A study on criteria used by students to infer the physical reality of objects: building categories of analysis

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Introduction

Research in Science Education has shown the importance of considering the nature of science as an integral part of scientific understanding (NIAZ, 2009; SCHWARTZ and LEDERMAN, 2008; GIL-PÉREZ *et al*, 2001). Many of these studies disclose students' perception of a science that rarely exceeds a naive empiricism, one that bestows scientists the domain of a safe method to explore nature. This commonly accepted concept places the content of science as revelations about the internal organization of the world.

Furthermore, in teaching material texts and in the words of teachers, the belief in the existence of an "essential reality" not directly perceived by the senses arises. This reality, obscured by the limitations of our perception, is the source of ultimate truths. Then, the role of a scientist is to accomplish this through a safe method, supported by experimentation and logical thinking.

This concept of science reflects an empirical-positivist idealization and has profoundly influenced teaching, forging a distorted view of the nature of scientific activity and the knowledge it produces. This concept contrasts with the important aspects of scientific activity effectively carried out, deserving emphasis in science education. Millar (1989) highlights two of these aspects: characterizing scientific activity as a human activity and the eminently provisional character of scientific ideas.

The statute of objects in the scientific theories and laws is another aspect of the nature of science to be considered. Ideas such as electric fields, energy and photons can only be perceived by means of a creative imagination, guided by the modern theories of science. These require disengaging the immediate senses and increasing theoretical belief. One of the goals of physics education should be to provide the means to conceive and deal with the entities within the theories and models (OGBORN & MARTINS, 1996).

Considering them as mere abstractions, or treating them as day-to-day objects could distort the physical knowledge, hence possible learning problems or difficulty in using such knowledge outside the classroom (PIETROCOLA *et al*, 2001). Thus, part of the physics education requires an ontological attitude shift (FINE, 1986) to conceive objects and criteria that can justify their existence in theories or models.

This paper presents part of a research project that investigates the criteria used by undergraduate physics students to confer reality to such entities in physics theories, because besides the content of theories, we understand that understanding the nature of these theories and the objects that are part of the scientific representation of the world, are also part of the scientific education of future teachers.

Realism

The everyday and science reality are characterized differently in epistemological terms (BERGER and LUCKMANN, 1984). This is an important divisor to address realism as a philosophical problem. The usual day-to-day life we experience is within a stable set of objects and relationships identified as an "immediate reality." People from the same social group tend to perceive it similarly and rarely reflect on this. Its *dynamic stability* (permanence

in mutability) relays it its own existence and autonomy, thereby considering it a “Reality”, unique, unchanging and permanent (BERGER and LUCKMANN, 1984).

In the scientific sphere the relationship with the entities is not the same as with everyday life. Many of the entities that comprise the representation of the world of science are far from the senses. This results in questions whether our assumptions about the world, which use these entities, are able to deal with the structure of the world, if they are the reflections of structures that exist independently of our theories.

On this theory/science objects relationship with the world, the scientific realism upholds that scientific theories truly describe the world, affirming the existence of entities postulated by the theories (LECOURT, 1999). This view is based on the idea of an external world that is independent of our knowledge and experience, which science seeks to attain substantial and correct information of its aspects.

Contrarily, anti-realism upholds that scientific theories are merely useful tools to obtain observable predictions. The meaning of science does not result from attempting to represent a world that exists independently of us, but rather from pragmatic virtues of the theories. These do not necessarily address the world as it is, but if a theory worked properly it could be accepted.

There are many arguments upholding realism and anti-realism, e.g., if what is deemed important emphasizes the predictive success of Science, the realist trend is more suitable, however, if it is to show the possibility of one event explained in different ways, then the anti-realists arguments are better. Both scientific realism and anti-realism propose to assign a meaning to empirical science, understanding it within a philosophical construct that allows to construct its global interpretation and analyze its foundation and purpose (PLASTINO, 1995), but neither are free of problems.

The research

This research addresses the criteria used by undergraduate Physics Education students in assigning levels of reality to objects in different concepts and views of the world. To achieve this objective, we applied a questionnaire[1] to undergraduate students in their final semesters of Physics Education at the University of Sao Paulo, Brazil. The questionnaire was adapted from Pinheiro’s work (2003), who conducted a similar research with high school students. The Likert scale was used to assign levels of reality to the objects, also a justification presented for the chosen level of reality.

Our questionnaire comprised three “classes” of objects/entities: the first (Class 1) consists of objects typically considered “real” in the usual sense, present in everyday life; the second (Class 2) consists of abstract domain entities; the third (Class 3) consists of entities from the scientific area. Table 1 displays the entities used in the questionnaire.

