sciences in which these entities are primarily created (e.g., physics, chemistry) or from the learners who have already conceptualized them as preconceptions, but also from the sign vehicles constructed to "transfer" them during the learning process (i.e., rhetorical figures, gestures, storytelling, use of material objects). Thus, any learning situation is regarded as consisting of acoustic and visual forms and modalities, which affect its content. In other words, the production of meaning is based on a three-factors syntax consisting of the synergies of verbal, kinetic, and spatial elements [6]. Multimodality is perhaps a key pillar of science teaching and learning, with each semiotic system offering various modalities as meaning-carriers, while each modality frequently carries different information [3], [7]–[10]. In general, the morphology of the teaching framework leads to the emergence of specific modalities (iconic gestures) while learners, for their part, develop a multimodal syntax (speech, space, body) [11]–[13]. In this context, the human body specifically constitutes a factor for synergy and for the conceptual "welding" of the modes of communication [1], [5], [14]. It should be noted that contemporary approaches argue that cognition is linked to processes of movement and of the human body's physical interaction with the environment [15].

Embracing the contribution of semiotic resources in the meaning-making process, Givry and Roth [16] state that mental representations of the concepts and phenomena of the natural world do not simply constitute an individual's internal issue; they have characteristics related to the morphology of the environment and the actions of learners. Previous researchers argue that conceptual change is understood as: "i) Evolution in the use of modalities (using words to describe an object, instead of designing it by deictic gesture); ii) Evolution into the same modality (using more gestures to describe the same objects); and iii) Evolution of the link between different modalities (the time between talk and gesture decreasing)."

This article is focused on the narrative character of science teaching, i.e., the ability of various semiotic systems to produce signifiers inside physical space, which create narrative spaces. These spaces, created by material signifiers (i.e., speech, body, spatial entities) refer to 3D referents, regardless of whether they exist in the time and space in which the narration takes place. For example, the snapshots of the oscillation of a spring of a school textbook image, tell the story of a 3D material spring, which however, does not exist in the physical space where the narration is taking place, i.e., in the classroom during the teaching moment [17], [18].

In this article, the discussion will center on the 3D signifiers involved in the production of meaning and, actually, those that can change their form and/or dynamics in space, thus increasing their narrative capacity. The discussion covers the human body as well as material objects, because the ability of the first to signify is indisputable, while as for material objects, given their ability to move in space and collaborate with the human body, they too possess narrative dynamics [19]–[21]. It should be noted that the current analysis excludes the spoken word since the verbal analysis of meanings already occupies an important place in the tradition of science education. Thus, this paper's objective is to describe the signifiers related to the 3D nature of science teaching and of the human body and material objects in particular. Factors, although not related to traditional orality, do participate in a dynamic way in distributed cognition [22]. This is associated with the integrated approach to learning, according to which significations are carried out through the learners' action experiences in each environment, something that in recent years has been systematically explored in science, mathematics and information and communication technologies (ICT) education [10], [23], [24]. Any analysis of the human body and material objects, should be preceded by a discussion on the inherent potential of verbal, somatic, spatial, and sonic signifiers to create "3D" referents as imaginary creations. Namely, in each case, whether this is the physical space the learners are occupying, or the imaginary space manifested through the narration, all signifiers cause learners, as existing members of the material world and of experience, to think in terms of materiality. Either through physical experiences or imaginatively, learners participate in worlds containing the acts and forms of 3D signifiers and/or "3D" referents.

2. THE NARRATIVE CHARACTER OF SCIENCE TEACHING

Science teaching in the classroom, consists of signifiers, which locate the concepts in spaces outside it. The linguistic and non-linguistic treatment of natural phenomena contains referents that exist outside the school and, consequently, invoking the learners' imagination is a teaching requirement. It should be noted that to activate their imagination, learners use abstraction and narration to transfer themselves from the physical space they occupy (classroom) to other places [17]. Thus, this is the requirement for teaching science, since the objective is to escape from the phenomenology of "here" to the imaginary (the abstract world) of "there" or of "elsewhere". This function is achieved by activating the semiotic resources, with the human body playing a dynamic role. Bodily actions are a key means of activating the imagination, since they assist in the construction of narrative worlds, within which learners actually live and think. Whatever happens in the material world of the classroom that is realized through semiotic systems, invites learners to imagine and construct concepts in an intelligible "there" [13], [25]–[27].

