Models as signs: extending Kralemann and Lattman’s proposal on modeling models within Peirce’s theory of signs

1. Introduction

It is well acknowledged that scientific models have a variety of different roles: explanation, prediction, theory-testing and teaching. Frigg (2006, 49) has pointed out that, in order to use scientific models to perform any of these functions, they must first be able to represent. But, if scientific representation is indeed a basic function that models have and if it allows other roles to be carried out, a series of important questions arise: what do scientific models represent? And how do they do it? In which respects is scientific representation similar (or different) from various other forms of representation, such as pictorial or linguistic representation? And how does the representational role that scientific models have influence their other roles? The last few decades have witnessed the emergence of an extensive literature that addresses those questions. But, even if this literature has clarified a number of issues around which there is now some agreement, there are still key divergences on some of the aforementioned questions.

For instance, the question about what scientific models represent has elicited different, and often seemingly irreconcilable answers. To illustrate this, Barberousse and Ludwig (2009, 57) have maintained that ‘models represent fictional situations.’ On the other hand, for Teller (2009, 244), even if models often involve fictional elements, they are ‘used as component fictions to represent the real trajectories or real objects, the real fluid behavior of real bodies of water.’ Let us call these two opposed views representational ficitionalism (RF) and representational realism (RR) about scientific models.

Though RF and RR advocates appear to endorse diametrically contrasting views about what scientific models represent, I believe there is no tension at all between RF and RR, since models can represent both fictional situations and real objects. This is not surprising given the nature of models. Indeed, models are, in my opinion, extremely versatile entities, and the failure to appreciate their huge versatility has led to the rise, not only of the dispute between advocates of RF and advocates of RR, but also of the *parallel* debate between those who think that models represent indirectly (e.g., Giere 2004 and Frigg 2010) –let us call this position IR– and those who think that models represent directly (e.g, Toon 2010 and 2012) –let us call this position DR.[[1]](#footnote-1) The different positions in these two debates (RF vs. RR and IR vs. DR) have been articulated to address central questions about scientific representation.[[2]](#footnote-2) In particular, two of the questions that participants in these debates tackle are the following ones: (1) how can we make sense of models that do not seem to represent any real scenario? and (2) how can we make sense of models that misrepresent their objects? Now, depending on which position on models is adopted, different challenges arise. For instance, an advocate of RF may state that models that do not seem to represent anything real represent fictional entities, though he then faces questions about the ontological status of these entities.[[3]](#footnote-3) Or, an advocate of IR may state that a model misrepresents its target since some of the properties of the model do not correspond to or fit well with any properties of the target. But he then faces questions about how properties of a fictional entity or an abstract object can in the first place correspond to or fit with properties of a concrete, real target.[[4]](#footnote-4)

To address the tensions in these debates (in particular, the tension between RF and RR), I propose the following: granting that a scientific model is a *representation* of some sort, perhaps it can represent not just one thing but various things. To appreciate how this is possible, consider the following example: suppose that, while you are driving, you see a road sign with a stylized airplane picture.[[5]](#footnote-5) This picture can be used to represent an airplane, but also the direction of the airport and the airport itself. Now, the reason for this is that the stylized airplane sign has an iconic aspect (insofar as the sign is *similar* in certain respects to an actual airplane), an indexical aspect (insofar as the sign is oriented toward the airport in a certain way, thus *pointing* in a specific direction) and a symbolic aspect (insofar as the sign is used *conventionally* to represent an airport and not, say, an airplane factory). Thus, if scientific models function basically as representations (i.e., if they are a certain type of signs), perhaps they can be used to represent different things, just as the stylized airplane sign does.

Considering this, the thesis I aim to establish in this paper is that the positions of RF and RR advocates can be reconciled through the use of a framework provided by Peirce’s theory of signs. In this, I am pursuing a strategy that Kralemann and Lattman (2013) have recently proposed. This involves using Peirce’s theory of signs to address questions about the ontological status of models raised by Mahr (2009) and other authors. Building on and extending the work of Kralemann and Lattman, who argue that scientific models are necessarily icons, I defend two claims: (i) even if scientific models are indeed icons, they also often have indexical and symbolic aspects (i.e., they can also functions as indexes and as symbols depending on the context in which they are deployed and the specific use they are given) and (ii) this representational versatility of models conceived within a Peircean framework can help us to dissolve the tension between RF and RR by showing that models can represent fictional situation or real states of affairs depending on the circumstances in which they are used. In addition, I also show that, if we accept a Peircean framework where models are conceived as signs having different semiotic aspects, we can develop a satisfactory account of scientific representation that satisfies the main desiderata that Shech (2015) has underscored after critically examining prior accounts of scientific representation made by Suárez (2004) and Contessa (2007).

I proceed in the following fashion. In section 2, I review in detail the proposal made by Kralemann and Lattman to address the question of the ontological status of models, which involves appealing to Peirce’s theory of signs (in particular, to the distinction he made between icons, indexes and symbols), and I show briefly what are the advantages of this view. In section 3, I offer an extension of the proposal of Kralemann and Lattman that shows that scientific models have not only iconic features, but also indexical and symbolic ones and I show how this enables us to address the tension between advocates of RF and of RR. In section 4, I show how conceiving scientific models as a type of signs that may have not only iconic, but also indexical and symbolic functions within a framework offered by Peirce’s theory of signs enables us to develop an account of scientific representation that meets the desiderata that Shech presents. Finally, I present in section 5 a very brief conclusion that outlines some lines of future research.

