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IN SEARCH OF A REALITY: MODELS AND MODELISATION IN SCIENCE TEACHING ACCORDING TO THE EPISTEMOLOGY OF MARIO BUNGE.

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Abstract

In this work we present some critics of the constructivist movement who over-valued the action of the subject in detriment to the intrinsic value of scientific knowledge. For us, this is a epistemological consequence, related to the way Thomas Kuhn's ideas were incorporated into Science Education. We present the ideas of Mario Bunge on the role of models in science trying to obtain harmony between the individuals constructions and the empirical domain.

INTRODUCTION

The constructivist approach was the movement with larger impact in science education during the 80's and 90's. Its criticisms to the naive empiricism, that permeated proposals for science teaching, generated positive transformations in the direction of educational research. In the context of reformulation, the increased value attached to the individual's role in the apprehension of new knowledge and the awareness of the importance of the students' preconceptions stand out. These results were important in the definition of curricula and in the choice of methodological strategies. In spite of this, in the last decade, a number of critical papers pointed to interesting questions related to implications and consequences of the constructivist movement.

In 1989, Millar had already questioned if the awareness (late in his point of view), that all learning is fruit of a constructive activity of the individual, should necessarily imply in constructivist teaching. Other studies tried to reflect on the directions of the investigation inside the constructivist movement.[1]

Recently, in that context, three papers emphased the criticism against the epistemological foundation that grounds the constructivist discourse. The aim of the criticism was not the constructivist movement as a whole, but the tendency to generalize and radicalize the metaphor of *making* associated to the action of the subject, in detriment of other metaphors like *discovering* and *founding* that are more associated to the object of the knowledge (Ogborn, 1995). This extreme position is clearly expressed in self-denominated *radical constructivist,* proposed by Glasersfeld (1989). "Radical constructivism became well-known, mainly through the criticism directed to the rest of constructivism, named by the author as trivial constructivism – that had as a principle the fact that knowledge cannot be received passively, but is actively built by the knowing subject" (Santos,1996, p. 26). In the words of Glasersfeld:

Radical constructivism, thus, is radical because it breaks with convention and develops the theory of knowledge in which knowledge donates and does not reflect in the "objective" ontological reality, but exclusively in the ordering and organization of the world constituted by our experience. The radical constructivist has relinquished "metaphysical realism" once and for all. (Glasersfeld 1987, p. 199, apud Matthews, 1992).

In that conception, the function of thought is not the search for the ontological reality of the experiential world, but exclusively its organisation, starting from a process of continuing adaptation. The epistemological aspects of analysis are based on the impossibility of an accessible external physical world, be it directly or indirectly. Its focus of attention is on the individual's internal subjective world and on its construction processes. Matthews synthesizes the epistemological and ontological theses of Glasersfeld in the following way:

1. " Knowledge is not about an observer-independent world;
2. Knowledge donates not represent such the world; correspondence theories of knowledge are mistaken;
3. Knowledge is created by individuals in historical and cultural context;
4. Knowledge refers to individual experience rather than to the world;
5. Knowledge is constituted by individual conceptual structures;
6. Conceptual structures constitute Knowledge when individuals regard them the viable in relationship to their experience; constructivism is the form of pragmatism;"

(Matthews, 1994, ca 7, p. 149)

Sucthing (1992) pointed out several problems in Glasersfeld's arguments. There is confusion among "immutability, certainty and objectivity ", there is not a clear definition of the concept of "construction" and the use of the term " experience " is associated to the most radical and orthodox version of empiricism. He also called attention to the negligence of social aspects in the analysis undertaken about the production of knowledge.

The option for learning centered on the individual is not exclusive of radical constructivism. In a less emphatic way, other authors present similar ideas. Matthews

(1994, cp. 7) produced an extensive analysis of papers indicating that most, overvalue the individual's role in the construction of knowledge in detriment of elements belonging to the physical world. The individual's action and the ways engendered by him to give a sense to his/her sensitive experience determine a very private knowledge about the world. This generates a sensation that an obstacle, impossible to overcome, exists in the attempts to understand the world, and that we would be condemned to a subjectivity dictated by our own thinking self.

