Multidisciplinary Journal for Education, Social and Technological Sciences
http://dx.doi.org/10.4995/muse.2015.2226
EISSN: 2341-2593

The epistemic representation: visual production and communication of scientific knowledge.

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Received: 2013-12-15; Accepted: 2014-08-08

Abstract

Despite its great influence on the History of Science, visual representations have attracted marginal interest until very recently and have often been regarded as a simple aid for mere illustration or scientific demonstration. However, it has been shown that visualization is an integral element of reasoning and a highly effective and common heuristic strategy in the scientific community and that the study of the conditions of visual production and communication are essential in the development of scientific knowledge.

In this paper we deal with the nature of the various forms of visual representation of knowledge that have been happening throughout the history of science, taking as its starting point the illustrated monumental works and three-dimensional models that begin to develop within the scientific community around the fifteenth century. The main thesis of this paper is that any scientific visual representations have common elements that allow us to approach them from epistemic nature, heuristic and communicative dimension.

Keywords

Illustrations; models; pictures; photography; images; simulation; epistemology; communication; science

Multidisciplinary Journal for Education, Social and Technological Sciences
http://dx.doi.org/10.4995/muse.2015.2226
EISSN: 2341-2593

> "Aristarchus of Samos published hypotheses of whose foundations is that the universe would be much higher because it assumes that the fixed stars and the Sun are still, as the Earth rotates around the center and that the magnitude of the field is such that those the circumference of the circle representing the Earth is described by the distance to the fixed stars as the center of the sphere to the surface, which is impossible because, lacking central magnitude, cannot have any reason to the surface sphere. "
>
> Archimedes. The Sand Reckoner.

1. Introduction.

The heliocentric theory of Aristarchus of Samos is known mainly through the reference made to it by Archimedes (c. 287-212 BC) in his *Psammites* or *Sandreckoner*, who cites to refute it on the grounds that it is unfounded, as is clear from the argument that ends the quoted text. Aristarchus (c. 310-230 BC) had a significant influence on his contemporaries for his revolutionary proposals but, until today, has reached to us only one of his works, and preserved "by joining the anthology astronomical tracts in the work of Pappus of Alexandria "(Coronado, 2006: 4). That is, nowadays, his work is credited as authorship of this crucial, and now proven, scientific assertion, indirectly through to us by Archimedes, and other authors including Plutarch too, who compiled and discussed their daring theories, expanding its influence whenever his work communicating the original purpose to others transcending time and space in which the theory was developed.

The reflections on the nature of the heavenly bodies occupying both Aristarchus and Copernicus or were based on the observation of astronomical phenomena and mere intuition and, later on with Galileo, supported by data validation more or less accurate collected about their behavior depending on the measuring instruments used and illustrations drawn through the telescope. Tycho Brahe, although he had the most technologically advanced resources available at his time, was the last astronomer who observed the heavens with direct vision, without any optical instruments intermediating

http://dx.doi.org/10.4995/muse.2015.2226
EISSN: 2341-2593

it. The wealth of data collected only was useful for it to develop a mixed theory about the movement of the planets around the Sun and the Earth, that would be revised a few years later by his pupil Johannes Kepler, who tested *heliocentrism* and shared it with Galileo, as shown in interesting that maintained communication through written correspondence (Appelbom and Gallows, 2001).

Galileo built his first telescope in 1609, and next year a microscope, developed from pre-design of a prototype describing by Dutch Zacarias Janssen, of which we have evidence of its existence since August 1595, and immediately began to make illustrations about his observations. In 1610 Galileo himself also performed microscopic views of insects, specifically a bee, and also published his famous careful edited and detailed drawings of the Moon and the phases of Venus, *Siderius nuncius*, summarizing his astronomical observations. Tycho Brahe, a few years earlier, worried about building of three-dimensional cosmological models constructed as product of his observations of celestial bodies, as he explained with a function that "was primarily cognitive: to convey to another the main motions of a special scheme would be more than readly done with words or pictures "(Mosley, 2006: 216). In other words, to represent in the best way possible the theoretical model of the solar system in order to facilitate dialogue with other astronomers, as purpose to develop astronomic knowledge in a scientific way that would describe celestial phenomena studied with the participation of scientific community.