2. Kralemann and Lattman’s use of Peirce’s theory of signs

One of the most important questions raised in recent years about scientific models concerns the so-called ‘ontological puzzle’: granting that there are many different types of entities that are scientific models (e.g., the double helix DNA model built by Watson and Crick, the Lotka-Volterra model of biological populations, etc.), what makes them all models? This question is pressing because, as Mahr (2009) admits, scientific models exhibit a great diversity (e.g., some are concrete things such as a toy vehicle or a biological organism while others are abstract entities such as a system of differential equations or a set of computer instructions) and there does not seem to be a feature common to all these various entities.

Now, to address the ontological puzzle, Kralemann and Lattman have proposed considering scientific models as a certain type of signs within the framework of a Peircean view of scientific representation. The rationale for this approach is twofold. On one side, it enables us to vindicate the insight of Frigg that I mentioned in the introduction, namely, that a scientific model must, first and foremost, *represent*, since one of the features of signs is that they are assumed to stand for something.[[6]](#footnote-6) On the other side, conceiving scientific models as a kind of signs allows us to subsume scientific representation into the framework of a general semiotic theory that covers other forms of representation.

To grasp the generality of Peirce’s theory of signs, consider the word ‘airport’. Peirce would agree that the word functions in English as a specific sign because it represents a certain entity (i.e., an airport) in virtue of a conventional connection that is understood by English speakers. However, linguistic signs are not the only existing signs. As Grice (1957) pointed out, certain non-linguistic entities (e.g., a column of smoke) are signs of certain things (e.g., a fire) because there is a causal connection between them. And there are other non-linguistic entities (e.g., a portrait of Napoleon Bonaparte) that are signs of other things (e.g., Napoleon Bonaparte) because they bear a certain similarity to the things they stand for. This variety of representational relations that different signs may bear to many objects is captured in Peirce’s theory of signs by the following characterization of a sign:

A sign, or *representamen*, is something which stands to somebody for something in some respect or capacity. It addresses somebody, that is, it creates in the mind of that person an equivalent sign, or perhaps a more developed sign. That sign which it creates I call the *interpretant* of the first sign. The sign stands for something, its object. It stands for that object, not in all respects, but in reference to a sort of idea which I have sometimes called the *ground* of the representamen. (CP 2.228)

As this passage shows, Peirce characterizes a sign as something that represents or stands for something in some respect or capacity, which he calls the ground. This characterization, which is triadic insofar as Peirce defines a sign in relation to the object that it represents and to the person for whom the sign represents that object, is general enough to encompass all the previous examples. Indeed, the English word ‘airport’ is a sign of the airport because it stands for its object in virtue of a specific ground, which is a linguistic convention. The smoke is a sign of a fire because it stands for its object in virtue of a different ground, which is a causal connection. And the portrait of Napoleon Bonaparte is a sign of Napoleon Bonaparte because it stands for its object in virtue of another ground, which happens to be a certain similarity. As we can appreciate, Peirce’s theory of signs allows us to provide a general account of these different forms of representation.

In addition to allowing a systematic treatment of various different instances of representation that goes beyond linguistic representation, Peirce’s theory of signs has another key advantage that Kralemann and Lattman emphasize: it enables us to understand why, if scientific models are taken to be a type of signs, they have many characteristics that they do typically exhibit. For instance, it is widely acknowledged that scientific models represent only some aspects of their targets because they omit various characteristics of them as they are built through abstraction.[[7]](#footnote-7) Within a Peircean theory of signs, this feature of scientific models is perfectly understandable to the extent that, as Kralemann and Lattman observe, it is just a particular instance of the general way in which all signs represent:

Every sign stands for its object, but due to its non-identity [to its object] *only in single respects*. A photograph of a house, e.g., represents only the visual appearance of a specific house, but not its material or its spatial extent, this visual appearance, in turn, being categorically different from the corresponding physical properties of the thing itself, which acts as the object of the photograph. So, every sign implies a respect, and it is especially this respect that Peirce calls the ‘ground of the representamen’. (2013, 3401 my emphasis)

Another important feature that models exhibit is that, although representing is one of their important features, this is not something that they do *per se*. As both Suárez (1999) and Frigg (2002) have emphasized in their discussion of models conceived as mere structures, models do not represent anything by themselves. In order to be able to represent, a model must be built and used in a specific context by an agent (or a group of agents) who makes it stand for something.[[8]](#footnote-8) The fact that scientific models do not represent anything by themselves (but only in relation to certain agents)[[9]](#footnote-9) is also properly captured by the conception of models as a type of signs that Kralemann and Lattman propose. Indeed, given that they (2013, 3401) underscore the fact that within Peirce’s view ‘nothing is a sign by itself’, the proposal enables us to capture the insight that models can only represent when they used by intentional agents.