Pozzer-Ardenghi [28] also emphasized the search for a communication channel between "here" (classroom) and "there" (outside the classroom). These researchers refer to the shifts in body positions of the speaker (educator), the movements of the body in general, the prosodic features of the voice, and the use of pronouns as factors that shape the narrative framework. All these factors contribute to learners imagining that they are in places and engaged in activities outside the classroom environment, dealing with scientific code in the "here", the "now", and the "then" [29].

In particular, for the discussion of the code of the inscriptions (graphs, maps, diagrams), Roth, Lawless, and Tobin [30] considered that by using gestures, especially iconic ones, listeners are transported from the material place that contains the image (blackboard, book) to the place of narration. When discussing a drawing, a graph, or even the arrangement of material objects, learners use gestures to move, rotate, and reshape entities that exist in the material space or to create entities that are, at the moment, absent from the action area. This leads to the creation of imaginary worlds, realistic or unrealistic. In such worlds we can place objects, people and entities and co-operate with their mental images [17], [31], [32]. For example, the learners that cope with a mechanical pulley system in physical space can use their imagination to create mental images of it in order to be able to predict its later states. Thus, they give the opportunity to the mechanical system, on an imaginary level, to move, rotate, change and generally obey a scenario with spatio-temporal variables (mental animation) [33].

In the following dialogue between a teacher and a learner, the spoken word, assisted by the material object "spring", creates a place that consists of the entities "greengrocer", "spring scale", and "fruits".

> "Teacher: When you shop at the greengrocer's … have you noticed that the greengrocer has a spring scale (Holds a spring)? Have you seen it? Doesn't the scale have a spring? What's it for?
>
> Learner: To measure force.
>
> Teacher: To measure force. What force? The force of the weight of the fruit. Essentially, to measure a force, what do we need to measure, the … (shows the spring) deformation" [34].

An appeal to the imagination takes place so that, based on their own experiences, learners will imagine themselves in a greengrocer's shop—or will be more observant the next time they go—focusing on the scale and perhaps, if it's visible, on its spring. This narrative space, composed mainly of the spoken word, invites learners to work with the mental images of the entities involved, something that although possibly more demanding, in many cases leads to desirable learning outcomes [32], [35].

It is worth noting that narrative spaces can be created not only of the spoken or written word but also through the use of the human body, visually, and through sounds as well. Figure 1 shows the teacher constructing the narrative space, assisted by a "pendulum", which as a referent, is located outside the classroom. The field of action only contains its physical representation. Figure 1 contains two snapshots where the teacher embodies the entities "string" and "sphere", while subsequently, he himself physically represents the oscillation of the pendulum. When gestures and, generally, bodily expression represent entities and refer to actions outside the physical space, they then can constitute a facilitative factor in learning. The research of Ping and Goldin-Meadow [35] conducted with young children regarding the concept of quantity conservation is characteristic. It demonstrated that the gestures the teacher used, invoking the children's imagination, to refer to material objects absent from the field of action were elements of the children's imaginary world and mental images that influenced their learning.

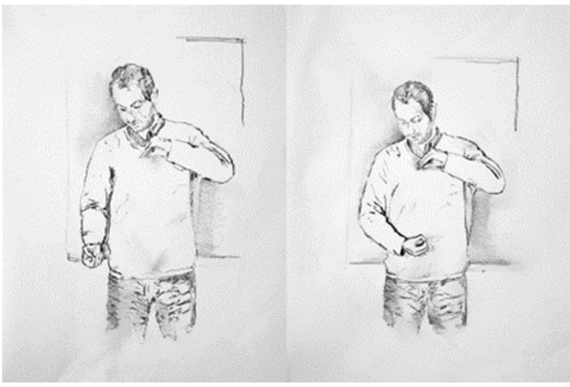

Figure 1. Physical representation of two positions of a "pendulum"

Figure 2 is a visual representation of a spring-bar system. One can see two successive snapshots of a rotating bar, which is released by a coiled vertical spring. It should be noted that in terms of visual semiotics, this particular inscription carries a specialized code and comprehending it requires the viewer to possess special knowledge. In other words, everyday life does not come with a vertical spring and a rotating bar. Consequently, in their effort to approach them mentally, learners create an imaginary space with the mental images of the spring-bar; there they can "turn" the bar, "compress" the spring, and generally "observe" the movement of the system using their imagination exclusively.

