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EPISTEMIC, COGNITIVE AND SEMIOTIC SIGNIFICATIONS IN SCIENCE TEACHING: THE CASE OF SOUND

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Abstract:
The main idea expressed in this paper is that scientific concepts, as teaching objects, are invested with meaning through epistemic, cognitive and semiotic significations. It is described how the concept of sound is presented through: a) the various scientific and non-scientific fields in which sound constitutes an object of study and research, b) the students' personal formation of knowledge and c) the modes that can be represented in the material world. Such an approach allows us to define the structure elements used in the teaching of concepts and phenomena even before these become active teaching objects. This seems to be useful in lesson planning, in the training of pre-service and in-service science teachers, as well as in curricula design.

Keywords: epistemic, cognitive, semiotic significations, sound

1. Introduction

The theories and the methodologies adopted and constructed in the various fields of knowledge influence the signification of the concepts they deal with. It is acknowledged that the varied study of our world also constitutes the intent to make differential meanings. Physics and chemistry, as well as visual arts and philosophy, conceptualize the same entities ascribing different meanings to them. For example, physics interprets sound as the product of dynamic interactions among the particles of a medium and typically approaches it through frequency, amplitude and overtones. In Ancient Greek tradition, as a different cultural context, both Aristotle (*On the Soul*, book II) and Pythagoras (*The First Philosophers*, p. 87) link sound to the relative motion of two objects; whatever moves produces sound, even if we don't hear it. The visual arts conceptualize the aesthetic side of sound through the interaction between various means and materials (e.g., the interaction between the human body and spatial installations). All these approaches concern scientific, philosophical, aesthetic or any other kind of formal

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signification, thus constituting an epistemic dimension in the construction of knowledge.

Moreover, as has been forcefully shown in science education, a major role in the signification of scientific entities is held by students' mental representations. Students, either on an individual or a social level, build concepts through their cognitive processes. Depending on the epistemological view, one can perceive mental representations as preconceptions, alternative ideas, misconceptions, naïve beliefs, initial ideas, intuitive knowledge, et al. (Smith, diSessa & Roschelle, 1993). However, in any case, students construct personal significations of the natural world and thus knowledge attracts a cognitive dimension.

Especially during the last two decades, a part of the research conducted in the field of science education has centered on the study of different aspects of teaching and learning on the basis of a semiotic perspective (Kress, Jewitt, Ogborn & Tsatsarelis, 2001; Pantidos, 2017; Moro, Mortimer & Tiberghien, 2019). Thus, meaning is given to entities through the modalities used for the representation of these entities in a teaching context (Pozzer-Ardenghi & Roth, 2010). In general, the rhetorics of the learning environment (i.e., the interactions between speech, the human body and spatial configurations) gives form to the knowledge itself assigning a semiotic aspect to it (Givry & Tiberghien, 2012; Impedovo, Delserieys-Pedregosa, Jégou & Ravanis, 2017).

This study attempts a kind of conceptual composition in the light of the school knowledge about sound constructed through the various scientific (and non-scientific) fields, the students' ideas, and the modes used to represent it. From this perspective, the paper discusses how a) epistemic, b) cognitive and c) semiotic viewpoints contribute to assign meaning in the concept of sound.

2. Types of significations

2.1 Epistemic significations

Our understanding of sound normally relies on how it is notionally constructed within the various fields in which sound constitutes a subject of study and research. Physics usually examines it in terms of frequency, amplitude and overtones; psychology and neuroscience focus on how a human being perceives and interprets sonic stimuli; while the new direction of acoustic archaeology investigates the acoustic properties of the ancient sites in their connection with, for example, rituals. Theatre, radio drama and cinema use sounds to perform actions and events or to signify soundlands. Phonetics treats the human voice as an instrument for producing sonic patterns; the visual arts incorporate sounds into installations; urban design takes into account sonic parameters in the construction of buildings and urban space, and so on.

In fact, when examining sound through the various contexts of scientific research and human activity, a range of different significations emerge which can be called *epistemic*. Although in modern Greek the word *episteme* means *science*, 'epistemic' carries a wider meaning, not directly connected to 'scientific'. Given that in Ancient Greek language the word *epistemic* etymologically refers to the verb *epistamai* (i.e., 'I am an expert at something'), or to the noun *episteme* (i.e., knowledge, skill, competency), the current study perceives the term 'epistemic' in this wider sense. In that view, 'epistemic' describes the systematic construction of the knowledge about concepts, phenomena, activities, events and situations within specific fields which are not necessarily considered to be scientific (i.e., physics, but also the visual arts).

What follows concerns how sound is demonstrated through physics, ancient Greek philosophy and the visual arts. The main idea behind such a view is to examine, apart from physics, which features of sound are constructed into other fields. A further goal is to investigate how 'heterogeneous' facets of knowledge can contribute to the teaching of sound.