Thus, in virtue of these two reasons, considering scientific models as a type of signs appears as a potentially fruitful approach in order to address the ontological puzzle. Having shown this, Kralemann and Lattman raise the following question: if scientific models are signs, what specific type of signs are they? To tackle this, they offer a closer examination of Peirce’s theory of signs. In particular, they remark that Peirce draws a distinction between three types of signs in his early works:

It follows that there are three types of representations: 1st Those whose relations to their objects is a mere community in some quality, and these representations may be termed Likenesses [or Icons]. 2nd Those whose relation to their objects corresponds to a correspondence in fact and these may be termed Indices (…) 3rd. Those whose relation to their objects is an imputed character, which are the same as general signs, and these may be termed Symbols. (W2, 56)

As we can appreciate, Peirce views signs as being divided into three main kinds that differ on the basis of the ground that they rely on to represent their objects: icons represent their objects on the basis of a similarity relation (which is grounded, for Peirce, on the sharing of some feature), indexes represent their objects on the basis of a causal or another factual, brute relation[[10]](#footnote-10) and, finally, symbols represent their objects through a conventional relation (which relies, as Peirce argues, on the ascription of a certain feature to an object, as when we ascribe the command to proceed with caution to a flashing yellow light). Given this distinction, Kralemann and Lattman consider what kind of signs scientific models are, and they put forth the following thesis:

Since the classification of (the functional aspect of) signs into icons, indexes and symbols primarily has, as regards its definition, a conceptually exclusive character due to Peirce’s theory of categories and since no model is primarily and essentially an index or a symbol –an index represents its object in a direct, intrinsic, e.g., causal manner and a symbol by a primarily conventional or habitual reference– models must necessarily belong to the class of icons (or put, another way, their iconic aspect is the prevailing, basic one). (2013, 3405)

To support this claim, Kralemann and Lattman (2015, 3405) contend that this ‘is shown by scale models or photographs: these signs represent their objects by a way of similarity between their own quality and the quality of their respective object.’ In addition, they (2015, 3405) maintain that all models without exception have an iconic dimension as ‘they all obviously bear an essential similarity to their objects which serves as the basis of their representational quality.’ Following Peirce, Kralemann and Lattman highlight too that the similarity in question does not have to boil down to image-like similarity (which corresponds to what Peirce calls ‘images’) since Peirce distinguishes in his works two other types of similarity: structural similarity (which is the basis of icons he labels ‘diagrams’) and semiotic similarity (which corresponds to icons that he refers to as ‘metaphors’). In virtue of this, icons, which are a type of signs, are further divided according to Peirce into three sub-types of signs: images, diagrams and metaphors.

Some scientific models seem to correspond to this taxonomy rather neatly. For instance, some fence-line contrast photographs function as ecological models, as Hongslo (2015) has shown, because they represent vegetation changes over time in a region in virtue of image-like similarity between the photographs and the depicted phenomena. Other models such as the Lotka-Volterra equations function as models in virtue of the existence of some structural similarities between the differential equations and the fluctuations of both prey and predator populations.[[11]](#footnote-11) And, finally, some models such as Darwin’s tree of life in his *On the Origin of Species* may represent phylogenetic relations between living and dead organisms in virtue of a semiotic similarity between the object and the model.[[12]](#footnote-12) Considering this, I am in overall agreement with the view that Kralemann and Lattman present of scientific models as necessarily having an iconic aspect. This agreement raises two further questions: granting that scientific models necessarily have an iconic aspect *qua* signs, can they also have indexical and symbolic functions? And, if this is so, can we use this fact to solve the tension between RF and RR advocates?

3. Extending Kralemann and Lattman’s proposal to reconcile RR and RF

Let us consider now in detail the issue of whether scientific models, in spite of having necessarily an iconic aspect, can also have indexical and symbolic aspects. Kralemann and Lattman maintain in the passage where they present their thesis that the distinction between icons, indexes and symbols is mutually exclusive in virtue of Peirce’s theory of categories. But they point out in a footnote (2013, 3404, fn5) that this does not preclude that ‘several or all the semiotic functions –which Peirce grasps by way of the *termini technici* icon, index and symbol– may be present at the same time in any empirical entity that acts as a sign, though with regard to a different aspect.’ Thus, even though an icon cannot be an index or a symbol *qua* icon, Kralemann and Lattman acknowledge that an entity that functions in some specific context as an icon (e.g., a photograph of the Eiffel Tower that represents the Eiffel Tower through similarity) can have at the same time but in a different respect an indexical function (e.g. it can point to the actual existence of the object it represents *via* a causal relation) as well as a symbolic function in a different respect (e.g., it can function as a souvenir of a honeymoon trip *via* a certain convention). Now, if entities such as photographs that function as signs can display at the same time various semiotic functions in different respects, is it the case that scientific models can also have indexical and symbolic functions?

A brief look at the recent literature on modeling shows that various scientific models have, in addition to their iconic aspect, indexical and symbolic aspects. For instance, when Leonelli considers how certain specific exemplars of *Arabidopsis thaliana* can function as models after being developed in laboratories through a process she labels ‘material abstraction’,[[13]](#footnote-13) she points out that the specific exemplars function as models not only because of their similarities to wild instances of the plant, but also because the process of material abstraction has two key features:

It is aimed at the material replication of features of plants. These features are selected as desirable insofar as they allow us to explore unknown aspects of *Arabidopsis* biology (e.g, the regulatory mechanisms responsible for the phenotypic differences between Lan and Col ecotypes). The stability of these features across different laboratory settings is a necessary condition for the resulting model to have representational value. (…) Without agreeing on the traits that should characterize Lan and Col specimens as models of Arabidopsis plants, there can be no study of their regulatory systems, nor can results achieved through such study be applied to other species. Specimens that do not possess the traits selected by NASC researchers do not constitute trustworthy representatives of *Arabidopsis* wild types. (2008, 522)