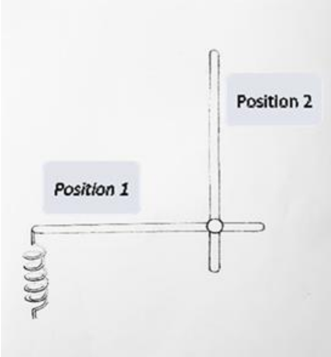

Figure 2. Rotation of a bar

Spaces expressed through sounds, being perhaps more abstract, require a greater effort on the learners' part to journey in them. For example, the sharper sound (https://www.youtube.com/watch?v=5I_cvSbz2l4) reflects a gradual increase in frequency. One perceives that this change in frequency creates a sound landscape that refers to "filling a vessel with water that falls with a certain momentum." More specifically, when the surface of the water gradually rises, the wavelength of the produced static wave becomes shorter. The result is a corresponding increase in frequency, making the sound sharper. Similarly, in the video (https://www.youtube.com/watch?v=qvWxhhi0_yk) the timbre of the sound refers to a moving car on a F1 race track. The perceived frequency of the F1 car first increases and then decreases as the car passes an immobile observer/listener, which, from a physics point of view, corresponds to the Doppler effect. The sonic signifiers invite learners to use their imagination to create spaces in which they can mentally manage the various "3D" entities. Generally, signifiers can construct or suggest places that are structurally governed by various degrees of abstraction.

Thus, Figure 3 describes a familiar space, where a bike with a rider slows down by braking rather abruptly; the resulting inertia causes the rider to "want" to maintain his existing kinetic state and he continues moving and is launched forward. This particular "story" encapsulates Newton's first law, inertia and decelerating movement. It creates conditions for learners to embody inertia in 3D physical space, giving them the opportunity to use their imagination to search for similar or related experiences in their everyday life. Conversely, Figure 4, which contains a speed/time graph on decelerating motion, requires learners to be familiar with the written code of the diagram in order to understand it.

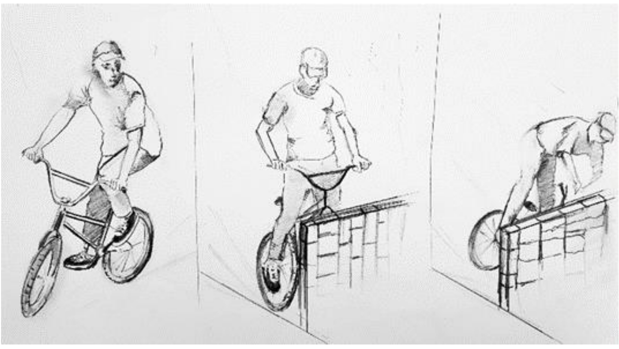

Figure 3. The rider is launched forward due to the inertia

When teaching physics, the narrated "stories" obviously need interpretations. The different quality of the signifiers involves corresponding semantic requirements. Thus, Figures 3 and 5 constitute situations that are related to embodied everyday experiences and narrate Newton's first and third law respectively, while Figure 4, as a graph with a special code, is far removed from its referents. In other words, the static, two-dimensional, inclined line of the graph in Figure 4 refers to a moving, 3D, smoothly decelerating vehicle found in our everyday world, such as, for example, the bike in Figure 3. Under no circumstances, however, is the relationship between Figures 3 and 4 explicit and obvious.

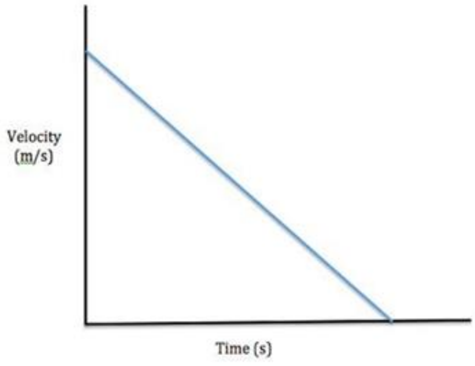

Figure 4. Decelerating motion

Figure 5. Action and (re)action

Regarding code in the context of mathematical formalism and special representations in general, it seems necessary the creation of semantic connections between these abstract representations and the knowledge of everyday life. After all, this is the way that science supposed to operate; that is to enable, through knowledge construction, to move from physical world towards the world of signs. The didactic process operates in a similar context, with the main goal being the reshape of the pre-existing mental representations of the trainees in order to acquire, to a certain extent, compatibility with the scientific models. Therefore, whether they are entities that appear in the classroom, or entities that narrative places outside of it, either abstract or concerning the knowledge of everyday life, it is required through teaching process to create semantic bridges between them. In this context, the cultivation and invoke of learners' imagination as well as their training in the production of synergies between the various semiotic systems (oral speech, human body, material objects, simulations), can bring closer the codes of abstraction with the codes of physical reality. Consequently, science teachers are called upon to carry out intertextual transitions "travelling" to narrative worlds constructed by the various semiotic systems [36].