2.1.1 Epistemic significations introduced by physics

According to physics, sound, as a wave, is:

> "*…an alternation of properties of an elastic medium, such as pressure, particle displacement, or density, that propagates through the medium, or a superposition of such alternations; sound waves having frequencies above the audible (sonic) range are termed ultrasonic waves; those with frequencies below the sonic range are called infrasonic waves*" (Parker, 1997).

Each simple sound is characterized by two physical properties; *frequency* and *intensity (amplitude of oscillation*), while complex sounds comprise an extra (third) feature, that of *overtones*. Given that any sound, as a wave, propagates through a material medium forcing its particles to oscillate, frequency reflects the number of cycles completed by the periodic motion of a particle in a unit of time, intensity is connected to the amplitude of the oscillation of the particle, and overtones is a component of a complex tone having a frequency higher than that of the fundamental one (Parker, 1997, pp. 165, 211, 314). Overtones can be either harmonic, when their frequency is an integral multiple – greater than 1 – of the fundamental frequency (i.e., stringed or wind instruments), or inharmonic, when their frequency is a non-integer multiple of the fundamental frequency (i.e., percussion instruments). Furthermore, with respect to how a sound is perceived by humans, subjective features of sound are also considered. These are: *pitch*, which corresponds to frequency; *loudness*, which is connected to intensity; and *timbre*, which reflects overtones. Especially for complex sounds, timbre or quality is related to the number of (higher) harmonic components (overtones) as well to their intensities (amplitudes) (Halliday and Resnick, 1966, p. 505). Knowledge regarding the objective and subjective properties of sound offers explanations in terms of physics and traditionally constitutes the reference knowledge in any effort made towards didactic transformation.

2.1.2 Epistemic significations introduced by ancient Greek philosophy

Archytas (born between 435 and 410 and died between 360 and 350 BC; *Stanford Encyclopedia of Philosophy*) refers to sound as the result of one body striking against another. Similarly, in his *On the Soul (Peri psychis)* Aristotle (384-322 BC) claims that sound is produced when a body strikes another one, mentioning however that this does not happen for all materials; according to Aristotle gasses striking each other do not produce any sound at all.

> "*Actual sound requires for its occurrence (i, ii) two such bodies and (iii) a space between them; for it is generated by an impact. Hence it is impossible for one body only to generate a sound – there must be a body impinging and a body impinged upon; what sounds does so by striking against something else, and this is impossible without a movement from place to place*" (*On the Soul, Book 2, 8*).

Therefore, at least two bodies are needed to be moving relative to one another in order for sound to be created. In fact, the place to place *movement* of a body is the fundamental prerequisite for the production of sound. Chrysippus (280-207 BC) mentions that sound is the result of the striking of the air which finds itself between that which produces and that which hears the sound. He also approaches the propagation of sound in a similar way to that of ripples formed when a pebble is tossed in a lake.

In his treatise *On the Heavens (Peri ouranou, Book 2, 9)*, Aristotle talks about the harmony of the spheres. Through this concept, which was held by the Pythagorians and appeared for the first time in Plato's *The Republic* (*Politeia, Book 3*), Aristotle underscores the connection between sound and motion.

> "*So given that the sun, the moon and stars, in all their quantity and enormity of size, are moving at such a great speed, it is impossible, they claimed, for them not to produce a very loud noise*." (*The First Philosophers*, p. 109).

It seems that associating sound (a sound wave) to the relative movement constitutes a hidden feature of this particular phenomenon. In this context *anything that moves (has speed) produces sound*. This view agrees, up to a point, with the general theory of relativity, according to which, by taking up space, every material body, e.g., a planet, disturbs (curves) the time-space continuum. It stands to reason, therefore, that the shifts in position and movements in general of a celestial body disturb space and time at specific regularities. Thus, even though humans cannot hear them, the 'sounds' of the planets are unique because the movements of the planets are distinct and particular. Consequently, the disturbance of time and space caused by these movements is also specialized. To some extent, human's walking, butterfly's flying, or dancer's rhythmically movement stimulates the air molecules at a specific regularity. Of course, in these cases, the human auditory system cannot convert such inaudible frequencies into nerve signals. However, such kind of disturbances into the air, still exist looking forward from human technology to build appliances receiving and analyzing such complex kinesic-"sonic" regularities.

2.1.3 Epistemic significations introduced by the visual arts

Sounds have also taken an indisputable interest in the visual arts. A typical example is that of David Byrne (2009) who transformed an old building (Camden's Roundhouse) into an enormous musical organ. By connecting, through cables and wires, a pump organ keyboard with the building's pillars, pipes and beams, he gave visitors the opportunity to play with the setting and make it sing. Furthermore, quite a few visual artists create installations incorporating sound resources, or are experienced with constructions which produce harmonic sounds. In an attempt to create musical sounds/artworks, Lin Emery and Robert Morriss (1986), a sculptor and a physicist-educator respectively, made Kinesone I. Located in a courtyard setting and comprising 14 metallic pipes, each 4½ inches in diameter and 9 feet high, Kinesone I produced musical tones as it swung in the wind (see Figure 1).