As this passage suggests, using an instance of *Arabidopsis thaliana* created in the laboratory through material abstraction as a model involves, in addition to the iconic dimension that characterizes all models, the two other semiotic functions. In order to represent some *Arabidopsis* wild types, the model organism must be such that it can be used to indicate (i.e., to ‘trace back to’) these wild types. This indicating or ‘tracing back’ is possible since there is a series of causal links existing between the model organism and certain wild specimens that obtain in virtue of certain phylogenetic relations and of laboratory manipulations. In virtue of this, the *model* organism represents other *wild* organisms since it operates as an index, just as the presence of petrified wood in an area (e.g., Petrified Forest National Park) operates as an index of the existence of vegetal life in another era. Moreover, certain features of the model organism stand for features of wild organisms (and not others) because the scientists who created it selected *via* a convention certain features as desirable and left others aside. In virtue of this, some features of the model organism represent features found in the wild exemplars insofar as the features in question function as symbols.[[14]](#footnote-14)

As this example shows, an entity that functions as a scientific model can be, if we conceive it within the framework of Peirce’s theory of signs, a model in different ways since it can operate in some respects as an icon, in others as an index and, finally, in others as a symbol. This insight allows us to vindicate a distinction Liu (2015) has recently made in order to reject a deflationary conception of scientific representation proposed by Callender and Cohen (2006). Callender and Cohen defend a view of scientific representation according to which it is first and foremost a matter of conventional *fiat* within a framework that they label ‘the General Gricean account’ and that they (2006, 70) characterize in terms of the following central claim: ‘all (…) types of representation can be explained (in a unified way) as deriving from some more fundamental sorts of representations that are taken to be mental states’. For them, in principle any entity whatsoever can be a scientific model of some phenomenon P as long as the entity in question is such that it reliably elicits the appropriate belief states in people that employ the model.[[15]](#footnote-15) To be more specific, on the view that Callender and Cohen defend, while causal, resemblance and/or isomorphic relations may bear a certain role on whether an entity can be used to represent successfully a certain phenomenon P, they only function at most as pragmatic constraints since the key element behind scientific representation is a conventional stipulation. In virtue of this, Callender and Cohen (2006, 77) endorse a position where ‘scientific representation is just another species of representation to which the General Gricean account is straightforwardly applicable.’

Now, on one side, Liu finds (quite rightly, I think) this conception of scientific representation too deflated since it leaves aside causal and resemblance relations as mere pragmatic constraints, and puts all the weight upon the conventional or symbolic relations.[[16]](#footnote-16) But, on the other side, he also wants to preserve the idea that there is an important conventional or symbolic element at work in cases of scientific representation. To incorporate all these elements, Liu draws a distinction between two different types of signs that are used to represent in science (which he calls, following Callender and Cohen, ‘representational vehicles’).[[17]](#footnote-17) For Liu, there are symbolic vehicles and epistemic ones, and the difference is the following one:

[Symbolic vehicles], whether linguistic or non linguistic, are essentially arbitrary physical objects that people use by agreement as tags or marks for the things they want to refer to. (…) Epistemic vehicles, those vehicles that we usually see in acts of modeling things or event is the world, scientifically or otherwise, are not used as symbols (…) A cursory look at the use of such scientific models would reveal two rather obvious points: (i) they cannot be had, unlike the symbolic vehicles, through a stipulation among the users and, more importantly (ii) they have features that are regarded as relating to their targets in such a way that they can be used to show or επχδειξη the targets or to learn about them. (2015, 46)

Liu maintains that this difference is important because it enables us to defend the claim that scientific representation has an epistemic aspect while also conceding that the representational use of models also has a conventional aspect. Liu’s distinction between epistemic and symbolic vehicles thus provides a valuable lens to study scientific representation since it allows us to appreciate that it is a multifaceted phenomenon, with both epistemic and symbolic dimensions.[[18]](#footnote-18) Thus, a further reason to accept the thesis that models not only have iconic but also indexical and symbolic aspects is that, in addition of allowing us to make sense of how the process of material abstraction described by Leonelli endows models organisms such as *Arabidopsis thaliana* with representational value vis-à-vis other specimens, it also enables us to capture and vindicate the distinction that Liu makes between symbolic and epistemic vehicles. Indeed, if an item is employed as a scientific model in a context that stresses the conventional relations it bears to its target, it operates as a symbolic vehicle. And, if the object is used as a model to represent its target in a context that stresses the indexical and iconic relations that it bears to its target, the object operates as an epistemic vehicle.

I have offered some reasons to support the thesis that scientific not only have iconic features, but may also have indexical and symbolic ones that operate in different contexts, depending on the specific uses the models are given. But can we use this fact to reconcile the tension between advocates of RF and of RR? As I mentioned previously, I want to present an argument to establish this. The structure of the argument is the following: I consider first some examples of scientific models that are deemed to support the position of advocates of RR. On the basis of the thesis that models are signs that may have indexical and symbolic functions in addition to an iconic one, I argue that, when they used for certain purposes and in certain contexts, these models represent fictional situations. I then consider some examples of models that are used to support the position of advocates of RF and, on the same basis, I argue that these models represent, when they are used for certain purposes and in certain contexts, real properties or real states of affairs. Finally, I argue that the tension between RF and RR can be resolved in way that vindicates an important observation about models made by Morrison and Morgan (1999).