3. MATERIAL OBJECTS

Material objects acquire an unmistakable semiotic perspective in science teaching if they are co-construction factors of the learners' mental representations. Papert and Harel [37] considered them as 'objects to think with', carrying a semiotic potential given that learners, by handling them, create signs and gradually forming a communication relationship. Objects can be integrated into different frameworks of action by acquiring alternative usages and thus promoting creativity and divergent thinking [38], [39]. Science teaching requires, on the one hand, the use of specialized materials, appliances, and instruments, which learners must familiarize themselves with and train in their use. One such example is a simple electrical circuit, consisting of a switch, electrical source, voltmeter, and resistor. On the other hand, everyday objects that learners are familiar with can be used, revealing hidden properties and differentiated uses. Figure 6 shows a glass that contains water and oil. While in everyday life both materials are food, they can also be used unconventionally, i.e., as components of an inhomogeneous mixture. Oil has a lower density than water and consequently floats on it.

Figure 6. Glass containing oil and water

Similarly, although a lemon can also serve as food, if a nail with a protective zinc coating and a copper coin are inserted into it, then the lemon becomes a galvanic element Zn-Cu as shown in Figure 7. Usually, we drink the water but a glass of it serves as a converging lens producing an inverted image if an object is positioned at a greater distance from the focal point as seen in Figure 8. Generally, the use of objects in a fashion different than that specified by their manufacturer is gaining momentum in science teaching.

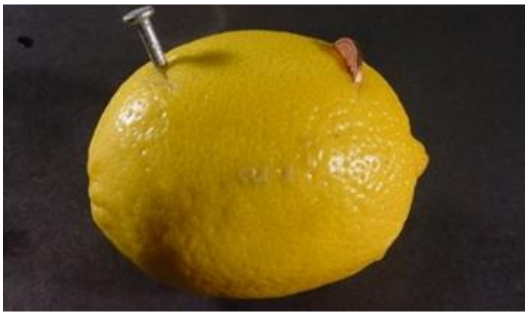

Figure 7. Lemon acting as a battery

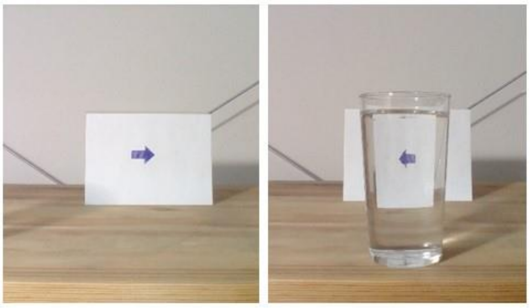

Figure 8. Inverted image

Moreover, in terms of visual semiotics, when objects are approached as images, as visual stimuli that lead viewers to interpretations, then the images of material objects are open to multiple interpretations. Thus, as a visual form, a snapshot, or even a change in which a material object participates, is open to many different readings. An 'image' from the action of an object or successive 'images' of it, constitute one or more moments of its history. That is, the ability of the object to capture in its form the entire interactions with animate and non-living entities. In this context, the observer is asked to interpret these 'images' along with the changes in the 'image' of the object by attributing denotations and connotations [40], [41].

With reference to Figure 9, we can picture "a collapsed bottle". On a first reading, an observer understands that mechanical pressure exerted from our hands made it crashed; at the connotation level crashing is due to the negative pressure produced inside the bottle. Of course, the connotative interpretation is more demanding and requires specialized knowledge and skills to understand the unobvious. More specifically, pouring some hot boiling water into a plastic bottle, the water vapor fills the bottle and pushes some of the gas air molecules to go out from it. At the same time some of the air that remains inside the bottle is heated and expands pushing also gas air molecules outside the bottle. Hence the amount of the air in the bottle reduces. Tapping the bottle, the reduced but still hot air molecules remain in the bottle. When cool the tapped bottle by pouring cold water over it, the water vapor condenses to liquid water and the gas air molecules contract. These lower the pressure inside the bottle. At this point of the experiment the outside atmospheric pressure is much higher than the pressure inside the bottle and makes the bottle collapse creating finally a balance between inside and outside pressure.

