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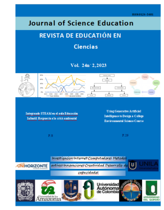

Scientific representations: conceptions and learning implications

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ABSTRACT

Representations in science education have become a prominent theme in recent years. Their implications for learning science are well established. However, the epistemological approach to scientific representations has recently been analyzed, showing that it is relevant to understand how teachers and students struggle with scientific representations. To understand how the philosophical approaches are relevant, a brief description of the semantic and inferential views and their implications for science education. Mainly, the role of the subjects in both approaches is analyzed, showing that teaching and learning processes are better understood from the inferential approach than from the semantic view.

1. Introduction

In all levels of science teaching, the teaching processes imply the use of representations in their diverse forms: verbal, graphical, symbolic, models, objects, simulations, and different combinations of them. Those representations demand by students (and teachers) the interpretation and use of build descriptions and explanations about systems, phenomena, or concepts that representations intend to represent to constitute helpful epistemic artifacts to help students understand and learn scientific knowledge. However, this daily use of representations in school is usually used without any reflection that scientific representations do not have a unique view or conceptions and are not only tools for communication, that those views have implications for understanding the construction of scientific knowledge. Nowadays, the relevance of representations in the research in science education has increased, and several proposals to consider them in teaching processes and the questioning of the epistemological conceptions about representations and their implications for science education are beginning to be considered. This paper will briefly show some implications for science teaching of the two main views of scientific representations, the semantic view and the inferential/pragmatic view, and illustrate how the characteristics of representations from the inferential view contribute to understanding how students face scientific representations.

2. Representation as an epistemic entity

People develop interpretations, explanations, and actions over their environment through representations. The representations are mental entities that, as a set, constitute the world vision of subjects individually and collectively when the representations, abstract or concrete, are socially shared. The representations, abstract or concrete, happen in time, space, and specific context and, of course, can change with the development of subjects and their role in their socio-historic context. When the subject expresses his representations, it become a concrete expression in a sign-material form that makes them collectible, interpretative, utilizable, and transformative entities applicable to subjects, individually and collectively, to understand and construct knowledge.

So, representations are epistemic entities, that is, constructed and constructive entities. This epistemic conceptualization of representations, as Contessa (2007) named it, is shared by philosophers from diverse orientations and temporalities, as shown in the following three fragments:

In The World as Will and Representations, Schopenhauer points out: "The world is my representation: this is a truth valid concerning every living and knowing been,

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although man alone can bring it into a reflective, abstract consciousness.It then becomes clear and certain to him that he does not know a sun and an earth, but only an eye that sees a sun, a hand that feels an earth; that the world around him is there only a representation…" (Shopenhauer, 2010 edition, p. 113; From Spanish Edition)

Max Wartofsky writes:

"This environment is the world made by human praxis – nature transformed into an artifact, now embodying human intentions and needs objectively. Beyond this, perceptual activity is now also shaped to, and helps shape a new and different world, namely that world which is a cognitive construction, and is embodied in our representation, as theories and models in science, and as pictures in art". (Wartofsky, 1979, p. 195).

Ian Hacking said:

"… human beings are representers. Not *homo faber*, I say, but *homo depictor*. People make representations" (Hacking, 1983, p. 132)

The emphasis on the philosophical analysis of representations has been focused mainly on scientific knowledge. Therefore, it is expected that the debates become from the philosophy of science. However, as Suarez (2016) points out, these debates and philosophical positions are relatively recent in the philosophical field, becoming approximately fifty years ago. Representations and one of their primary expressions, the models were analyzed in the twentieth century. The dominant logical positivism attributes the products of science some identifications with reality. Then, it considers representations as descriptions of the reality or part of it, and therefore, with scarce philosophical interest. It was when the semantic vision (Van Frassen, 1980), coming from their structuralist position and with the emphasis of Giere (1998), introduced models or representations as cognitive processes, giving visibility as entities for the epistemological analysis and debate.