Let me present the first part of the argument. In order to start with as uncontroversial a case as possible, let us consider a model that was built explicitly to represent a part of the natural world: the US Army Corps of Engineers San Francisco Bay model in Sausalito.[[19]](#footnote-19) By focusing on this specific model, an advocate of RR can make the case that scientific models do represent real states of affairs. I certainly do not want to dispute this claim, but here it would certainly pay off to be more precise. I agree with advocates of RR that the San Francisco Bay model represents a real state of affairs when the model is used to study the variation in intensity and direction of tidal flows in the San Francisco Bay area. Moreover, I would add that it represents a real state of affairs because, though the model operates as an icon (in virtue of certain structural similarities between the model and the bay) and as a symbol (in virtue of the agreement of the model’s creators to make it stand for the San Francisco Bay area), it functions mainly as an index insofar as it is related to its target by a causal connection that relates variations of the tidal flows in the bay to changes in the model.[[20]](#footnote-20)

However, if the model is used for other purposes (e.g., to study the likelihood of earthquakes impacting the Bay area), what the model represents is not a real thing, but a fictional situation since the physical model is clearly an idealization that omits many elements (e.g., faults) that would be necessary to represent accurately the real geological structure of the Bay area. In virtue of this, I argue with advocates of RR that models may indeed represent real states of affairs. However, since models can also represent fictional situations, advocates must also acknowledge that this is a contingent trait that depends on the context in which the models in question are deployed and the use they are given, since these factors determine what Peirce called ‘the ground of the representamen’.

To appreciate how the ‘ground of the representamen’ can determine whether the model represents a real state of affairs or a fictional situation, let us consider a second example. To defend RR while accepting that some models involve fictional elements, Teller presents the following interesting thought-experiment:

Imagine that when Euler developed his hydrodynamical equations everybody actually believed water to be a continuous medium. These equations give an excellent description of many aspects of the fluid properties of water. Then these practitioners discovered that water is not a continuous medium (…) But now that we know that water is not a continuous medium, its characterization as continuous takes on the status of a fictional element in otherwise very accurate models. (2009, 245-246)

What I find extremely interesting about this thought experiment is that it shows how an advocate of RR such as Teller is compelled to admit that models represent, when they are used in certain contexts and for certain purposes, fictional situations. Indeed, the hydrodynamical equations of Euler represent a portion of a real state of affairs when they are used to study the fluid properties of water, and this is because the model operates as an icon vis-à-vis a certain aspects of the fluid properties of water in virtue of certain structural similarities. However, if the model is used to represent, not only the fluid properties of water, but the overall molecular structure of water (which involves the constant formation and break-up of hydrogen bonds that makes water a discrete medium), then the model functions deliberately as a symbol as it is conventionally used to represent a fictional entity.

I turn now to the second part of the argument. Let us consider an example that supports the position of advocates of RF: the case of the mathematical model put forth by Fibonacci that represents the growth of a rabbit population. As Frigg has pointed out in his analysis of this example, this model –which describes the population growth in terms of the equation P(*tn*)= P(*tn-1*)+ P(*tn-2*), where P(*tn*) is the number of rabbits at time *tn*– omits many features that that real populations of rabbits exhibit: the mortality of individual rabbits, the unavailability of food at certain stages, etc. In virtue of this, Frigg argues that models such as this one represent fictional entities:

The above equation is not about rabbits *per se*; it is about rabbits that never die, a garden that is infinitely large and contains enough food for any number of rabbits, and rabbits that procreate at a constant rate at constant speed. This is not by any standards an accurate description of the real situation; it is a fictional scenario and P(*tn*)= P(*tn-1*)+ P(*tn-2*) is true of this scenario. (2010, 106)

If no real scenario corresponds to the model, it would appear that what the mathematical model represents is a fictional situation. However, I think that, just as in the previous case, it would off pay to be more precise. The equation does not represent accurately any real, concrete scenario for Frigg; rather, it is used to generate an abstract model-system. In this circumstance, the equation functions explicitly as a symbol of the model-system because we conventionally use the equation to generate a fictional scenario (which, for Frigg, functions as a prop) that enables us to establish certain claims that hold true within the model-system. But this is just part of the picture. Indeed, for Frigg, not only are model-systems represented by equations and other model-descriptions via *particular* conventions but, as he maintains when discussing another example, the model-systems usually represent themselves concrete portions of the real world:

(…) consider the Bohr model of the hydrogen atom. On the current analysis this model consists of a model-system, which is specified by a model-description and which is described by a model apparatus (classical mechanics plus the Bohr-Sommerfeld quantization rule). A number of facts obtain in the model-system, among them that it has discrete energy levels. We then take the model system to denote real hydrogen atoms, and then use a simple key (…) to translate this fact into the claim that hydrogen itself has discrete energy levels. (2010, 128)

As this passage shows, the model-system in this example operates for Frigg as an icon since it represents a portion of reality *via* structural similarity between the mathematical structure that electron orbits have in the model-system and the spatial structure of trajectories followed by actual electrons in hydrogen atoms. Considering this, we can then appreciate that, though Frigg endorses RF when he considers the nature of the relation between model-description and model-system, he also endorses RR when he considers the nature of the relation between model-system and target-system. Now, within the Peircean framework proposed here, Frigg’s simultaneous endorsement of RF and RR is perfectly consistent since each position corresponds to a different semiotic relation between different objects. To be specific, what Frigg calls ‘p-representation’ corresponds to model-descriptions operating as symbols vis-à-vis model-systems and what he calls ‘t-representation’ corresponds to model-systems operating as icons (or indexes) vis-à-vis target-systems.[[21]](#footnote-21)

Let us consider a second example that has been used to defend RF. Barberousse and Ludwig have argued that one of the best examples that illustrates their position is the case of the Ehrenfest model in thermodynamics, which is used to explain how two bodies with different temperatures that are put into contact progressively tend to a state of thermal equilibrium. The Ehrenfest model involves thinking of the two bodies in thermal interaction as a box divided into two compartments labeled A and B, and such that A contains initially a series of balls numbered 1 through N. The model also involves supposing that we randomly draw a number between 1 and N (all draws are supposed to be equiprobable), and the ball that corresponds to this number is moved to the other compartment. Now, the model is usually of great interest to physicists, as Barberousse and Ludwig remark, in virtue of two things: insofar as the number of balls in A tends to N/2 as the number of draws increases, it reflects what happens to the target system during thermalization and the model enables us to predict with a probability of 1 that the system will return to its initial state after 2N steps (which corresponds to Poincaré’s recurrence theorem).