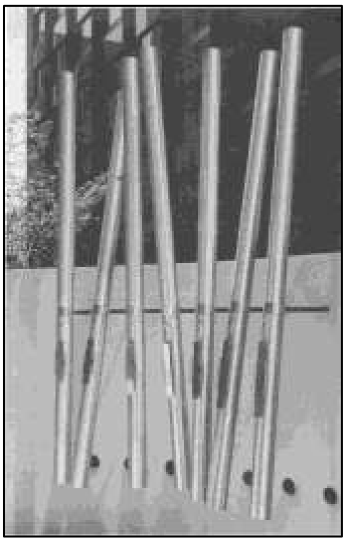

Figure 1: An installation that combines movement with the production of sound

For the production of sound, Kinesone I made use of a mechanism similar to that of a marimba or a xylophone. Each pipe had a rectangular bar adjusted onto the lower edge of the pipe. As the wind made them vibrate, the pipes would strike these bars, producing sounds. The physical properties of the bars, the positions of the bar supports, as well as the position in which the bars were struck determined the frequencies produced. The role of the pipes was to amplify the sound. In general, Kinesone I could produce sounds of a long duration that approximated musical tones. Such installations that activate recipients' senses are perceived as multimodal ensembles of sight, sound and motion.

Attention should be also paid to the remarkable work of the sculptor Takis. From the early 1960s Takis experimented with musical tele-sculptures through the use of electromagnets. Electromagnetic field would force material objects, such as strings and pins, to vibrate and produce musical sounds. In 1962, in collaboration with Earle Brown, Takis produced his first musical sculpture entitled *The Sound of Void*. A small wire heated by weak electrical current produced a sound that reverberated in the void (see Figure 2). Takis described it as "*the solitary cry of a bird; a short hum*" (Kampas, 2003, p. 209).

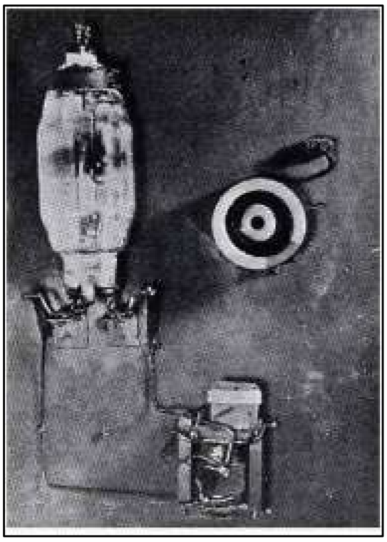

Figure 2: *The Sound of Void*. Exhibited in New York's Cordier-Ekstrom Gallery under the title *For Eyes and Ears* in 1963

Another acclaimed sculptor George Zongolopoulos expressed in terms of installations his views on motion, water, sound and light.

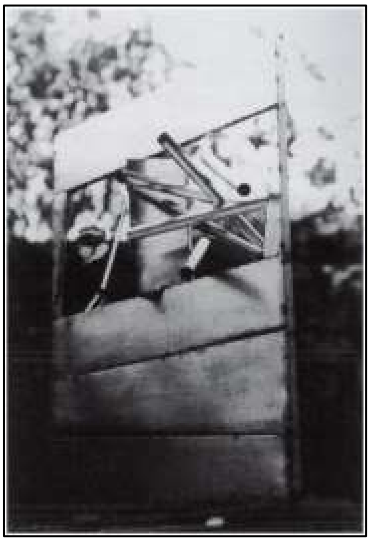

Figure 3: A system with metallic pipes, water and sounds

Based on physical laws, in the exhibition *Hydroichi* (Watersounds), he introduced assemblies such as this of a set of moving metallic pipes with running water inside, which generated sounds as the pipes forced the water to flow in various directions (Kampas, 2003, p. 222).

From a similar perspective the designer Peter van der Jagt proposed installations using common materials (see Figure 4).

Figure 4: In this original doorbell, when electrical current flows through it, the coil becomes an electromagnet which forces the metallic core inside it to move, striking the glasses and producing a sound like two clinking glasses (Van der Jagt, 1994)

Similarly, Figure 5 illustrates an exhibit in Interactive Science and Technology Exhibition Hall in *Eugenides Foundation* that links sound to electromagnetic radiation, as well as to other phenomena (e.g., the photoelectric effect). In this particular installation, either by shifting places or by moving a part of his/her body, a person in a specially constructed space interrupts the light from falling on the crystals. Before the light flow was interrupted, the crystal received the light and due to the photoelectric effect it played the role of a source of electrical power by channeling electricity to a circuit. Yet as the light is (rhythmically) blocked by the person, the supply of current to the circuit is also interrupted. This activates a system for the production of sounds which is connected to the crystal circuit. Thus, this set up allows the person using it to move (either rhythmically or arbitrarily) in the enclosed space and to produce sounds.