However, representations and models and their implications for scientific reasoning have some antecedents in the scientists themselves. In the XIX and beginning of XX centuries, the position and thinking about the role of representations in science had some representatives, such as Henry Hertz (cited in Hacking, 1983) and Ludwig Boltzmann (cited in Suárez, 2016). In half of the twentieth century, philosophers such as Carnap (1995) and Harré (1960) analyzed the analytical function of representations and models. For the second half of twenty century and the beginning of the twenty-first, the representational debate has increased, so philosophers such as Hacking (1983), Pitt (1981), Damerow (1996), DaCosta and French (2000), as many others, has abord the theme of representations with deep and intensity.

Although the use of representations and their concretion in models has been considered long ago, the debate about their structure, function, and relations with the represented continues and will develop different visions. Some of the questions of the debate are: What do those representations represent? Which relationship has the representation with the target? Have representations entity by themselves? What is the subject's role in representations? These questions and many others are the focus of the debates. A summary of those debates, a description of some characteristics of representations, and a position about them related to science education are presented in the following sections.

3.What is the relationship between scientific representations and the represented?

The intuitive answer to these questions is that representation should show some relations of isomorphy or similarity. For example, the drawing of a chair represents a chair object because everyone knows that object and can identify in the representation its similarities. The representation has the same components, and the form with those components keeps spatial structural similarity. However, this representation of objects is not functional for symbolic representations, even graphical ones, in which similarity is impossible and, therefore, is not a valid criterion for all kinds of representations.

Isomorphic criteria, however, have been relevant for scientific representations, scientists, and philosophers. These criteria have changed over time and are recognized as the named *semantic view*, which focuses on the meaning and value of representations in structures isomorphic or homomorphic with the represented. A scientific representation is a set of elements with operators and relationships constituting a structure considered, almost in part, isomorphic with the reality that this position considers representations to represent. So, these representations are valid themselves, and their consequences (inferences and explanations) imply that they build with them is true or scientifically valid knowledge.

4.The semantic view of representations

The fundamentals of this conception are based on some identification between the representations and the represented, which means there is no arbitrary significance but substantive between both entities.

The conception that implies a total or partial isomorphic relationship with the real systems is a strong version that supposes a structural or functional component of the representations that colligate to real systems and affirms that almost a part of reality is cognoscible and, therefore, determines true criteria for scientific knowledge (Da Costa y French, 2000; Thomson-Jones, 2011). For example, DaCosta and French (2000) establish that if the elements of the theory structure do not fully interpret models and their functioning in the development of scientific knowledge, they are almost partial. Those arguments strengthen the idea that the structure of theories is the regulator of true relations; because representations and their expression as models have elements such as structure, they have the elements to build knowledge from those structures (Chakravartty, 2010). Then, mathematics, computer models, and functional models (e.g., g particle model, equations of rigid bodies, or maquettes of molecules) are representations that, by their structure, are valid because they partially represent reality. Then, it is possible through them to corroborate inferences or explanations from those representations.

Massimi (2011) defends structuralism and its relationship with reality under the argument that if the conceptual significance changes and does not correspond with reality, it is the structure that accounts for reality. If an experimental confirmation is added, the knowledge generated is considered true. Other authors defend the structuralist point of view with the rationale of the temporal persistence of structuralism as a good explanation of the functioning of scientific theories, as in the set-theoretic-approach (Díez, (2002); Gädhe, (2002);

Moulines, (2002), others with the adequacy to explain historical episodes (Caamaño, 2009).

However, this structural-realist position has had several critics, mainly from two aspects: one from logic and the other from the role of the subject in representations. From logic, it [1]has been shown that isomorphism, partial or total, implies the achievement of relations of symmetry, reflexivity, and transitivity as extensional structures that structuralist affirm representations have. In their analysis, Suárez (2003, 2004) shows that any isomorphism or homomorphism cannot fulfill those three conditions.

The criticism concerning the role of the subject is that the semantic view does not incorporate the subject. The only relevance of the representations is their similarities and structure. Therefore, with these conceptions, it is impossible to explain why there are mistakes in the representations if the representation is similar to reality. Recognizing that the subject should have some role, Giere (1998, 2010) developed a proposal to assign some role to subjects. That is, representation requires some agent that implies two aspects: intentionality and purpose of the representations. As he points out in the following scheme:

"Agent intention (1); use of model M(2), M represent part of the world W(3); to some purpose P(4)" (Giere, 2010, p. 274)

In the scheme, Giere gives the subject the role of identifying and making some possible action (purpose). However, in the identification process, the agent connects with reality to assign the representation elements to the world (W3). In their argument, Giere (2010) ruled out truth or falsity as criteria for representations because there are no linguistic entities from which it is possible to asseverate falsity or truth. Then, the criteria should be the similarity to validate some representation to belong to scientific knowledge. Suppose Giere's arguments are relevant and separate from the strong structuralist vision. In that case, his prevalence of similarity does not solve the objections that critics of the semantic view pointed out.