Barberousse and Ludwig (2009, 65) claim that this example provides support for RF because ‘it is clear that the Ehrenfest model represents a situation that is incompatible with our best physical theories (...) In none of these theories, is it possible to let molecules cross the wall one by one without disturbing the totality of the remaining system.’ Considering this, they argue that the model cannot represent a real state of affairs, but rather represents a fictional situation. I do not dispute the underlying truth of that claim. What I would only add, emphasizing some elements of what Barberousse and Ludwig maintain, is that the model represents a fictional situation if it is intended to represent the totality of the system because nothing in reality corresponds accurately to it. And, in this case, the model works as a symbol since it is used conventionally to represent the whole process of thermalization, which involves complex causal interactions between molecules that cannot be captured by a mere probabilistic process. But, as Barberousse and Ludwig concede in a further passage, the model seems to have also a key ‘epistemic interest’ (i.e., it also tells us what the world is like),[[22]](#footnote-22) which consists in the following:

The epistemic interest of the Ehrenfest model is that it allows us to isolate the probabilistic component of the statistical-mechanical representation, and to show that this component alone, when separated from the causal-dynamical component, is similar to some aspects of the behavior of systems of molecules. (2009, 66)

Thus, when the Ehrenfest model is taken to represent, not the whole process of thermal interaction between two bodies, but just some features of the behavior of molecules, then the model clearly represents a portion of the real world insofar at it operates as an icon: the model represents part of a physical system through the structural similarities between the lottery process that the fictional macroscopic balls are subject to and the action of the thermodynamic forces that the actual molecules are subject to. In virtue of all this, considering this example through the lens of Peirce’s theory of signs enables us to see that the position of Barberouse and Ludwig is not really at odds with RR.

I can turn now to the third and final stage of my argument. I have previously shown through the study of various examples of models used by advocates of RR to support their position that these examples can be seen, once they are viewed within the framework of Peirce’s theory of signs, as being perfectly compatible with the position of advocates of RF (and *vice versa*). In virtue of this, I contend that, when we conceive scientific models as signs that can exhibit not only iconic but also indexical and symbolic functions, we can see that there is no one way in which models represent. In other words, there is no ‘right’ answer to the question: ‘Is representational realism or representational fictionalism about models the correct view?’ In my view, both are correct because one and the same model can, in virtue of displaying different semiotic functions, represent either a real state of affairs (or a portion of it) or a fictional situation or feature, *depending on the context in which the model is deployed and the use that is made of it*. This position, which is a kind of representational pluralism about scientific representation,[[23]](#footnote-23) is supported by the fact that it allows us to vindicate an observation made by Morgan and Morrison (1999). According to them, models are, first and foremost, instruments of a certain kind that enable us, as many other instruments do, to accomplish a variety of different tasks. Just as a claw hammer can be used to drive a nail through a plank of wood or to subsequently pull that same nail from the plank, a model can be used, as Morgan and Morrisson show, for different purposes: in some circumstances, it can be used to represent a theory while it can be used in different circumstances to represent the world.[[24]](#footnote-24) This versatility of models that Morgan and Morrison highlight is a trait that can be satisfactorily explained if we think of models as complex signs with different aspects that can be emphasized (or, on the contrary, downplayed) by various users of the models depending on the goals that these users have and the context in which they are used. Thus, in virtue of this, it seems that adopting and extending the proposal of Kalemann and Lattman allows us to reconcile the tension between advocates of RF and of RR.

4. Using the extended proposal as an account of scientific representation

I have argued in the previous section that conceiving scientific models as signs with not only iconic but also indexical and symbolic functions or aspects enables us to address the tension between supporters of RF and of RR. Now, if my argument is correct, a further question arises: can we use my proposal to address further open questions concerning scientific representation? In this section, I want to make a case for the thesis that the proposal that I present here can be used to address a crucial question, which is: ‘how can we develop a good account of scientific representation?’ In response to this question, several authors have put forth a number of interesting proposals, such as the inferential account of scientific representation articulated by Suárez (2004) and the interpretational account defended by Contessa (2007). However, even if both accounts capture some important aspects of what scientific representation is and how it works, Shech (2015) has highlighted certain significant shortcomings that both accounts exhibit and he has also pointed out what features a good account of scientific representation should have. To be more specific, Shech has shown (quite convincingly, I think) that, although Suárez’s inferential account is attractive because it stresses the importance of viewing scientific models as entities that can be used to make certain inferences about a target, it is silent on what allows certain inferences and not others to be licensed. In a similar way, Shech has also argued that, even if Contessa’s interpretational account of scientific representation is attractive in being sensitive to the fact that in order to separate valid and sound surrogative inferences one must adopt an interpretation of the target in terms of the vehicle used to represent it, it cannot account for cases in which a scientific model misrepresents its intended target. Now, in order to address these shortcomings, Shech (2015, 2466) maintains that a satisfactory account of scientific representation requires taking scientific representations ‘to be intentional objects that come with reference, semantic content, and a representational code, with faithful representations acting as epistemic representations that are ontological guides.’[[25]](#footnote-25) Given this description, my purpose is to show that the proposal that I have defended earlier (namely, that scientific models should be considered as signs within a Peircean framework that have iconic, indexical, and symbolic functions) has the potential to allow us to develop a good general account of scientific representation.