Figure 5: As the visitor moves, sounds are produced
(Eugenides Foundation, *Virtual Percussion Instruments*)

In general, visual arts installations offer the possibility of familiarizing oneself with natural phenomena. Even though they tend towards everyday life, they connect science to social and technological activities through art (Tselfes & Paroussi, 2009). In this way, the conditions are created to bridge the cultures of everyday and scientific thinking (Hawkins and Pea, 1987), contributing to the building of school knowledge (Ravanis, Koliopoulos and Boilevin, 2008; Ravanis, Christidou and Hatzinikita, 2013).

2.2 Cognitive significations

Sound has also attracted considerable interest in science education over the last 30 years. As in the case of most physics concepts, the discussion about sound in all grades of schooling has primarily focused on the students' constraints about the nature of sound, sound production and sound propagation (Driver, Guesne and Tiberghien, 1985). Therefore, many students attribute, among other things, *material properties* to sound, arguing for example, that sound cannot move across solids (because a "solid" does not go through another one) (Lautrey and Mazens, 2004). Besides, quite a few students have a strong belief that sound does not propagate in terms of a wave and usually connect it with its source (Asoko, Leach and Scott, 1991). As regards sound production students propose mechanisms associated with the context in which sound is generated (Watt and Russel, 1990). Some of the most common misconceptions are that: "*sounds can be produced without using any material objects", "hitting an object harder changes the pitch of the sound produced", "sounds can travel through empty space (a vacuum)", "sounds cannot travel through liquids and solids", "when waves interact with a solid surface, the waves are destroyed*" etc. (Hapkiewicz, 1992).

Eshach and Schwartz (2006) in an attempt to go deeper into students' thought with respect to the materialism of sound, took advantage of Reiner, Slotta, Chi & Resnick (2000) framework called *substance schema*, in order to discover to what extent eighth grade students materialize (substantialize) concepts (e.g., sound) by attributing to them a range of material properties. Specifically, Eshach and Schwartz (2006) demonstrated that most students apply to sound *pushable* properties (e.g., "*sound is pushed by the air, water, a barrier, is attracted by a stethoscope, or hits the walls*"), *frictional* attributes (e.g., "*sound experiences drag when it propagates through wate*r"), *containable* characteristics (e.g., "*sound (voice) is contained in bubbles*", or "*sound may be locked in closed spaces*"), and *transitional* features (e.g., "*sound moves in straight, spiral or in a form of crescent shaped lines*") (ibid. 746-753). The same researchers also indicate that students actually believe that the mechanism through which sound travels depends on the medium. In the same context, students believe that sound changes form when it passes from one medium to another.

With regard to the *substantiality of sound*, Mazens and Lautrey (2003) and Lautrey and Mazens (2004) recognize five mental models which correspond to three naïve theories. According to the first theory, students consider sound as a material substance. That is to say, when students are asked to explain why they hear a sound propagating through a material, they claim that sound cannot move across solids (model 1). When students deal with situations from everyday life which disclose contradictory data (e.g., they do hear the noise from outside when they are in a closed room), they adopt the idea – in terms of the solid – of the presence of holes (model 2), or perceive sound as a harder substance than the solid, hence being able, due to its hardness, to penetrate the solid (model 3). The second theory categorizes sound as an entity which is a substance but with immaterial properties. Thus, sound can be invisible or transparent as a ghost or smoke (model 4). Finally, the third theory poses sound to a transmission context by adjacency with students describing its propagation using terms such as 'vibrating' or 'resonating' (model 5).

2.3 Semiotic significations

In this section, the propagation of (sound) wave and frequency are explored in different semiotic contexts. Semiotic approach is based on the view that different modalities representing scientific entities signify them in a unique way (e.g., Roth & Lawless, 2002; Abrahamson, 2009; Chachlioutaki, Pantidos & Kampeza, 2016). It is assumed that a learning environment, through its proposed morphology, conceptualizes in a particular way the phenomenon of sound. The following analysis includes excerpts (as examples), mainly from teachings, in which aspects of wave disturbance and frequency are signified by the verbal and written texts, the human body, material objects and drawings, as well as by sound related signs (e.g., Pantidos, Valakas, Vitoratos & Ravanis, 2010; Pozzer-Ardenghi & Roth, 2010). It should also be noted that each sign system is presented separately, despite the fact that meaning is structured through the concurrent contribution of all semiotic resources. Nevertheless, this separation emerges the potentiality but also the affordances of each sign-vehicle.