In this paper we are concerned precisely, but not with strictly historicist spirit, focusing our attention on epistemological, heuristic and communicative dimension, perspective that analyzes how ontological and relational features of different media for visual representations induce the significant changes in the practices and forms of understand the production and distribution of scientific knowledge over the past centuries, from the artwork to contemporary virtual simulations. Our work, to sum up, addresses the knowledge representation primarily from a visual and communicative perspective,

http://dx.doi.org/10.4995/muse.2015.2226
EISSN: 2341-2593

without being impaired for over a text is necessarily brief we deal, but only tangentially, some other inescapable issues related with philosophical, sociological, psychological, or otherwise approach, realizing that have already been treated extensively and thoroughly, and much better, from other academic disciplines.

In any case, our main thesis is that it has to review the role that visual representations are in the production, processing and distribution of scientific knowledge, and we will deal with it because we understand the Science is up about visuals and creative visual thinking and communication are inherent in their development.

2. Representation and Models in Science.

In a recent work that addresses the current production of knowledge in contemporary laboratory environment from a micro-semiotic approach (Allamel-Raffin, 2011) clearly shows the complexity of the representation and the problems that we have been saying. In this study we analyze the conversational exchanges of people involved in the collection and validation of the images recorded by a transmission electron microscope (TEM) at the Institute of Physics and Chemistry of Materials in Strasbourg, and their initial assumptions and conclusions aren't too far at all classical concerns regarding the representation and the critical arguments about we have outlined in the previous example. As the study shows how the TEM image production in the laboratory concerning lacking external macroscopic, is an added difficulty makes very difficult to distinguish *artifacts* and *epistemic object*, unwanted effects introduced by the technical system contaminate the sample. But work explicit, especially, as the generalization of the meaning of the images obtained is revealed as a problem inherent to science, supporting this thesis in the detailed analysis of conversational interaction between researcher and technical that shows the difficulty of select and determine the adequacy of the obtained image, that acquires epistemic status only after a complex communicative argumentation that sanctions by consensus its validity.

The TEM image, meanwhile, has no visible reference but it presupposes, and becomes even more relevant the communicative exchange and argumentative discourse among scientists to determine suitability. The small planetarium that help Brahe to represent his theories about the heavenly bodies were also cosmological models but, in this case, in three dimensions and sometimes with a certain movement to represent also its behavior in time. In any case, model that makes its referents recognizable in relation, preferentially establishing direct visual analogies or explicitly supported data whose visual representation is sanctioned only as epistemic object in his communicative dimension.

In these simple examples we have the enormous complexity inherent in any representation and interpretation issues, the questions of meaning and development of knowledge and, also, it is clear their eminently dialogical nature and the importance of the communicative dimension. We have no way to compare what we see with what the image shows TEM. To validate these representations we use a strategy of interpretation in which what matters is the relationship between authors and readers, establishing a dialog auto- reflective within the scientific community participant facing a technological system that acquires relevance and importance in itself.

The peculiarities of the statute and the relationship of the author and the reader in these types of communicative exchanges have been well identified in the essential text of Umberto Eco, 1979 *Lector in fabula*, which accounts for the ability to text to mediate between both, autonomous and ideal on in the middle of author and reader expectations, and sums in his famous concept *model reader* from linguists work as Jakobson, Peirce or Saussure in textual semiotics. Not dwell too much on the specifics features of textual semiotics, theoretical approach in our opinion obsolete in many of his proposals, but we are interested, however, and we will take care of it right away carefully, the notion of *model*, a generic concept and used extensively in various areas of science in applications apparently as diverse, among many other examples, as approach to the nature of

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http://dx.doi.org/10.4995/muse.2015.2226
EISSN: 2341-2593

knowledge and scientific creation, study the characteristics of human cognition, analyze sociological or cultural or other areas or, simply design and develop technological tools.

Before that review these scenarios, we should briefly emphasize the relevance of communicative dimension in contemporary samples for scientific knowledge production apparently misleading may reflect production strategy based on naive consensus, as to presume that the own *evidence of represented the facts* in its forcefulness imposed itself among researchers over any other consideration of psychological, moral, cultural or socio-political-economic. But nothing is further that this idea from reality, the examples clearly reveal the power relations inherent in any communicative interaction, and in all of them, are, among other tracks, arguments of explicit authority used by persuasion, or dissuasion, imposing as valid discourse intersecting with consensus. Complex relationships across communicative interaction have been well studied extensively from various fields, especially from *Culture Critical Theories* of the Frankfurt School philosophers like Marcuse, Adorno, Horkheimer, Wittgenstein, Foucault, Derrida or Habermas, or by authors with more recent works like Mattelard, Ramonet or Chomsky, among many others. Discursive techniques whose analysis is being a constant in the History of Philosophy from Plato's Gorgias or Aristotelian poetics or *De Institutione Oratoria* of Quintilian, a tradition of studies also addressed recently, with public communication or educational approach, among others, by Knight (2006), Vickery (2000), Mazzolini (1993) or Balex and Carre (1985).