This type of orientation attributes a relativist profile to knowledge, excluding forms of constraint to the produced knowledge dictated by the external world. The relativism that follows has as a main result the decrease in the content of truth associated to scientific knowledge and its weakening in relation to other forms of knowledge. (Matthews, 1994, cap. 7)

The apparent aversion of most constructivists to everything that can be linked with the empiric domain is partly related to the epistemological model under attack. The criticism to the naive empiricism materialized, particularly, in the Aristotelian conception of knowledge, would be fully justified if there were not epistemological alternatives (Mathhews, 1994, cap. 6 and 7). In this view, "*doing* was excluded, because Aristotle saw the interference in the nature (i.e. experimentation) as a disturbance of the natural course of events and capable of clouding the vision of things as they are in themselves" (Ogborn, 1995, p. 124). The passiveness of the observer's metaphor in relation to the events, is the target for critical construtivists. Nevertheless, nowadays few epistemologists would seriously declare their option for the Aristotelian conception. Today, even the more empiricist philosopher would agree that no valid knowledge would be produced without a great individual investment. To have certainty of that, we only have to remember the metaphor of nature being submitted to *torture* in the anguish of making it reveal its secrets employed by Bacon, in his more famous writings. "Reality doesn't surrender easily ", a realist philosopher would say!

KUHN AND SOCIOLOGICAL TRADITION IN SCIENCE EDUCATION

Besides the criticisms to the constructivist conception presented above, it is important to make some comments on the epistemological debate in the middle of the century and on ideas that emerged from there and that influenced research in science education.

The growth of the opposition to logical positivism headed by Kuhn at the end of the 50's dispersed the hegemony of traditional scientific thought, centered on the basic concept of a "universal scientific method". The criteria there obtained, divided knowledge into true and doubtful, or better, in scientific and non-scientific which were, in a short time, abandoned, opening space for a true spring of *new sciences*, all of them claiming a place under the sun of a new era.

During the last decades, domains of human sciences such as history, anthropology, sociology, psychology, psychoanalysis, etc, started to claim a status granted before only to the, so called, experimental sciences, like Physics, Chemistry and Biology. When incorporating in their discourses the criteria admitted in the demarcation between science and non-science, they also incorporated part of the concepts emerging from the Kuhnian thought. It is interesting to notice, however, that the reception of Kuhn was differentiated. The sociological aspects of his analysis were more emphasized, particularly the thesis of the *incomensurability* and the concepts of *paradigm* and *Scientific Revolution* (Abrantes, 1998, p. 61). Abrantes attributes the reading of Kuhn to "...an irresistible seduction for those involved with the tradition of the sociology of knowledge and also for the ones that sought parallels between the practice of the natural and the social sciences".(Abrantes, 1998, p 62) Aspects of the Kuhnian work allowed, through its sociological theses and mainly by the use of the notion of paradigm, to legitimate practices less close of the scientific patterns of them and to elaborate comparative studies between knowledge in the, so called, natural sciences and other domains.

The research area of science education was not immune to the seduction of the Kuhnian ideas. The alternative conceptions movement (Gilbert and Swift, 1985, Duit, 1993) revealed in the students, the existence of pre-conceptions about the physical world which served as a counterpoint to scientific knowledge. The internal coherence and the resistance to change served as an application field to a paradigmatic theses, present in Kuhnian thought. The most popular theory of teaching in the constructivist context, the *Conceptual Change*, (Posner et al, 1992) possesses an epistemological and psicho cognitive structure similar to the *paradigmatic changes* foreseen by Kuhn among mature sciences.

The "new" philosophy of science, started by Kuhn and others was incorporated into educational discourse. The ideas on the internal organization of research communities, their maintenance mechanisms and change of concepts, laws and metaphysical assumptions were thoroughly used by the constructivists to deal with the students' alternative conceptions. At the same time that it dealt with the conceptual richness revealed by the alternative conceptions, it offered a consistent alternative to the empiricist model. Notions and internal analyses of the epistemological debate were quickly incorporated to the specific context of research into science teaching, as can be attested by the systematic and consistent use of terms such as " paradigm ", “hard core”, "epistemological profile", " epistemological obstacle", etc.