2.3.1 Verbal and written texts

In Example 1 the teacher conveys the message using mainly the spoken word. The oral explanation of 'propagation of the wave' is typical; a kind of transcription of the school book into spoken text. It is worth noting that this particular rhetoric is traditionally adopted by physicists (and physics teachers) when they explain sound as a wave.

Example 1

> *"by the term wave we mean a disturbance that propagates through space. For a wave to be created there has to be a source, which is to say the starting point of the disturbance, and a propagation medium, i.e., the space through which the disturbance will move. When the propagation medium is a material in which all particles interact with those adjacent then this medium is called an elastic medium. The wave that moves through an elastic medium is called a mechanical wave. In a mechanical wave the source of the wave is a particle of the elastic medium which is disturbed, i.e., which is displaced from its equilibrium position. The interaction of the particle with its adjacent particles causes forces which tend to return the particle to its equilibrium position and forces that tend to deflect adjacent particles from their equilibrium positions. As a result of this interaction the disturbance propagates, and all the points of the elastic medium consecutively carry*

out the same movement, moving around their equilibrium positions without moving to other points in space" (Pasithea).

In this case the teacher is referring to the wave source, the propagation medium, and the functional relations among them. However, this kind of narrative does not include examples taken from life experiences or use rhetorical devices such as analogy or metaphor. In this way the description remains at a formal level while linguistically it is closer to the scientific code than to everyday language.

Example 2 is a spoken text conveying also a similar tone concerning the concept of frequency.

Example 2

"*the inverse quantity which helps us study simple harmonic oscillations is frequency. Frequency is denoted by the letter f and its unit of measurement is the hertz, which is the inverse quantity of time. We could also say that its unit of measurement is* $1s^{-1}$. *Frequency can very easily be calculated by the formula* $f=N/t$. *Let us now move on to the period-frequency relation. Given that period and frequency are inverse quantities, that means that their product is equal to 1. Therefore, this very easily leads to a relation with the help of which we can calculate the period based on the frequency or the frequency based on the period. In particular the* $f=1/T$ *relation*" (Pasithea).

Correspondingly the definition of frequency in Example 3 is similar to that contained in a typical textbook or a scientific dictionary.

Example 3

"*the number of cycles completed by a periodic quantity in a unit time*." (Parker, 1997).

2.3.2 Bodily texts

Juxtaposed to Examples 1, 2 and 3, Example 4 (cf. Figure 6) and Example 5 (cf. Figure 7) illustrate aspects of sound wave concept and frequency through the activation of the human body. Specifically, in Example 4, during a lesson about the propagation of sound waves, the teacher stands at the front of the class as a particle of the elastic medium which receives the disturbance.

Example 4

Figure 6: "*I am the particle at a distance of x_1 from the source […] after a certain period of time from the initiation of the disturbance, it reaches me*"

The teacher refers to 'wave equation' using speech similarly to that of Examples 1 and 2. However, compared to Example 1, the teacher here activates physicality explaining the equation of the wave in terms of his body. The body transforms what is written on the board in mathematical code into a three-dimensional physical code more manageable by the students. The teacher's left hand showing himself is equal to the utterance "I am the particle," while the act of extending the right arm denotes the direction from which something – the wave disturbance – is coming. However, the most important part of the representation in terms of wave disturbance is the illustration of the particle.

Example 5 offers a similar possibility for the transformation of the mathematical code through the human body. Here too, compared to Examples 1 and 2, the mental images suggested to the viewer are clearly different. The physicist Paul Hewitt narrates through the vivid use of his body. He has drawn a floor plan of a wave disturbance. Thus, the wave travels across the surface of a lake and its source is a bug jiggling up and down. The points which make up the concentric circles correspond to the maximum positions of the particles of the elastic medium through which the wave propagates. Hewitt places one hand on the outermost circle, while his other moves back and forth between the outermost and the approaching circle and his mouth produces the periodic sound – a paralinguistic sign – of "plip plip plip" each time his two hands come in contact (see Figure 7).

Example 5

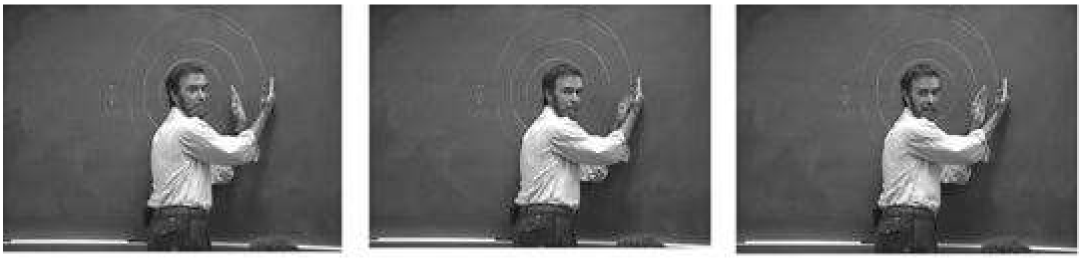

Figure 7: While discussing the Doppler effect, the teacher asks how the frequency of the wave is related to the frequency of the vibrating source (i.e., the bug): "*The frequency of the wave is the same as the frequency of the vibrating source*" (Hewitt, 2012)

In this particular example, Hewitt is referring to waves on liquid surfaces in general. Nevertheless, the way he addresses the concept of frequency through his body can represent any kind of wave, including sound waves. Besides, as has already been mentioned, in this paper is assumed that mechanical and sound waves are equal, in the sense that anything that moves produces "sound".