Let us consider the first requirement that Shech introduces, i.e., that scientific representations are intentional objects with a reference, a semantic content and a representational code. Now, if we conceive scientific models as a type of signs (in accordance with the characterization of signs offered by Peirce in the passage that I cited above in section 2), we can then appreciate that they are straightforwardly intentional objects since signs are characteristically for Peirce *about* certain things; they also clearly have reference since signs are presumed *stand for something* for Peirce and they have specific semantic contents since they create *interpretants* in the minds of their users as Peirce points out.[[26]](#footnote-26) Moreover, given that Peirce holds that our reasoning is a semiotic process and that it is the use of certain signs that licenses some inferences,[[27]](#footnote-27) it is then also clear that, if we conceive scientific models as signs, they also are associated with a certain representational code which, according to Shech (2015, 3469), ‘licenses valid inferences from vehicle to target.’ This code, as Shech also observes, may be in some cases well known (thus allowing the sign to be used to draw sound inferences) or it may be unknown (thus requiring to be ‘deciphered’).[[28]](#footnote-28)

Let us consider now the second requirement that Shech introduces, i.e., that a good account of scientific representation should be able to provide an account of how faithful representations act as ontological guides (i.e., how they tell us what the target is like). As Shech also points out, in order to explain this, a successful account of scientific representation must also be able to explain the occurrence of cases of misrepresentation. Considering this, two of his main objections to the accounts of both Suárez (2004) and Contessa (2007) are that neither one is able to account in a satisfactory way for cases of misrepresentation, and that neither is able to provide a good way of distinguishing accurate representations from misrepresentations. Now, I contend that within a Peircean framework where scientific models are conceived as signs with different semiotic aspects, there is a way to explain the occurrence of misrepresentations and to draw a distinction between faithful representations and misrepresentations.

To see this with more clarity, let us consider Peirce’s views on perception. According to Peirce, what we usually call ‘perceptions’ are really composed of two different but deeply interrelated elements: the percept, which ‘does not stand for anything’ (CP 7.619) and is just ‘one single and undivided whole’ (CP 7.626) that is exhausted by its phenomenal quality (which Peirce calls its Firstness) and by its exhibiting an interaction between perceiver and perceived object (which Peirce calls its Secondness), and the perceptual judgment, which ‘professes to represent the percept’ (CP 7.627), and is, precisely in virtue of this, ‘of the nature of the sign, a representation’ (Haack 1994, 17). Now, as Haack also points out, a key characteristic of perceptual judgments for Peirce (which is also shared by all other signs) is the following one:

The perceptual judgment (…) is a representation; it is propositional, hence true or false, certain or uncertain. It is according to Peirce, indubitable, incorrigible; that is to say, it is involuntary, and so outside the scope of logical scrutiny or correction. But it is, for all of that, fallible; it may *mis*represent the percept. (Haack 1994, 17-18)

Within Peirce’s view, since all signs are characterized in terms of the relations they bear to their objects and to their interpretants, misrepresentation is something that can (and does) occur when the relations between sign and object and sign and interpretant do not match with each other. To appreciate this in the case of scientific models, let us consider one of the examples that Shech discusses: the representation of phase transitions. As he (2015, 3478) observes, phase transitions may be either represented by discontinuities or by sharp but continuous enough changes and, as he also points out, although ‘both representational structures are in (in principle) representationally adequate (…) given a background of scientific facts and theories –in this case, the atomic theory of matter– we say that one representational structure is a misrepresentation while another is not.’ If we adopt my proposal, we may explain this difference as follows: although both representational structures are empirically adequate since their corresponding signs generate in the minds of the scientists who use them the same interpretant (i.e., they allow the same grasp of the phenomena studied), one of them is a misrepresentation because the signs that correspond to the two representational structures stand for different objects, one of which does not exist. In virtue of this, my proposal allows us to offer an account of how misrepresentation can (and does) occur when using scientific models.

Let me turn now to the last element that, according to Shech, a good account of scientific representation should explain: how faithful representations can act as ontological guides (i.e., tell us what the world is like). As Shech points out, there are models that misrepresent the world[[29]](#footnote-29) but are very useful in terms of allowing inferences that enable us to offer satisfactory explanations of phenomena or to make successful predictions whereas other models may be faithful to their target systems but they are mathematically intractable. Now, in order to accommodate these cases, Shech maintains the following:

(…) a tenable theory of scientific representation needs a conceptual and terminological framework that allows us to differentiate between those aspects of a vehicle that that we think tell us what the target is like –the ontological sense of scientific representation– and those aspects that solely license sound inferences –the epistemological sense of scientific representation (2015, 3480)

In response to this demand, I contend that my proposal here provides us with a framework that enables us to distinguish the aspects that Shech mentions. Indeed, if we conceive scientific models as signs that can function in some circumstances as icons, in others as indexes and, finally, in others as symbols (depending on the goals of the agents that use them and the context where they are used), we have the resources to differentiate the ontological and epistemological aspects of models *qua* representational vehicles. Insofar as indexes represent their objects through a causal relation, I contend that the aspects of a scientific model that we think tell us what the world is like are those that function primarily as indexes vis-à-vis the objects they stand for. This claim is supported by the observation that, when we use models to tell what we think the world is like (as engineers do when they use the San Francisco Bay model), the models that we use almost invariably require *calibration*, as Weisberg (2013, 96-97) remarks. Now, since calibration is a process dependent on causal relations that is intended to establish a relation between the values of a certain real quantity (e.g., temperature) and certain indications of an instrument (e.g., a thermometer), one can argue that models only tell us what we think the world is like (which is the ontological aspect of scientific representation) if they are calibrated. And, since a model’s being calibrated involves having compared the measurement values that it delivers to those provided by a certain known standard to minimize measurement uncertainty, using a calibrated model to tell us what we think the world is like involves viewing it as an index that ‘points towards’ some aspects of the world, just as a calibrated thermometer ‘points towards’ a feature (i.e., temperature) of a system.