As common practice in scientific activity in contemporary laboratories, temple of mediation and collective technical consensus among scientists for the production of knowledge in our time, have been critically addressed on numerous occasions over the past decades, including by Latour and Woolgar (1979), Knorr-Cetina (1981), Lynch and Woolgar (1990) and Latour (1990). We shall not dwell more on all on the detail the cultural, sociological or educational approaches of visual representations of knowledge

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and their derivations in this brief paper, but to advance the thesis statement with we heading this head we are going to discuss in some detail what we mean when we talk about *models* and their role in the representation of scientific knowledge.

The three-dimensional representations were produced hundreds of years ago, as in the example of Tycho Brahe, with rudimentary materials available at the time, and progressively was made on technical and new media began to avoid more versatile and manageable use, growing as an entire industry to boost its production to extensive and strong demand for cosmological models by astronomers (De Chadarerian and Hopwood, 2004) of wax reproductions of the human body by naturalists (Chen, 1999), or prototypes for use in mechanical engineering (Linson, 2003). The models, in this sense, became the expression and / or demonstration of previous theories but also may were used as precursors to the development of new theories. It is clear, that models and theories are interrelated, although it is difficult to establish this relation, how as pointed Frigg & Hartmann (2012):

> “One of the most perplexing questions in connection with models is how they relate to theories. The separation between models and theory is a very hazy one and in the jargon of many scientists it is often difficult, if not impossible, to draw a line”.

Other authors adopt a stronger cognitive perspective to determine its nature, as Wartofsky (1979) who does not hesitate to assimilate modeling to own inherent characteristics of cognition: “all models are one or another form of linguistic utterance, used to communicate and Intended factually true description ... we begin modeling, therefore, with our first mimetic acts, and with our first use of language.” And conclude “we continue modeling by way of what, on various grounds, have been distinguished as analogies, models, metaphors, hypotheses, and theories “, following the track of Phylysin work, Pinker, Kosslyn (Block, 1981) or Shepard & Cooper (1982), was summarized well in this collection assertion in Gardner’s seminal work on cognitive psychology and

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EISSN: 2341-2593

visuality by Kosslyn (1987: 354): “the information stored (in memory) as correspondence with the thing and not arbitrary represented “.

Nevertheless, and independent to the approaching perspective and the insurmountable obstacle to differentiate the models of the theories themselves, we should highlight the representational capacity of the models for the production of knowledge and their cognitive and communicative nature. Especially interesting is its heuristic potential, and we take care of it a little after, as has rightly been pointed Jordanova (2004: 443), for those models (in reference to material and dimensional) “have long been an important issue in the history of science, medicine, and technology, thanks to the concern of Particularly philosophers and sociologist with models as heuristic devices for scientific thinking”. In a similar vein, Morgan and Morrison (1999: 10) have characterized mainly models as “autonomous agents” and “instruments of investigation”, and Winsberg (2010: 8) follows this path to address contemporary cutting edge virtual simulations, but pointing the unique in that they are often made because the data systems that intend to study are limited, so apply with the aim of replacing experiments and observations as data sources themselves to provide potential models about the world.

There is also a second meaning of the term that is specifically focused on the referent and is most common in artistic activity and we found everywhere in our media culture, but also explicit characterizes our TEM image of the sample. We refer to the common form of so-called *models*, subjects or objects, to represent artistically and free of all *artifacts*, all imperfections that pollutes it, connecting deeply with the Platonic proposal archaic operating on the binomial *model / copy* and based on the concept of *ideal*. This intentional idealization of representation of referent itself underlies what has come to be known in the classical tradition as Canon, examples of which can be found easily in many contemporary cultural manifestations, but in what we want, too on how to address the scientific representation, contemporary creations with both cutting-edge science instrumentation as illustrated in the monumental works of the fifteenth century.