Even with the incorporation of subjects or agents, if the similarity prevails, the relation reality-similarity is another problem. Suppose it is given by valid that it is possible to make a representation almost partially similar to reality. In that case, it is valid that those part of reality is subjects known previously. If that is so ¿How can this previous knowledge be guaranteed to be part of reality? ¿How does it explain the possibility of building several or plural representations or models about the same portion of reality?

5.The inferential/pragmatic view of representations

The problems presented by semantic conception, even in their weak version, in which it is acknowledged that total similarity is not available and gives some role to the subject, do not solve the critics as shown in previous paragraphs. To avoid that criticism, new conceptions or views about scientific representations have surged under the following considerations: the representations are subject' dependent in a substantive form; representations do not require any relations of similarity with the represented; representations may be erroneous, that fail to represent some target; is possible to constructing representations of fictitious entities; representations are not symmetrical, transitive nor reflective.

With these bases, diverse approaches are developed and, if all of them recognize the necessity to accomplish those conditions, have had diverse forms to understand the functioning of representations. One of the first authors to develop a position was Suárez (2004), who proposed that a representation is characterized by the *force of the representation* and its capacity to allow the subject with *surrogate reasoning*. By force of representations, understand the sufficiency that the representation had to represent the target, the condition related to the second characteristic, and the possibilities of the subject to make inferences through surrogate reasoning. Then, the highlight of representations is that subjects can make valid inferences with them, so Suárez calls their approach *Inferential Conceptions of Scientific Representations.* Inferences in this conception imply the existence of a subject with the possibility to make those inferences, which count with the conceptual and cognitive resources to determine the force of the representation and made with their representation components the surrogate reasoning. In terms of Suárez:

"A represent B, if and only if (i) the force of representation of A point to B, and (ii) A allow to an inform and competent agent to obtain specific inferences with respect to B" (Suárez, 2004, p. 773).

As noted, this inferential conception does not require any criteria related to some similarity with the represented, only that representations will be helpful to make valid inferences with them. However, the idea of the force of the representations is somewhat blurred, and also, what implies an informed and competent subject or agent?

Regarding the role of the subject, Contessa (2007) establishes that an informed and competent subject will understand a subject capable of interpreting the representations (or model). In their analysis, Contessa adheres to Suárez to conceive representations from the inferential point of view; however, they noted those characterizations are insufficient and propose that the representation is epistemic. That is, consider that it is convenient to establish necessary and sufficient conditions implicit in the interpretative process that the subject should be made with the representation; "Interpretation is what grounds both scientific representation and surrogative reasoning" (Contessa, 2007, p. 51). Contessa calls their proposal *Interpretational Conceptions of Epistemic Representations*. As noted, the subject should have those conditions of competence and information for interpreting the representation, conditions without which the subject cannot recognize intentionality, functionality, and purpose of representations to be considered an epistemic entity. Contessa proposes that the interpretation process should accomplish the following conditions: 1) The subject takes the vehicle (representation) as those denote the target; 2) to any entity in the vehicle, there is a biunivocal correspondence with some object of the target; 3) to any arrangement of entities of the vehicle there is a biunivocal correspondence with an arrangement of entities of the target; 4) for any arrangement of functions and entities of the vehicle,

[1]Symmetry is not fulfilled because the represented does not represent the representation. It is not reflexive because the representation does not represent themselves and is not transitive. If A represents B, and B represents C, it is not necessarily true that A represents C.

there is a biunivocal relationship with the denotations of arrangements and functions and entities in the target (Contessa, 2007, p.58; Author rephrasing). It should be clear that biunivocal correspondence does not mean similarity or isomorphy, only that the elements of representation can be assigned a correlative element with the represented, even if these elements do not have any similarity of form or structure.