Figure 9. A collapsed bottle

Figure 10 constitutes a similar case of multiple readings regarding material objects on the level of visual change. A sequential viewing of the two images, as two different forms of the same material object, shows that some factors caused this change. At the denotation level, this particular change could be interpreted as the product of mechanical pressure; at the connotative level, as the result of thermal expansion caused by an increase in temperature under exceptional climatic conditions. Indeed, when heated, the molecules of the metal rails alter the relative distances between them and lengthen. If the manufacturer had not planned to leave gaps between two consecutive pieces of rail, then the elongated sections pressing against each other would result in distortions as evidenced in Figure 10. The first interpretation might be more popular, because in everyday life, mechanical results are more obvious than thermal ones, and the lack of specialized knowledge might be the factor leading to it. Respectively, different interpretations about the two directions of the drawn arrow in Figure 8 could be an action of turning the paper upside down or an action of putting a glass of water in front of it. In another instance, an image of a paper clip in a glass of water and another image of the paper clip outside the glass can be attributed to the act that someone put his/her hand in the water and took out the clip or he/she used a magnet to remove it.

Figure 10. Thermal expansion of railroad tracks

What is important for science teaching is the didactic use of these visual changes. Teaching learners to focus on changes related to the form of material objects and experimental devices and on the search for multiple interpretations promotes inquiry learning and cultivates critical thought. In general, change can be considered a tool that helps assign meaning to a sequence of situations. In that sense, students can seek to interpret why at least two instances in a teaching procedure are linked. These can be successive incidents in an oral narration, different sections of a diagram, different indications on a measuring instrument, and so on. The interpretation process starts when students are invited to assign meaning to a sequence of these narrative pictures. It should be noted that the students can provide multiple interpretations for a specific change depending on how any previous relevant conceptions they might have relate to the existing context.

4. HUMAN BODY

Many researchers in science teaching focus on gestures, adopting the distinction between iconic, ergotic and deictic. Iconic gestures are those that are a morphological representation of some human action or an (in) animate entity, ergotic gestures are associated with the handling of material objects, while deictic gestures are those that point in one direction (usually with the forefinger) [21], [42]. All these gestures, including movement in space (proxemics), create conceptual connections with the spoken word and the material environment [1], [43]. For example, in teaching activities, when physically active, preschool-aged children can produce iconic, deictic, and ergotic gestures as thought acts [44]. Pantidos *et al.* [45] starting from the semiotics of the theater, refer to gestural or kinetic signs, involving the entire human body, which can produce images and point to as well as handle objects. Regarding the latter, these researchers refer to manipulation of an actual object, manipulation of a model (e.g., of a water molecule), as well as of objects, which, although absent from the field of action, are implied.

Iconic gestures are bodily forms that represent the shape and movements of the referent, while they can also acquire a symbolic character. Ping and Goldin-Meadow [35] argue that they contextually link the spoken word with the material entities in a learning state, while emphasizing that even when material objects are absent, iconic gestures create conceptual synergies with the mental images of the objects. In related research, the previous researchers demonstrated that, faced with conservation of quantity as the learning objective, learners aged 5–7 developed more complete reasoning when teachers provided them with both oral instructions and iconic gestures for specific projects, compared to when instructions were exclusively oral. Actually, the morphology of a learning environment influences the forms of the iconic gestures displayed by learners. Thus, specific gestures create a conceptualization framework for each respective phenomenon or concept. Roth also argues that such a process leads more quickly to cognitive achievements, as opposed to a process during which iconic gestures would not be activated. Usually, such situations commence with learners using embodied actions to express their questioning and investigation. For example, handling a globe as an act of investigation leads to the discovery of spin as a property of the specific object, as well as to the production of corresponding iconic gestures.

Approaching the iconic bodily expressions in teaching physics, they can be perceived as factors that create meaning [45]. Thus, these gestures might represent a human act (e.g., pushing or pulling someone/Newton's third law) or an inanimate entity and its action (e.g., a photon colliding with an opaque object). They can collaborate with the spoken word in such a way that the human body represents an inanimate entity that experiences an action (statement: "I am kicking a ball") or even the entity itself acquiring the qualities of a person (statement: "I am a fast-running ball"). Generally, iconic bodily expressions resemble to a small or large extent the form they represent, producing syntactic spoken word/bodily expression/spatial entity structures. Additionally, when teaching activities are based on embodied actions, bodily expression plays a central role. For example, when, during an activity on the phenomenon of shadow formation, learners play the role of the obstacle and investigate where there is shadow, using their body to depict the journey of light. In other cases, when trying to explain something, learners may use iconic gestures for a short period of time.