2.3.3 Spatial texts

In Examples 6 and 7 Paul Hewitt again approaches by drawing different aspects of wave propagation.

Example 6

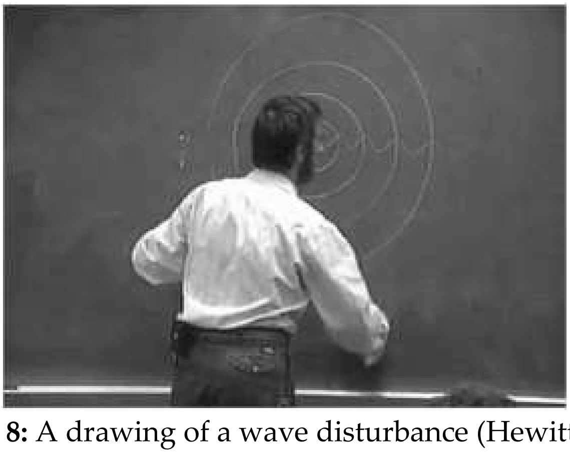

Figure 8: A drawing of a wave disturbance (Hewitt, 2012)

More specifically, in Example 6, Hewitt has drawn a series of concentric circles showing wave propagation. This particular illustration (i.e., concentric circles) is morphologically related (similar) to what actually takes place when a wave travels across the surface of a liquid. But through the drawing, Hewitt explains how exactly these concentric circles are formed. He draws a waveform which begins from the source and ends at the outermost circle. The waveform's maximum points coincide with those of the concentric circles (cf. Figure 8). That means each circle is made up of points of the elastic medium which are located at the maximum (positive) maximum displacement.

Similarly, in Example 7, Hewitt adds another aspect to the concept of wave propagation.

Example 7

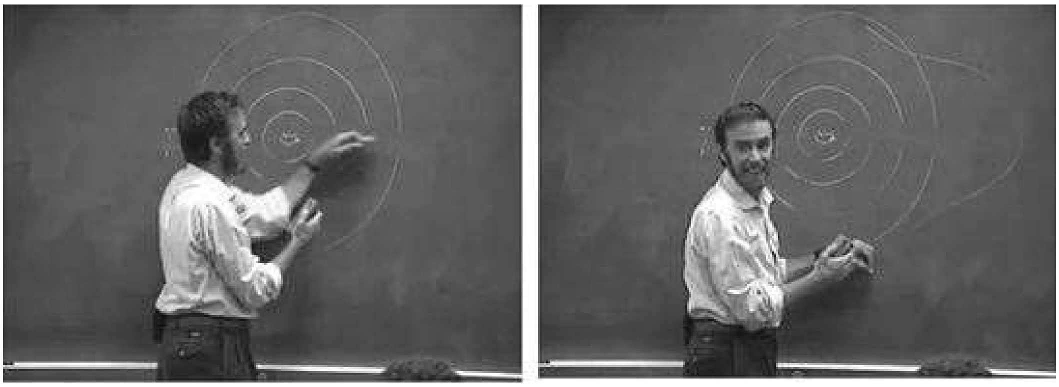

Figure 9: "The waves go out in all directions. And the fact that they're circles is kind of evidence that they go out in all directions at the same speed, isn't that true? Like, if it went faster over here (*he shows the direction through the horizontal movement of his hand*), then the wave would sort of be like that (*he draws a curved line*)…" (Hewitt, 2012)

If the wave did not propagate at the same speed through the elastic medium, then what we would observe, when for instance tossing a pebble into a lake, would be the picture shown in the second part of Example 7.

Actually, Examples 1, 4, 6 and 7 shed light through the various modalities to the various aspects of the concept of the 'wave (sound) disturbance'. Each element conveys different conceptual content.

Similar roles in signification process are played by other two-dimensional illustrations, such as graphs (see Example 8), apparatuses (see Examples 9, 10), and simulations (see Examples 11, 12).