Taking as a base the Kuhnian thought, many investigations were concerned with analyzing the curricular structuring and the teachers' conceptions about knowledge production, etc. The conclusions indicated the existence of beliefs in a reality independent of any preliminary theoretical construction, legitimazing, in a certain way, the Aristotelian ideals of neutrality for the elaboration of sound knowledge.

The sociological theses of the Kuhnian thought gave origin to the so called *social epistemology* that denies the independence from reality of socially built patterns.[2] The title of the article by Bruno Latour "Give me the laboratory and I will raise the World ", expresses with clarity the ideal of the studies of the so called Strong Program, that takes the sociological theses of Kuhn to an extreme, denying the existence of a Trans-social reality.[3] Also here, the absence of references that are external to the group of practitioners generates a relative knowledge supporting the radical theses of Glasersfeld. In the extreme, the social epistemology also implies in legitimazing the knowledge of adolescent students that, in agreement with research, seem to present alternative conceptions very similar, figuring as alternative communities to those constituted by scientists.

TEACHING AND EXTERNAL REALITY

Turning scientific knowledge relative, as well as breaking with the belief in an external reality can generate a negative expectation. It is not worth studying science arduously for so many years if it does not relate to the external world. If reality does not exist and everything we know about it is fruit of conventional patterns, why should one substitute the personal conceptions about the world? Statements of that nature could have been uttered with reason by students of scientific subjects, sufficiently exposed to constructivist theses. It would remain to scientific knowledge to be limited to the school context and/or to its utilitarian aspect, as an aid to the formation of professionals of technical areas. Science would tend to be relegated when confronted with seemingly more attractive cultural options like the occult, religion, astrology, or more practical ones like computation, economy, and others

In the past, the sciences were learned because there was the belief that, through them, the secrets of nature would be reached. This aim probably motivated great wise intelectuals, like Aristotle, Galileu, Newton, Maxwell, Einstein, Planck and others, independent of each ones line of thought. A clear aim for scientific education can be infered from this statement: the one of enlarging our knowledge of nature generating adequate images of reality. This aim would be associated to the apprehension of scientific knowledge independently from the pragmatic and utilitarian aspects.

In the classroom, still far away from the constructivist theses, scientific subjects are treated by teachers in a excessively internalist conception. The *didactic contract* (Brousseau 1982) established in the school context had always privileged the mechanical activities of resolution of standard exercises. Particularly in Physics and in Mathematics, the activities are generated without the concern that the taught contents be related with real, or supposedly real situations.

Unconstrained by phenomena and, consequently, also by reality, science teaching gradually lost its vitality being transformed in an activity essentially restricted to the classroom and the textbooks. The complexity of reality was considered by school science courses as a pedagogical obstacle and gradually abandoned. The purely theoretical activities took their place for being consensual and having restricted problematic dimension: they generate an abundance of exercises starting from some examples where solutions are not the focus for discussions and controversies in the classroom. This contributed in deepening the ditch between science and reality.

These factors generated a school science more and more distant from the reality experienced by the students. Science started to participate only a little in the explanations required by the individuals in their everyday life, until it became knowledge restricted to the school context. Research in alternative conceptions has been confirming such a statement, indicating that the students are not very inclined to conceptual changes: they maintain their conceptions in spite of all scientific teaching received (Santos, 1996).

Very little has been done to make the students notice that the scientific knowledge taught in the school serves as a form of interpretation of the world that surrounds them. The students do not see the scientific theories as capable of generating ingenious explanations on well-known phenomena. The color of the sky, the thermal sensations of an object, the electric discharges, etc, are themes not treated in the school and end up receiving personalized explanations, influenced by faiths, myths, and all types of non-scientific information. On its own, the scientific knowledge learned by the students seems unable to operate in these situations and in many cases lead them to conclusions contrary to those observed. In these conditions it is very difficult for a student to abandon his/her alternative conceptions. Therefore, it is not strange that science is just restricted to the school situation.

Fourez (1994), when advancing the *Scientific and Technical Literacy*, proposes the definition of a context where scientific knowledge can generate some autonomy, implying that the apprentice has a capacity to negotiate his/her decisions, in order to communicate, to control and to take the responsibility to face real and concrete situations. To be scientifically literate would be, then, to acquire competence in the treatment of the immediate reality, defined by everyday life.