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As pointed timely Kusukawa (2006: 85), the production of illustrations in the works of Fuchs and Vesalius was related to the recovery project works of Dioscorides and Galen and based on classical sources. These monumental works, also *Historia Animalium Gessner* (Kusukawa, 2010), were mostly illustrations with pedagogical purposes and maintained close relations with the written text, but the most important is their intention to be *models* for the rest of visuals knowledge that circulated at the time, appealing to the classics and his encyclopedic completeness of their publications, as Vesalius, for example, who explicitly adopted idea of Canon from sculptor Polycleitus (450-420bc). The works of these authors were not save to criticism from his contemporaries, who expressed great reservations respect to the scientific validity of their artwork as faithful reproductions of Nature, arguing strongly that “one can from live plants often recognize their pictures , but from plants pictured, one could never gain knowledge of new live plants”, or “eschewed the notion pointed canonical body of an altogether, and chose to depict individual, particular organs, With Their subtle individual differences in size, shape, and configuration”(Kusukawa, 2006: 92).

There is an extensive philosophical tradition about the nature of the model since at least Plato reaches contemporary textual semiotics as we have shown, is acceptable, at least in our opinion and non-deepen the complexity inherent in the term this brief example allows us to approach the concept from two perspectives. The expressed and instrumental character and we have been discussing and collects well Griesemer Keller, who distinguishes between models *for* and models *of*: “characterises as models *for* various kinds of tools scientific activities, intervention or materials Such a concept and theory development, in addition to their role in representing objects (or phenomena) already in existence, models *of* things” (Griesemer, 2004: 435). But above all, it should be stressed that these were *idealized representations with communicative purpose*, which *epistemic* and *heuristic* nature, as we’ll see below, does not depend on support. That is, *both the illustrations on paper or haptic three-dimensional models are only representations, and representations are always models*.

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3. The contemporary *epistemic representation*.

When the director of the Paris Observatory, François Jean Dominique Arago, publicly presented Daguerre's invention on 1839, August 19, to the members of the Académie des Sciences and the École des Beaux Arts, vehemently justifying his interest for four reasons: the originality of the invention, its relationship to the arts, and it obvious practical uses, and above all, it great advantage to science. Photographic techniques quickly joined the scientific work and, although there were a few short years of scientific illustrations coexisted with photographic reproductions, very soon those were considered little more than an oddity and were quickly were replaced by mechanical procedures inherent in the new technology.

Its inventors, Niepce and Daguerre, had expressed the same effect in the new image registration procedure that had been developed, and wanted to represent "real" nature, with a desire for progressive perfection of technique to achieve excellent levels of quality. With identical premises Henry Fox Talbot, recognized worldwide as an expert botanist and mathematician with also extensive knowledge of optics and chemistry in addition to being a poet and politician, worked, around 1839, to develop procedures for image registration that lead to edit the first book illustrated with photographs of history *The Pencil of Nature*, in 1844. Talbot's purpose was to continue and complete with new techniques his invention in order to reproduce images of the taxonomic work that had opened the natural philosopher Swedish Carl von Linne in the late eighteenth century, following the trail of the monumental works already mentioned that began to develop and distribute from sixteenth century. Talbot was claiming, in short, with an encyclopedic collection of Nature developing an image reproduction system that mimicked the botanical specimens with the utmost *truth* and *fidelity*, as years later similarly continue manifesting Ramón y Cajal about "the perfection that images had reached at the time making it possible, finally, with the new advances for color photography" (Ramon y Cajal, 1912).

The first astronomical photographs were made by Daguerre himself commissioned by Arago, but with limited success, which did not prevent the illustrious geographer and naturalist Alexander von Humboldt who received excited and slightly crisp imperfect image registered in the daguerreotype he could contemplate January of that year. Humboldt started to publish a few years later, in 1845, his *Cosmos*, including photographic images, and after the public presentation the new technique was soon adopted by scientists from different specialties, among the first Ettinghausen, who attended the conference of Arago and, on returning to his laboratory, performed the first photo of a cell under the microscope, early understanding that photography could even replace the specimen for research (Thomas, 2008). The evidence, the *occulata certidune* or virtual witnessing, began to perform the final assault for the independence or representation from its referent, playing a fundamental role in the creation of epistemic objects themselves. An evidence overlapped to epistemic representation that was located between nature and technology with its own identity and autonomy. An epistemic representation that in the case of living organisms German philosopher Nicole C. Karafyllis has recently called *biofact* (Karafyllis, 2003), that became itself the referent and replace it.