Objects/Entities	**Class**	**Source**
Cotton, air, scent, chair, star, melody, lightning	Class 1	“Everyday”
Friendship, thought, dream	Class 2	“abstracts”
Atom, caloric, gravitational field, electron, magnetic force, mass, relativity of time, spin	Class 3	“scientific”

Table 1 – Objects and/or entities.

This questionnaire was administered to students of the Physics Teaching Methodology II course, at the University of São Paulo, in the 2nd semester of 2003, and

[1] Due to lack of space, the questionnaire is not presented in this work.

answered by 33 students. Generally, the students take this course at the end of their undergraduate course.

Results

The students answered the questionnaire indicating the intensity degree of reality for a particular entity, then justifying their choice. In a previous work (MARINELI and PIETROCOLA, 2009) we presented the number of responses given by the students, for each level of reality in the Likert scale, for the entities in Table 1.

Then, to understand the students' criteria to assign the degrees of realities to the entities, we analyzed the justifications provided, which were grouped into 11 categories. Some of the categories were suggested by Pinheiro's work (2003), while others emerged from our own analysis.

The students' justifications were usually words or short phrases. When there was more than one type of justification in the student's response, it was classified in more than one category.

The categories are listed below.

Category A – C x A (concreteness / materialness / solidity x abstraction / idealization / imagination)

The responses categorized here are fixed on "concreteness", on the materialness or solidity of an entity to justify the high levels of reality or, conversely, on abstraction, the idealization and imagination to justify the lower levels. They are always intersubjective aspects (and not intrinsic to a single individual). Some of the justifications categorized are: "*Concreteness*, "*It is materialness*", "*Abstraction*", "*functional idealization*"[2].

Category B – Description / Characterization

This category comprises answers that make some kind of description of the entity, or somehow characterize it, as a justification for the degree of reality attributed. Examples: "*Image, index of the existence of a solar body*" [for the star], "*It is brain waves that are translated into real images*" [for thought and dream], "*pure abstract speculation*" [for the caloric and gravitational field].

Category C – Understanding

This justification expresses the dependence between the intelligibility of the entity and intensity of the reality attributed to it. Examples: "[...] *it is part of my real-world concept*" [for the air and chair], "*I do not know what is*" [for thought], "*Hard to understand*" [for the relativity of time], "*I do not understand*" [for the spin].

Category D – Existence

Here the statements of simple existence or nonexistence of a specific entity were grouped, without another justification of the degree of reality attributed. Some examples of these responses are: "*Unreal*", "*Does not exist*", "*We know it exists*".

Category E – Model

This classified the phrases that use the term "model" as a justification for the degree of reality attributed or those that make some reference about them. Examples: "*Model*", "*Exists as a model*", "*It is a representative body*" [for the caloric and gravitational field].

[2] The students' sentences were written in Portuguese. The English translation is ours.

Category F – Outside the limits of knowledge

Here the statements about *not possible to know for sure about the entity* were included. Examples: "*We cannot evaluate*" [for the dream], "*It may be a human invention*" [for the electron], "*Not even the Physicists know what it is*" [for the electron].

Category G – Perception

This category comprises justifications based on perception through the senses, possibilities of manipulation, of interaction; perception through devices, measuring, or even perceptions subject to or related to feelings: "*I can see*", "*I can touch*", "*I feel*", "*I see by using adequate devises*" [for the atom], "*I can measure*", "*I never saw it*".

Category H – Perceived effects

These justifications are based on the perception of an effect attributed to the entity, explained through it. Examples: "*It causes observable changes*" [for lightning], "*I cannot regularly handle it but I perceive the related phenomena*" [for the atom and electron], "*Remarkable effects*" [for the gravitational field and spin], "*I can feel its effects*" [for the magnetic force].

Category I – Subjectivity / Interpretation

This category comprises the justifications that explain the perception of an object that is unique or intrinsic to an individual. Some examples of the affirmations are: "*My idea of scent is an interpretation that my brain makes*", "*It exists only for the individual who conceived it*", "*Subjective factor*" [for friendship].

Category J – Explicative support

These responses express that the existence of the entity in question must be real in order to explain something known, that is, it is possible to explain some other phenomenon through it. It only appeared for the science entities. Examples: "*It explains well the structure of matter* [...]" [for the atom and electron], "*I cannot touch it, but serves to explain some things*" [for the spin].