In that sense, it seems urgent to re-insert reality as an object of science education. Not in the way determined by naive empiricism, but emphasising the knowledge built by science as *sketches* of reality. For that, the enlargement of *social constructivism* attributing to it a **realist** ontological dimension is necessary.

The reality would then constitute an *objective-obstacle*.[4] To attempt to unmask the nuances of the real world by means of increasingly sophisticated scientific theories would be a strong rationale for science teaching. The interpretation of everyday life would benefit by the learning of scientific knowledge, justifying the substitution of personal conceptions. In it, the apprehension of reality would become the final aim of science education, which is to be pursued through the construction of models.[5]

In that sense, we offer, in what follows, an epistemological alternative to relativist constructivism. Based on the use of models and in its link with an external and complex reality, we advance the idea that science teaching can abandon radical and subjective constructivism, without going back to the empiricists theses. Without giving back to science the status of an absolute and unquestionable truth, it is possible to define its exact value as a historically validated activity of interpreting the world and, as such, a legitimate way of building “true” images of reality.

MARIO BUNGE ON MODELS AND MODELISATION

Contrary to Thomas Kuhn's option, Mario Bunge's philosophical conception belongs to the tradition of analysis centred on the internal structure of the products of scientific research. Theories particularly constitute, for him, the central axis of the sciences and he dedicates attention to them.

His trust in science and its methods in the search for truth and for the solution of the problems of humankind led him to be labelled "positivist" by some modern intellectuals. That is somewhat unjust if one takes into account that he rejects Empiricism and its modern streams.[6] Mario Bunge himself admits to being called a positivist if that means being "scientificist ".[7]

Leaving aside issues related to labels or classifications, Mario Bunge is a *realistic* philosopher, standing back from empiricism for his ontological presuppositions relative to scientific research, in particular about the existence of a world external to the known being and the several reality levels associated to it, to his faith in the existence of internal laws of this world and in its limited cognoscibility.[8] When it comes to ontological presuppositions, Bunge goes further to state that it is not just a case of postulates which placed *a priori* in the scientist's work, but that science itself is “permeated by ontological ideas, sometimes heuristic, other times ontological ".[9]

The discussion on models in his book begins with the analysis of their function in the constitution of the *theoretical knowledge* of the sciences. For him, the capacity of producing theoretical knowledge is a characteristic of science developed by modern societies, since in the pre-industrial societies faith, opinion and pre-theoretical knowledge were enough.[10] For Bunge, the theoretical character of knowledge becomes a measure of scientific progress, more than the volume of accumulated empirical data. This would happen exactly due to the theoretical progress of a certain area of science in *apprehending* reality.

In this context, he starts to turn the role of theories and their relation with reality into something more precise. Bunge states that "every **specific theory** [11] is actually a mathematical **model** of a piece of **reality** ". TR page 10 This statement presents the main elements of the epistemological debate that he intends to develop, that is to say *Theory*, *Model*, and *Reality*.

Models are placed as intermediaries between the two limiting instances of scientific action, the theories and the reality, through the mediation of the interpretations of the empirical data. Throughout his work it will become clear that theories, although of fundamental importance, are worth nothing by themselves in the scientific context, because abstractions produced by our reason and intuition would not apply *a priori* to real things. On the other hand, empirical data, in spite of being closer to reality, cannot be inserted into logical systems and generate knowledge. From this apparent dichotomy between the *theoretical and empirical*, modelling is introduced as a mediating level.

In effect, Bunge defines three fundamental elements in the theorising process:

1 – *Generic theory* - that applies, potentially, to any part of reality, but by itself, for the fact of being general, is impotent for solving problems.

2 – *Model-object* - that are conceptual images (and therefore abstract) of the elements belonging to a real system that one intends to interpret through a general theory.

3 – Theoretical model (or Specific theory) - " ...is a hypothetical-deductive system that concerns an object-model " (Bunge, 1974, p 16) and "..., is obtained by attaching subsidiary suppositions to a generic structure... covering a specimen instead of an extensive kind of physical system"(Bunge 1973, p 53).