At those first scientists- photographers soon joined researchers from various areas such as Roger Fenton, who in 1850 published *Human Primate Skeleton*; Anna Atkins, who began to build botanical taxonomies recorded on photographic paper collections of algae and ferns from 1843. A few years later, Dr. Jules Luys was forced to resort to photography to save his reputation with the criticisms of an illustrated publication on the central nervous system of the human being, who had had to reissue in 1873 with the title of *Iconographie Photographique des Centres Nerveaux* including impeccable seventy photographic images and sixty-five lithographs that eliminate any subjectivity in presenting their

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EISSN: 2341-2593

research results. The photographic representation showed their supremacy of the illustration, and even Darwin himself included photographs and engravings in the *Expression of the Emotions in Man and Animals*, published in 1872. And showed also very useful for subsequent technological developments, such as those made by the physiologist *chrono-photographer* Jules Marey, cinema immediate antecedent, or those published in 1884 by Ottomar Anschütz representing a sequence of storks taking off, flying and landing, that were fundamental to develop modern aviation. The use of photography also expanded in other areas, such as medicine providing medical breakthroughs, such as those conducted by Robert Koch in bacteriology or, a few years later, Ramon y Cajal in neurophysiology, which definitely strengthened the validity of the evidence microscopic photography.

The consolidation of photographic representations as evidentiary proof was, of course, far-reaching and won a double operation. On the one hand, definitely delegitimized any image or illustration that showed the slightest sign of *artistry* and, on the second hand, demanded autonomy from its referent while loyalty was such that it could perfectly replace as many dreamed, serve as an example the physiologist Marey "who dreamed of a wordless science", in words collected by Daston and Galison (1992:81):

> "There is no doubt graphical that expression will replace all others are whenever one has at hand a movement or change of state - in a word, any phenomenon. Born before science, language Inappropriate often measures to express exact or definite relations".

With the photographic pictures the assignation of authority status at representation to serve the uses of neo-positivist science as epistemic and communicative tool was over. It had erased any suspicious about the validity of the proxy and had blurred its relationship with the theories and the context in which it was generated. This neo-positivism would only widened and deepened over the decades, remaining unchanged throughout most of the twentieth century, characterized by the development of X-rays, diffractive optics and

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the radiosonde, and years later the electronic and nuclear technologies nuclear. But, above all, was expanded inside popular culture due to the development of new mass-media, popularizing as new technical images out the borders of scientific community, strongly reinforcing its status and authority.

The photographic representation, also, as we pointed out in relation to illustration or haptic models, kept intact in its heuristic ability for the elaboration of scientific knowledge, in addition enhanced greatly by the strong evidentiary value attributed. Furthermore, in the context in which it was first developed as cultural industry, photographic representation contributed significantly to the popularization of science. That is, further deepening and extending the communicative dimension of epistemic representations, spreading its scope abroad the bounds of scientific community to society, encouraging public expand neo-positivist concept has been called *see and believe* (Hüppauf & Weingart, 2008: 11). It became more than ever a epic narrative mythologizes scientific activity as the Big History of Science, which began to populate the discourse of mass media. You can find numerous example, from the popularization of DNA photography registered by Rosalind Franklin with which Watson & Crick developed his famous discovery, collected in recent work on the popularization of scientific images (Nikolow & Bluma, 2008); or, more specific surveys about the relationship of science to cinema and its influence (Kirby, 2011). Or simply having a look at work of some famous Nobel Prizes as Ramon y Cajal or Cecil F. Powell, whose research were impossible to carry out without the use of visual representation techniques, both photographic, without doubt a essential support to develop and disseminate scientific knowledge along the twentieth century.

But very soon, as we said, the new techniques of image production and critical theories of communication carry to new approaches from the philosophy and history of science, especially since mid-fifties of past century to revise complex relationship of the image with the *reality* and its implications on scientific models and theories, in brief, their

http://dx.doi.org/10.4995/muse.2015.2226
EISSN: 2341-2593

interdependence with the production of knowledge, and its former status started to redefine. Began to reconsider the nature of representation of new imaging technologies explicitly elaborated views that had no analogy whatsoever with their referents, because were created from vast amounts of data, and these were not visible directly, only interposing instrumentation and technique. That new tools showed very clear the role of intermediation in the representations early, as we can see easily realize today having a fast look over multiple display systems based on different types of sensors and capture techniques that build digital representation with multiple applications (MET, PET, Satellite, etc.). These new representations were becoming a simply translation of theoretical models about inaccessible directly referent to a graphic language for easy understanding and with and heuristic purposes, again leaving bare the nature of the representation as a model that had been diluted in photographic technology neo-positivism we commented, starting to be banish entirely by the serious challenge for the whole of science caused the already mentioned work of Thomas S. Kuhn.