The interpretative process described implies a subject with the information and competence to interpret, and that competence implies realizing the four interpretative conditions proposed by Contessa (2007). As can be noted, it is not enough to recognize the intentionality and purpose as proposed by Giere (1998; 2010); it is also necessary for the interpretative process for a subject to do a valid surrogate reasoning, validity that is implicit in the conditions of the interpretative process, independently that the representation will be erroneously representing some system.

Recently, another proposal that is congruent with the inferential position was developed by Knuuttila (2011), who incorporates the epistemic function of representation not only the subject and reasoning processes but also the relevance of forms and medium in which the representations (and models) are materialized, that she calls the *sign-material expression* of representation. So, representations are external entities that materialized in some medium and became *artifact*s in epistemic tools.

"... *epistemic tools*, concrete artifacts, which are built by various representational means, and are constrained by their design in such a way that they enable the study of certain scientific questions and learning through constructing and manipulating them. " (Knuuttila, 2011, p. 267)

It is relevant to note that Knuuttila's proposal considers not only the representation and its utility but also the construction of representation. Constructions that are not restricted to medium and use and incorporate the intentionality, that is, to build an epistemic tool for a definite purpose. Representations as epistemic tools have specific properties determined by the constrictions imposed by the design and medium in which the representation is built. The medium in which a representation is elaborated (graphics, schemes, objects, and others) imposes conditions for their interpretation and surrogate reasoning processes.

"... if they (*models*) are recognized as materially embodied manipulable objects into which a lot of scientific knowledge is already built, then it is evident that they provide something tangible for us to study and experiment with." (Knuuttila, 2011, p. 270).

Incorporating the sign-material in the scientific representations reaffirms that imposing any condition of similarity to representation to represent an entity or system is unnecessary. The only condition is that representation will be an epistemic tool to make valid inferences where valid does not imply true, but viable for the context in which the subject infers corresponding to each representation (model or theory).

6.What is the role of the subject in scientific representations?

In the semantic-structural approach, representations are characterized and justified by the similarity relationships between the representation and the represented, as previously explained, implying different subjects' roles. For those who construct the representation, the task is to identify similarities of form, function, or structure to guarantee that those representations are valid to represent the target and validate the explanations or predictions that representations allow. To accomplish this purpose, the scientific community point out their effort. For those who use the representations, for example, in learning or teaching processes, those representations are taken as corresponding to reality and, therefore, guarantee to achieve knowledge of reality.

In the first case, individuals have the central role because it establishes the principal similarities and differentiates those who are irrelevant. Faraday's representations of lines of force in the electric field exemplify the necessity of similarity in representations. In their representation of lines of force, Faraday was convinced that those lines were real, isomorphic entities with real force. In the second case, the users (including the constructor of representations because when that representation is external representations, all subjects are users), the representation becomes equipotent. That is, it is the same for any user who only requires to understand how to use them to solve problems or experiments. Representations become an entity itself, and, under this approach in science education, teachers and students are only users with no active role. Representations are independent entities of subjects.

From the inferential approach, representations are only possible conceived with the subjects. As a constructor, their task is to build a form and in a medium to express the representation with the goal that will be fructified to establish valid inferences, that is, build an epistemic tool, independently of any other consideration. As the user, the subject also has a central role, and the subject is required to give significance, that is, recognize the intentionality purpose and understand the functionality and sufficiency of the representation to reasoning with their elements and structure. Of course, that role will only be possible if the subject has the cognitive and conceptual elements to interpret and make surrogate reasoning with the representation. Another example from electromagnetism is the spin hexagons of Maxwell that do not have any similarity with electromagnetic field.

For learners of science, representation is not independent of him; it is attached to their possibilities of interpretation and to make inferences with them. This subject role opens the possibility to misunderstand the representation and make erroneous inferences that do not align with the scholar's dictum. However, representations are still an epistemic tool because they are entities with which a subject constructs interpretations and makes some inferences. Despite this, interpretation and inference are not that expected by the teacher and even can constitute some support to future understanding of the representations, that is, in this approach, a misrepresentation in not only the incorrect interpretations or the incorrect inference that should be eradicated of students, still be helpful for the learning process. Another relevant aspect is that the representations, as dependent on the subject, are not static as in the case of the semantic-structural view because the interpretations process and the surrogate reasoning can change as the cognitive and conceptual resources of the subject improve or change. In principle, those process implies a development in the subject closer to the scholar and scientific expectations for the subject's learning.