Example 8

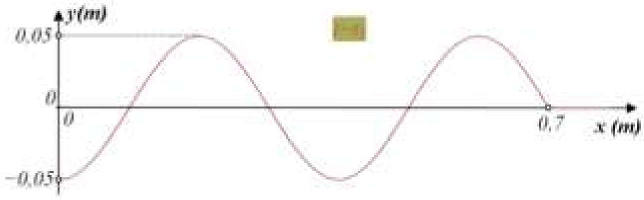

Figure 10: A typical section of a wave disturbance represented in a graph

Example 8 is a refined – and more abstract – version of the illustration of Example 6. That graphical representation of a section of the sinusoidal wave is the next meaningful form towards the illustration in Example 6. Perhaps these two examples offer a kind of bridge between what is observed on the surface of a liquid during the propagation of a sound wave and the graphical representation of a section of that wave. Similarly, the configuration of Example 9 (cf., Figure 11) also serves in the signification of sound concept and maybe offers an adequate context against students' alternative views that attribute material properties to sound (e.g., "sound passes through miniscule holes").

Example 9

Figure 11: A sound source causes the vessel containing it to vibrate

The apparatus in Example 10 (see Figure 12) illustrates the sound effect. The screen consists of round metal surfaces which are free to move slightly. By hitting the membrane of the drum (which is at a distance from the screen), the user forces the intervening air particles to oscillate. As a result, the metal surfaces of the screen vibrate. This, at least on a first level, indicates a cause-effect relationship between these two objects.

Example 10

Figure 12: The drum causes the screen opposite to vibrate
(Eugenides Foundation, *Sound Waves*)

Typical/specialized significations are also offered by simulations such as those of Examples 11 and 12.

Example 11

Figure 13: An illustration about the concept of wave disturbance
(Colorado PhET simulations)

The representation in the Example 11 also visualizes the changes the user can make in frequency and wave amplitude. A change in frequency changes the distance between the bold colored curves, while a change in amplitude affects the color intensity of the curves (see Figure 13). The 'person' that interferes in the propagation space of the wave gives the user the chance to observe that her/his ear receives bold colored curves at regular intervals: a signification of frequency.

The content of the Example 12 in a first glance appears equal to the Examples 1, 4 and 6, but it carries a different conceptual load.

Example 12

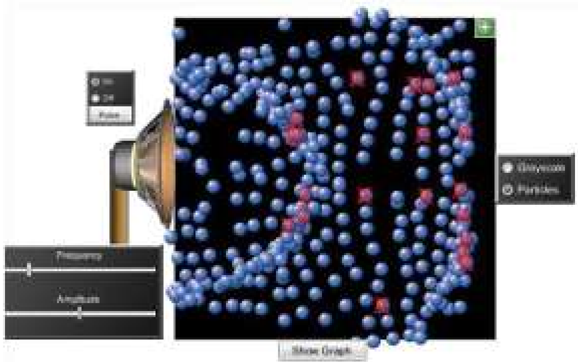

Figure 14: Another representation of how the air particles oscillate
during wave propagation (Colorado PhET simulations)

It conveys in 2-D* dimensions the way in which air particles move and especially their palindromic movement around their equilibrium positions. 2-D* refers to two-dimensional illustrations which, however, contain the concept of perspective. Moreover, these horizontal palindromic movements also visualize the concept of frequency.

2.3.4 Sound-related signs

Sounds can be also perceived as "imprints" of specific natural phenomena in the material world. In the simulation of Example 11 the user can hear various versions of a sound wave disturbance by changing its amplitude (volume) as well as its frequency. In a same way, in the case of the sound produced as a bottle is filling with water, the concept of frequency is approached acoustically. More specifically, when the surface of the water gradually rises, the wave length of the produced static wave is getting shorter. The result is a corresponding increase in frequency making the sound sharper (Example 13; https://www.youtube.com/watch?v=5I_cvSbz2l4). In another case, frequency can be realized through Doppler effect in the Example 14 (https://www.youtube.com/watch?v=qvWxhhi0_yk). The perceived frequency of the F1 car first increases and then decreases as the car passes an immobile observer/listener. Actually, Examples 13 and 14 deal with the concept of frequency in different everyday life contexts.

3. Discussion

According to physics sound is a mechanical wave propagated through dynamic interactions among the particles of an elastic medium. In that sense, *sound is closely connected with the concept of the wave* signified through wave mechanics (i.e., frequency, amplitude, overtones). In a level of how sound is perceived by humans it is defined by sharpness, audibility and tone. From the ancient Greek philosophers view, sound is produced by the *relative motion* of two objects (material entities); one of the entities could be air. In the visual arts perspective *installations* interconnect various material entities (i.e., the interaction between the human body and spatial entities) producing sounds. Eventually, sounds can be produced in various ways; from the laryngeal and oral cavity to the electromagnetic bell or the relative movement of the human body in space.

From a cognitive point of view students understand sound as something that has material properties (pushable, frictional, containable, transitional), does not propagate through solids and in the event that it does these solids might have holes or is a substance harder than the solid (materiality of sound). Also, the mechanism of sound traveling depends on the medium, sound changes its form from medium to medium, it is an invisible entity (i.e., like smoke), is connected to its sources or can be produced without using any material objects. Hitting an object harder changes the pitch of the sound produced, sounds can travel through empty space (a vacuum), and, when waves interact with a solid surface the waves are destroyed.