In our contemporary digital, our classical illustrations or images are rapidly being replaced by the term visualization in a multimedia universe of *mapped* representations (Tufte, 2006: 13) that are moving toward virtual simulation, and whose *artistry* has been highlighted (Manovich, 2002; Luminet, 2009), and resemble the illustrations of sixteenth century we have been mention along the text. The heuristic nature of representation is now shown us explicitly its model features, in the words of Humphreys (2004) collected in Frigg & Hartmann (2012) and referred to the virtual simulations:

“When standard methods fail, computer simulations are often the only way to learn a dynamical model something about; they help us to ‘extend ourselves’, as it were. In situations in which the underlying model is well confirmed and understood, computer experiments may even replace actual experiments, which has advantages and economic, minimizes risk (as, for example, in the case of the simulation of atomic explosions).”

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Thus, to address new virtual simulations we need, as Frigg & Reiss (2008) assert, a new approach from a) *metaphysics*, as “simulations create some kind of parallel world in which can be conducted experiments under conditions more favorably than in the ‘real world’“, a new analysis from b) *semantics* ”of how models / theories relate to concrete phenomena“, and from the c) *methodology* because it is an activity ”that lies ‘in between’ theorizing and experimentation“, and, finally, from d) *epistemology*. On these four requirements Humphreys (2009: 625) adds, in a critical article about, a “fifth aspect of simulations is that in the mathematically oriented sciences, progress is now inescapably linked to technological progress”, holding a controversial debate:

> “I have never subscribed to myself that metaphysical position. I have argued in this article that their second and third claims are incorrect. Computational science requires a new non-anthropocentric epistemology and a new account of how theories and models are applied. These requirements are, to me, more than Sufficient to justify the claim that significantly computational science is a new sui generis activity accompanied by new, recognizably philosophical, issues. These methods claims that lie ‘in between’ theorizing and experimentation are, I believe, best interpreted metaphorically“.

The controversy is served and the debate is open, and undoubtedly present in the near future than difficult to resolve, even more so when we are entering what is being referred to the era of simulation / gaming and video game culture, in which new screens begin to try from the perspective of the *interfaces* (Quaggiotto, 2012), but that’s another story certainly interesting to analyze in the near future but that exceeds the limits of this short paper.

4. Discussion.

In this work, no matter what we bring the following years and as a very modest contribution to broad and open-ended debate about it, we have analyzed the scientific

http://dx.doi.org/10.4995/muse.2015.2226
EISSN: 2341-2593

representations as epistemic and heuristic tools, especially focusing our attention on its communicative dimension as its scientific pretensions to become, in his demonstrative role, in *independent witness* to validate scientific research as a *model* of previous theories about *real*, all of them inherent features, in our opinion, to any scientific representation, regardless its manifestation in two or three dimensions and its materiality.

In short, we can state that in our present is appropriate to understand the production, processing and distribution of scientific knowledge from their *eminently visual and ideal* character and we have to address the analysis of illustrations, haptic models, images and virtual simulations as *epistemic, heuristic and communicative representations*:

- *Epistemic representations*, as a result of its own mainly purpose: to pack in their materiality some scientific knwoledge.
- *Heuristics representations*, in so far as their use provide tools to promote from itself further inventions and to create new knowledge from;
- *Communicative representations*, finally, as eminently communicative artifacts that serves to scientific community for interchange knowledge.

In order to present our findings with balance, we have to mention some limitations of this research. Could be interesting for future research, and necessary, to deal with the basis of historical and contemporary ideas about *representation* concept, but this approach could leads us too far from our main argumentation and in this paper we opt to admit simply that images and models are representations of “something”, as commonly is being used in literature of scientific communities. We are aware about it but despite this limitation we think this work will be valuable to start new interesting approaches and encourage new researchers to develop further investigations to the fundamental role that scientific images plays nowadays.

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