Science in particular, as a teaching subject, contains to a large degree the use of ergotic gestures by learners, since they relate to the handling of material objects and experimental devices [13], [21]. Interacting with material objects through the human body leads to more complete learning outcomes and is linked to learning even more abstract concepts [23], [46], [47]. In conditions where experimental devices are prevalent, all kinds of gestures, including ergotic, form a common communication code, a common descriptive language, and the spoken word is frequently unnecessary. While following an investigative thread, learners might operate devices, observe measurements, depict, point, and simply use the spoken word to create a voiced context [30], [48]. Young children in particular find that the use of ergotic gestures allows them to experiment and formulate and emerge different ideas, since by interacting with materials they can run and test scenarios, and redefine their practices, both individually and collectively [49].

Deictic along with iconic gestures are often used as interpretive filters by learners when producing explanations for photographs, drawings, and diagrams [45], [50]. In teaching science, teachers as well as learners, use deictic gestures to link the spoken word with elements of the space and also to denote entities that are not materially present. Thus, deictic gestures can uphold or emphasize material entities, while ergotic, through manipulation, can reveal their hidden properties [1], [51]. In science learning environments, the deictic function is characteristic and very often desirable relative to the spoken word, as in, for example, activities concerning the shape of the earth, with preschool children pointing towards the object "sphere" without uttering a word.

Creating forms through body is not limited simply to one instrumental level but is clearly linked to different levels of the cognitive processing of concepts. Hwang and Roth [1], extoling the human body's meaning-making functionality, argue that it is what harmonizes the various semiotic vehicles (written text, graphs, utterances, material objects), uniquely contributing to the formation of an explanation framework during the teaching of scientific concepts. Generally, research in science education has demonstrated that an improvement in the learner's bodily conceptualization is also an explicit demonstration of cognitive progress [2], [22]. For example, Pantidos, Herakleioti, and Chachlioutaki [4] compared two data analyses related to the spoken word and the gestures of preschool-aged children, examining conceptualizations regarding the shadow formation phenomenon. In the first case, the analysis covered each child's spoken words and deictic gestures, while in the second case, iconic gestures were added to the analysis. It was established that the second analysis was not only more accurate, but also showed improvements in the children's performance regarding certain aspects of the phenomenon, which were exclusively expressed through their iconic gestures. Additionally, gestures as ways of thinking in learning environments gradually lead to the conceptualization of scientific entities through the spoken word [51]. Roth, Lawless, and Tobin [30] reported that when learners acquire their first laboratory experiences, they replace the spoken word with gestures at this early stage. This occurs because at this stage, compared to gestures, the spoken word is incapable of conveying aspects of the new environment. The previous researchers declared that learners find ways to use their bodies to free themselves from this weakness of the spoken word and to imbue scientific entities with meaning. Generally, they believe that gestures can play a significant role even for complex scientific meanings.

5. CONCLUSION

Alternative uses of material objects can be a good way to bridge the gap between the phenomenology of the everyday and the scientific code. This results in exciting the learners' interest, while also cultivating observation in the context of everyday life, which enhances their exploratory skills. Moreover, approaching material objects as visual images, as well as focusing on changes in their image, cultivates the ability to detect variations and attribute causality to them. Generally, when learners search for multiple interpretations for a given form or a change in the form of an object or arrangement of objects, they are able to correlate between certain features of the material environment and aspects of scientific (or even school) knowledge.

Gestures and bodily expression in general function similarly, since they contextually integrate aspects of scientific concepts into the material environment, thus creating a hybrid communication code. For example, in Figure 8 iconic gestures representing the path of the light rays and deictic gestures showing the points where the rays "break" (refract), as well as combined gestures to define the outline of the image, are necessary for communication between what is perceived and what is mentally constructed. The creation of such communication codes could illuminate different aspects of the classic constructivist research for teaching and learning science.

The semiotic approach to science teaching emphasizes the ability of narratives produced by material objects and the human body to create bridges between the current "here" and the narrated "there". Science teachers should create the conditions that allow learners to integrate the codes of school knowledge into the material signifiers of the material objects and the human body. Generally, such an approach might offer additional tools for transforming scientific knowledge into school knowledge. Although the dynamics of a semiotic perspective are recognized in science education, more systematic research is appropriate.

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