The model-objects are formulated through the common properties, or admitted as common, of a certain group of real objects in focus. In spite of a high degree of reality, they don't allow any operation that goes beyond the establishment of similarities. On the opposite end we have the generic theories that, although highly operative (in function of their mathematical structuring) do not refer to anything belonging to the real world, although they may come to refer to it by addition of further suppositions.

According to Bunge this theoretical process aims at the interpretation of part of reality. This reality is always complex and its elements are particular. The approximation then, should be obtained initially through simplifications (idealisations), where classes of equivalent individuals are elaborated. For the elements belonging to those classes, properties and characteristics are attributed, that can then be treated by the theories.

The power of the theorising is exactly the capacity of the general theories to produce representations of reality, when grafted by those conceptual objects.

In the table that follows, Bunge(1974, p. 13) presents a list of situations modelled by science:

SYSTEM	MODEL OBJECT	THEORETICAL MODEL	GENERIC THEORY
Moon	Spherical solid rotating about its axis, in rotation, around a fixed point, etc..	Lunar Theory	Classical Mechanics and gravitation theory
Moonlight	Plane polarised electromagnetic wave	Maxwell equations for the void	Classical electromagnetism
Piece of ice	Lineal casual chain of beads	Statistical mechanics of casual chains	Statistical Mechanics
Crystal	Grid plus cloud of electrons	Bloch's Theory	Quantum mechanics

The model-object represents then the real object, and the theoretical model, its behaviour. In this sense, the theoretical model is a hypothetical-deductive system, a machine for generating propositions starting from initial propositions, that is to say that it is possible to make predictions from them. The predictions are possible because, being a network of deductive relationships, the model can extrapolate the situations for which it was initially built and to expose the properties and the behaviour of the model-objects inserted on it.

In the table of examples above, the *plane polarised electromagnetic wave* becomes a possible representation of the *moonlight*, whose behaviour can be obtained through the basic relations contained in the classical electromagnetic theory. From this, to explain the behaviour of such an object (for example, the formation of coloured halos when passing for a fine gas layer during the night) as well as making predictions (as to show that the brightness extinguishes when we make it pass through a polarizer properly placed, or to rotate the polarising plane by the application of a magnetic field) become possible tasks by means of the relations imposed by the electromagnetic theory.

It is senseless to question if a model-object is true or false. In being a more or less arbitrary idealisation (in function of the researcher's decisions), and more or less linked to the interests and possibilities that science has in a certain moment, it ends up by having only a conventional status. That configures with what Bunge defines as *conceptualist and fictionist materialism*, because the conceptual objects (or science constructs) possess a fake or conventional being, and may refer to real objects in the case of factual sciences.

It is not difficult to stick to the proposition that the success obtained by a theoretical model gives it the capacity to *represent* a certain domain of reality. Bunge goes further, attributing to it the capacity to *simulate* the real, when saying that every theoretical model should define internal mechanisms that support the relations existing in it. That position places him in opposition to the instrumentalist view that limits scientific work to obtaining *black-box* type models.[12] In such models the simple elaboration of correlation between the data and the results (inputs-outputs) is sufficient. Models of that type would be acceptable in the initial phases of scientific research, but sooner or later they should be substituted by more detailed ones, that will allow a explanation of such correlation from hypotheses about the internal functioning of the model.

In the context of Snell-Descartes law, for instance, refraction is conceived as part of a black-box model for light. However, when postulating that such law is consequence of the interaction of the electric and magnetic fields inside matter, we start to define the "hidden mechanisms" that allow us to explain that law.

The label "hidden mechanisms" does not deny its realistic meaning. The label just indicates that such mechanisms are not accessible to perception, but inferred theoretically from models. As the belief in every model includes some kind of theoretical guess, the fallibility of models should be constantly considered. For this reason, developing confidence in models presupposes critical appraisal and the possibility of conducting empirical tests. Thus, the hypothetical mechanisms would only receive the status of " things " when they could receive empirical confirmation.

According to Bunge's view, models would work as "doubles" of the reality. Model-objects, along wth their specific properties bounded by models would enable scientists to temporarily renounce reality and all its complexity and to deepen the model-object. It is in that sense then, that models would have ontological value, because they would be considered as - approximately and temporarily - reality.