Through a semiotic context of sound signification, frequency can formally described as "the number of repetitions per unit time" and denoted through the quotient $f=N/t$, while whatever difference exists between its various values is expressed only quantitatively (e.g., 5Hz vs. 25Hz). Typical verbal or written texts are connected with the description of formulas (see Examples 1 and 2) and become less typical though close to everyday language when analogies and graphical or bodily representations and simulations are used describing what they actually convey (see Examples 4, 5, 7 and 12), and not the abstractive content of the scientific code (see Example 8). Bodily expressions can represent the material entities (i.e. wave source and elastic medium particles) which take part in the propagation of a sound wave (see Example 4). Such representations visualize the propagation of energy and the rate at which it propagates (see Examples 5 and 7). Especially in Example 5, the repetitive motion of the hand between the limits of the two circular curves introduces the idea of periodicity. Example 7 and Example 12, carrying more or less degree of abstraction, are spatial representations which describe the morphology of the physical system that produces the sound wave and the transmission of the wave in time. In Example 11, the different shades of gray show which particles are in the maximum amplitude. Similarly, Example 12 represents the movement of these particles. Example 15 (see Figure 15) is a melding of these two images (the curves have been added by the author).

Example 15

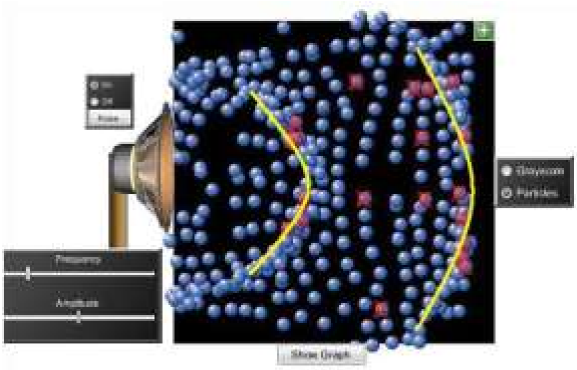

Figure 15: The line has been placed above the particles at their farthest position during their back and forth movement

Spatial codes can be blended producing hybrids with low or high degree of abstraction. Example 6 can be perceived as the result from mixing elements of Examples 7 and 8. Other spatial configurations can visualize the idea that sound passes through the non-visible air (Example 10) as well as through material obstacles (Example 9). Finally, sonic signals can be suitable for the signification of frequency and its differentiations (see Examples 13 and 14).

Eventually, how to answer the question “what is sound?” If the one answering is physicist the focus will be on wavelike form, frequency, amplitude and overtones. Aristotle would emphasize that sound is the result of the relative movement of (at least) two material entities, while a visual artist would underline the production of sound as a result of interactions among all kinds of materials, media, and appliances (e.g., robotic installations, the human body, et al.). A student would probably say that sound propagates through different media because they have holes (even miniscule ones), or that its propagation is due to the fact that, as a substance, it is less hard than the medium through which it travels. A student may also link sound to its source. A science teacher may answer like a physicist would, explaining sound in terms of how can be represented: depiction of the particles of the propagation medium, visualization of the rate at which energy is propagated, the materialization of the wave propagation, etc.

Obviously, signifying scientific entities goes beyond science teaching and affects the design of science curricula for all school grades. The idea of epistemic, cognitive and semiotic significations can be useful in organizing the curricula or transforming them into teaching practices. A physics teacher says:

> "*after four years of training as a physicist and ten years as an expert physics teacher, I had not understood that an acoustic and a mechanical wave are actually the same thing. This became clear to me when I studied Aristotle, who essentially says that whatever moves produces sound (regardless of whether we can hear it or not). This observation drastically moved my view towards a conceptual teaching approach about the phenomenon of sound. Thus, for example, 'a vibrating needle producing an audible sound wave in a liquid and this whole system being contained in a transparent vessel,' seems to form a semiotic pattern that satisfies the Aristotelian approach regarding sound, while at the same time going against some of the misconceptions related to sound propagation*".

Linking the aspects of scientific knowledge to a specific network of modalities, while taking into account the students' mental representations could be a context of constructing school knowledge (Alibali et al., 1999).

In summary, it could be said that epistemic significations give knowledge shape by means of the *different scientific and non-scientific fields*, cognitive significations assign meaning to scientific entities through the prism of the *personal formation of knowledge*, while semiotic significations give meaning to scientific entities in the context of the *representation of knowledge* in the sense of modalities. The design of school curricula and the training of pre-service and in-service science teachers based on these three axes of signification of scientific entities constitute the proposal put forward by this paper. Such a perspective is not limited to the concept of sound. It could apply to all the science concepts as subjects of teaching.

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