As noted, this inferential approach has different implications for teaching and learning processes than those derived from the semantic-structural approach.

7. What characteristics should be accomplished by the scientific representations from the inferential approach to apply to science teaching?

One of the aspects of representations that have yet to be considered is how to characterize a representation. From the previously described, aspects such as sign-material expression, denotation, intentionality, interpretations, surrogate reasoning, and correlation rules constitute diverse elements of representations that are related and interwoven to the subject and the representation.

Consider the inferential approach as an epistemic tool, a first characterization from this perspective Flores-Camacho et al. (2020) and Gallegos-Cázares, Flores-Camacho, and Calderón-Canales (2022) proposed a description of the characteristics and subject role in terms of be helpful to analyze the construction and understanding of scientific representations in teaching and learning situation. In this proposal:

One aspect the learner faces is to recognize the *intentionality* of the representation, that is, to identify what the representation intends to represent. Because the representations are not reflexive and go from representant to represented, the subject will recognize the denotative and relational elements of the representation. In this aspect (no implied first step), the subject can or can not recognize the representation' intentionality. For example, in Figure 1, the intentionality of the representations is to represent that gravity attracts the objects toward the Earth, but when a child is questioning what the representation represents, the child says, *"Is a giant girl jumping over the Earth."* The intentionality recognized by the child is very different from those who elaborate on those representations; the representation does not help represent the target.

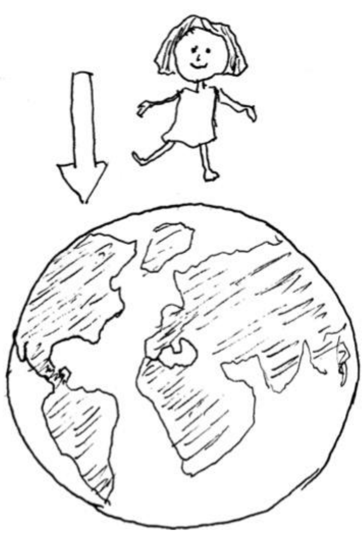

Figure 1. Typical illustration to show gravity force.

The *sign-material expression* is the form (graphical, symbolic, verbal, writing) and medium (paper, objects, electronic media, photograph, and others) to express the representation that has advantages and constrictions for a specific representation. The representation of Figure 1 (drawn on paper) does not allow the movement of the girl as in a computer simulation or a representation with objects when the Earth is a ball with a magnet, and the girl is a toy girl with another magnet, both magnets whose poles are opposite oriented.

The medium of the representation, as expressed by Knuuttila (2011), implies that this epistemic tool constricts the reasoning process in subjects. In the representations of the shape of the Earth that children build on paper, as has been documented by Vosniadou y Brewer (1992), versus the more sophisticated reasonings that children elaborate when a terraqueous globe is used to investigate (Schoultz et al., 2001). Jointly with recognizing the intentionality of the representation, the subject is *interpreting* them, establishing the significance of representation. So, subjects can recognize the elements and their function in the representation and associate them with the represented system or process, allowing subjects to make some surrogate reasoning. For example, in Figure 1, the interpretative process implies that subjects recognize one figure representing the Earth, the other representing a girl, one arrow representing a force, and the scenario representing the space when the objects interact. The intentionality of the representation of Figure 1 is that children can infer that people are on the Earth's surface because of the attraction of gravity force. However, the subjects do not necessarily recognize, interpret, and infer as expected and construct a different interpretation, that if they have denotative common elements (Earth, girl) others, the subject assigns another function, as the arrow indicating jumping instill of force, and taken into account the relative size of entities, that for the constructor of the representation are irrelevant.

Inferentiality is another indissociable aspect of the subjects on the representation because it results from the surrogated reasoning that depends on the subject's abilities. Return to the case of Figure 1; the child infers that the girl represents a giant (because of the relative size in the draw) that is jumping over the Earth, which is inferred from the elements of the functionality of the representation (the arrow that indicates movement instead of attractive force).