FINAL CONSIDERATIONS

As a final comment, we would like to say that for Bunge the models are the essence of scientific work. There would be, in the process of the creation of models, the progressive passage of the "real-noticed to the real-idealized". That process begins for the **idealizations** of the treated situations which would result in the object-models, and it finishes with the construction of the theoretical models, which would be the structures to emulate reality through hypothetical-deductive conceptual systems. To arrive to them, the construction of object-models and its incorporation in a general theory is necessary.

But one should not interpret the obtaining of models as an activity merely rational or mechanical. In spite of linking to the empirical aspects of the focused phenomena, given by the observation and results of experiences, the modelisation is a creative activity. For Bunge, there is interference of personal preferences, intellectual passions and the baggage of knowledge previous to the scientist, balanced and organized by *intuition* and *reason*. (Bunge, 1974, p. 22)

According to Bunge, "none of these components of scientific work - observation, intuition and reason - can, by themselves, give us knowledge of reality. They are merely aspects of the typical activity of contemporary research: the construction of theoretical models and their confirmation ".

In another study, Martinand (1986) points out the importance of the reflection on models and the modelling process because these can be an access road by means of which transformations can result in the teaching contents. It considers however that these reflections should be **guided** by the following questions: What does modelling do? What is its contribution? How does this work in scientific thought? What type of specific activities can be proposed in the classroom? In what way can these proposals be carried out? Which suggestions of progressions and learning rhythms could be proposed to organise the teaching? It also marks the necessity of knowing how spontaneously the students **make models** or what they do to appropriate a model. To answer these questions he judges it necessary to conjugate the following aspects: an epistemolgical analysis of the problem, the preparation, the execution and the evaluation of didactic rehearsals in the classroom and the precise observation of students development. Some of these studies are already being executed with available results. [13] The previous presentation about Mario Bunge's conception on models seems sufficiently clear to execute the requirement of epistemological analysis requested by Martinand. The models built by the science for Bunge would be the middlemen between the **generalised ideal theory** and **the specific realist empiricism**. The modelisation activity would be the true motor scientific activity.

By the introduction of the modelisation as objective to science teaching the students will be able to represent the reality. The concerns about the context of scientific knowledge construction should not be left aside, but submitted to the large objective of scientific education which is that of assuring the individual a better relationship with the world in which he/she lives. When physical theories are presented as something capable to supply us a picture of reality, even if they are painted in several different styles, competition is generated (in the positive aspect of the term) between the scientific conceptions and the alternative conceptions. The possibility of comparison and the taking of decisions on which forms to represent the reality will make the most critical and more capable students enjoy the insights that have fascinated scientists throughout the times.

Notes:

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[1] See, for example, Solomon 1994.

[2] For example, the ideas of Bloor, presented in *Knowledge and Social Imagery*, 1991, The University of Chicago Press., 2nd edition.

[3] In Knorr-cetina and M. Mulkay *Science Observed*, 1983, London: Sage

[4] Term introduced by J.L. Martinant (1986) in order “to use the characterisation of the obstacles as a way of selecting the objectives” for science education. (Astolfi, 1989)

[5] For a discussion on *Mental Models*, see Moreira ,1996; for a review of anglo-saxo literature on model and modelisation in science teaching, see Krapas, 1997. For a french definiton of models in science teaching see, Drouin 1988

[6] See comments of Bunge in Cupani, 1991

[7] Apud, Cupani, 1991

[8] Cupani, 1991. Those points refer to *ontological determinism* and *gnoseological determinism.*

[9] Bunge, 1977, apud Cupani, 1991, note 14

[10] Bunge, 1974, p. 9

[11] Boldfaces are added by me, while the italics will represent italics of the original text

[12] The reference to the models of black-box is understood here as the simplest version of a model, of which any internal mechanism is unknow, but just deductive relationships among external variables. Be " a system any, machine or organism, molecule or institution, and let us suppose that somebody wants to describe and to predict its behavior without being in charge in the moment, of its composition it interns nor of the processes, that can happen in its interior. It will be constituted as a model of the black-box " type then. Bunge, 1974, p. 19. Bunge will still proceed to a classification of theoretical models in box-black terms and translucent-box (1974, p. 98)

[13] Gilbert and Boulter (1996).

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