Category K – Transitive

In these justifications, the intensity of reality of the object depends on the referendum of something or someone. It transfers the responsibility for attributing reality to another, including for teaching instances: These are some examples for this type of response "*Studies have confirmed its existence*" [for the star], "*experimentally proven*" [for the relativity of time], "*I study*", "*Einstein said!!!*".

Total justifications in each category

The following table displays the total distribution of the sentences classified in each category.

Category	Class 1 (%)	Class 2 (%)	Class 3 (%)
Category A – C x A	19.0	14.6	12.9
Category B – Description/characterization	9.7	32.3	12.9
Category C – Understanding	3.5	4.2	2.8
Category D – Existence	5.3	12.5	8.0
Category E – Model	0.4	0.0	17.8
Category F – Outside the limits of knowledge	2.2	1.0	2.1
Category G – Perception	54.4	26.0	24.4
Category H – Perceived effects	1.3	0.0	4.5
Category I – Subjectivity / Interpretation	3.1	8.3	0.0

Category J – Explicative Support	0.0	0.0	6.3
Category K – Transitive	0.9	1.0	8.4

Table 2 – percentages of the answers classified in each category, by Class.

From this table we can see that category G "Perception" is the one with the highest number of justifications for the entities of Classes 1 and 3, and the second highest number is for Class 2. That is, the direct perception of something is the factor that contributes most to the inference on the reality of the entities in these classes. For Class 1 (the daily entities) the difference in the number of justifications that relied on perception in relation to others represents a significant difference: half of the justifications used in this category appeals to the senses. This seemed reasonable to us given that Class 1 brings together objects of the everyday world, an area in which the sensory organs are more operational.

For the entities of Class 3, a difference observed in the responses in this class from the others is that now justifications in the E "Model" categories appear, in addition to a significant increase in the justifications that entered the H "Perceived Effects", J "Explanatory support" and K "Transitive" categories. This may be explained by the fact that the entities of science cannot be directly accessed.

For Class 2, there was a greater number of justifications categorized as "Description or characterization." We can hypothetically say that the elements of this class are not as well characterized or defined as the other two classes, hence the reasons why the students define them.

The eleven categories inferred from the data analysis comprise a large number. Thus, in searching for a synthesis, we grouped the categories according to the focus of the justification declared by students. Five categories focused on the object/entity on which it seeks to justify the intensity of reality (Categories A, B, D, E, J); other four categories are directly focused on the subject itself (Categories C, G, H, I); There is still one whose focus is on another subject or something external to the relationship between the subject that responds and the entity (Category K). Category F was separated from the others in this form of grouping.

Adding the justifications in these groupings, we have the following values:

	Class 1 (%)	**Class 2 (%)**	**Class 3 (%)**
Categories focusing on the object (A, B, D, E, J)	34.5	59.4	57.8
Categories focusing on the object itself (C, G, H, I)	62.4	38.5	31.7
Categories focusing on the referendum of something or someone (K)	0.9	1.0	8.4
Outside the limits of knowledge (F)	2.2	1.0	2.1

Table 3 – percentage of responses classified category in each category, by Class.

It is possible to see in the table that while for objects of Class 1 (daily) the focus of the justifications is mainly on the subject that is attributing reality to the object, for Classes 2 and 3 the tendency is for the focus to be directly on the object. For Class 3, as aforementioned, there is also an increase in the responses that attribute to a third party the justification for attributing the degree of reality.

Final considerations

The categories that are listed enable addressing some aspects associated to how students understand the supposed "reality" of the objects they find in different contexts.

Some results were expected, such as the fact that the students used, in a preferential manner, access through the senses or a direct perception for the entities from the common

everyday area. However, there was also a significant number of such justifications for the scientific area. Some ideas of Berger and Luckmann (1984) help us interpret this result. The scientific field is a field delimited of meaning within the everyday reality, which in turn is compulsory and dominant. Thus, no one is separated from the common everyday field, and because of this, one can address entities that are present in the scientific theories and models in the same way the day-to-day objects are addressed. This may constitute an ontological obstacle in the future, preventing from addressing more differentiated scientific objects from those present in everyday life, as for instance the elementary particles that have a dual nature: they are particle and wave at the same time!

The difference between the concentrated focus on the object-type justifications (which appear more often for the entities of science and the abstracts) and the type focused on the subject (predominant for the everyday entities) shows that to a certain extent the university students characterize differently the entities from different conceptual domains.

We consider that the definition of these categories has the potential to lead to further studies on this research topic and to better inform us on the question of the ontological status of the science entities for physics students.

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