Added to the characteristic of representations is the necessity that the representations implicitly are elements of the reliability of the epistemic use of the subject; this implies that, in their structure and function, representation should be established elements to evaluate the viability/reliability of the subjects' inferences. To these, the subjects must have some *coordination rules* (Knuuttila y Boon, 2011), that is, to make some relation or connection with the represented system. These are instantiated in the possibility of making some action as observation, measurement, or equivalent action to compare the subject inference with the observable. Those observables can be previous subjects' experiences, not necessarily actual measurements. In the case of the child inference about a giant jumping over the Earth, the coordination rule implies previous referents as giants in children's tales, cartoons, or movies, referents with which the subject validates their inference.

The proposed characteristics of intentionality, interpretation, inferentiality, sign-material expression, and coordination rules are not independent; they are also not in a linear sequence. There are joined and interactional cognitive actions that imply that representations were epistemic-inferential tools that allow the construction and understanding of knowledge and the representational plurality of interpretations that particularity is notorious in learning science, as students' alternative conceptions have shown.

8.What educational implications inferential view of scientific representations can do?

The analysis of scientific representations in the field of science education is recent (Adúriz-Bravo, (2013); Campbell and Fazio, (2020); Cheng et al. (2021); Gallegos-Cázares et al. (2021); Flores-Camacho et al. (2020); Pozo y Flores (2007)). The ways to consider representations as central to teaching and learning are, and as expected, varied but correspond mainly to the semantic view of representations; that is, in the conception of models, theories as representations have implicitly some kind and level of similarity. In this variety of proposals, there are constructive processes (Nerssesian (2013), diSessa (2014), Prain & Tytler (2012), teaching with analogies (Clement & Brown, 2009), and student modeling of processes (Gilbert, 2008). A broad description of representations and science education is found in Flores-Camacho et al. (2020).

Concerning the previous considerations about approaches, roles, and characteristics of representations and their implication for educational processes, some principal considerations will be established.

-Representations are the means of interaction between subjects (teacher-student, student-student, materials and educative mediums – teachers – students), and that interaction can occur with different forms, modes, and mediums. This amplitude of interactions through representations should be recognized so that the educational actors can consider the usually unused representations.

-Representations require that educators recognize the intentionality and potentiality of representations for learning. The intentionality is relevant, as was shown in the example of the child's interpretations of gravity; this representation was built with some educational purpose. Gallegos-Cázares et al. (2022) show that students misrepresented their intentionality and frequently made inferences different from the expected. The inferential approach provides a form to analyze and anticipate different ways students misrepresent.

-For subjects to be able to interpret representations, it will be necessary to join diverse elements that accompany some specific representation, that is, to have other representations that can be ensembled in different levels to help the student enrich their cognitive resources to recognize the intentionality and functionality of the representation target. In the case of complex representations with many elements and relations, it will be necessary to establish partial representations or models that the subjects can align to integrate the implicit functionality in the central representation and not, as usually occurs, put together all the elements and functional relations in one representation. Multiple representations are then a factor that has shown advantages in learning processes, the reason for what, in the educative processes in school, should be established bonds between diverse forms of representations in diverse sign-material expression of representations.

-One aspect that regulates subjects' inferences and their pertinence is that subjects acknowledge the diverse coordination forms that can realize contact points between the inference and the represented to internally validate the inference they made (Knuuttila y Boon, 2011).

The previous paragraphs are only some elements that, from analyzing the scientific representations, can be applied to teaching and learning processes. Considering that more than all representation is an epistemic tool is needed because, for learning, those tools require additional meaning to the learner, can do surrogate reasoning and coordination with the represented, and allow the subject a representational transformative process in school. The transformative process is that, without them, it is not possible to conceive the learning of scientific knowledge. As in the example of the child that infers from Figure 1 a giant jumping over the Earth, the child must develop a transformative process, accompanied by the teaching process, so the subject can generate other inferences with which to make a transformative representation that is a change in how to understand all the elements that characterize the representation (intentionality, interpretation, sign-material representations, inferentiality, and coordination).

The conception or approach to scientific representations educative actors have (semantical or inferential) has implications over to favor or not those transformative representational processes in students.

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Figure legend
Figure 1. Typical illustration to show gravity force.