In addition, insofar as icons represent their objects through a kind of similarity whereas symbols represent their objects through a certain convention, I maintain that the aspects of a model that solely license sound inferences are those that function primarily as icons or as symbols. This contention is supported by two facts. First, there is a growing amount of psychological evidence showing that inferential processes (and, to be more specific, inductive inferential processes) are primarily acquired by infants on the basis of similarity (e.g., Shepard 1987, Sloutsky 2003, Weber and Osherson 2010). Second, there is also substantial psychological evidence showing that, as infants grow up, names progressively become markers of a common category, thus allowing individuals to make certain inductive inferences on the basis of them while ignoring similarities (e.g., Sloutsky et al. 2001, Keates and Graham 2007, Deng and Sloutsky 2013). In virtue of this evidence that suggests that our ability to make inferences depends crucially on similarity and on the existence of linguistic labels, one can then argue that, if we want to use a model solely to make certain inferences (which is the epistemological aspect of scientific representation), then we have to consider the model in question primarily as an icon or as a symbol. Thus, to sum up, we can satisfy Shech’s demand for a framework that enables us to separate the ontological and epistemological aspects of scientific representation using Peirce’s theory of signs. Indeed, within this framework, we can maintain that, when scientific models represent, the ontological role of scientific representation is done through the underscoring of indexical elements while the epistemological role is done through the underscoring of both iconic and symbolic elements.

5. Conclusion

I have argued here that, if we consider scientific models to be signs that possess iconic, indexical and symbolic functions within the framework of Peirce’s theory of signs, we can reconcile the positions of advocates of RR and of RF. I have also argued that adopting this framework is attractive since it provides the basis to develop an account of scientific representation that fulfills all the main desiderata that, according to Shech, a good account should fulfill.[[30]](#footnote-30) If what I have argued for here is correct, a couple of interesting lines of inquiry emerge: (i) can Peirce’s theory of signs help us to offer accounts of other functions (e.g., explanation, prediction, verification) that models have? (ii) If so, is it possible to develop, within the framework provided by Peirce’s theory of signs, a comprehensive account of all the functions that models have? I intend to pursue these issues in future work.

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1. It is important to emphasize here that the debates are parallel, but not identical. The RF vs. RR debate is about *what* models represent (fictional situations vs. real objects) whereas the IR vs. DR debate is about *how* models represent (indirect or two-stage representation vs. direct or one-stage representation). [↑](#footnote-ref-1)
2. In a prior version of this article, a reviewer asked whether there is a one-to-one correspondence between RF and IR on one side, and RR and DR on the other, and if this is so, whether this entails that they are two different sides of the same coin, so to speak. Though these questions are important, I set them aside here for the sake of space, though I intend to address them in future work. [↑](#footnote-ref-2)
3. Toon (2010, 84-85) articulates what is at stake here as follows: “What exactly are ‘imagined physical systems’ of ‘hypothetical entities’? Like a number of other authors, Frigg compares model systems to fictional entities, like unicorns or Count Dracula. Of course, the nature of fictional entities, and the particular question of whether such entities exist at all, is itself the subject of considerable controversy.” [↑](#footnote-ref-3)
4. In a recent paper, Frigg and Nguyen (2016, 228) attempt to address this question by introducing the notion of *I-instantiation*. The basic idea behind this notion is that a model M (say, a physical ball-and-stick model of a water molecule) I-instantiates a property P (say, the property of having the sticks form a 104.45° angle) iff its target T (say, a water molecule) instantiates a property P’ (say, having a bent three-dimensional structure where the covalent bonds between the hydrogen atoms and the oxygen atom are arranged 104.45° angle) and P’ is mapped onto P under a certain interpretation I. For Frigg and Nguyen, ‘this allows a model to I-instantiate properties that it does not instantiate.’ [↑](#footnote-ref-4)
5. I owe this example to Catherine Legg. [↑](#footnote-ref-5)
6. By this, I do not mean that denotation is sufficient for representation in the case of signs. Rather, my point here is the same that Shech (2015, 3468, fn12) makes: ‘the concept of representation presupposes that something is being represented, and it is in this minimal sense that representations are intentional objects.’ Thus, in my view, the concept of sign presupposes that there is something the sign stands for. [↑](#footnote-ref-6)
7. Even though some authors treat abstraction as a certain type of idealization (e.g., McMullin 1985), I follow here Jones (2005, 175) in distinguishing idealization from abstraction in the following manner: ‘we should take idealization to require the assertion of a falsehood, and take abstraction to involve the omission of a truth.’ [↑](#footnote-ref-7)
8. To put this idea in other words, if we conceive representing as a polyadic relation, we must, as Giere (2004, 743) puts it, ensure that ‘one place, of course, goes to the agents, the scientists who do the representing.’ [↑](#footnote-ref-8)
9. In a prior version of this paper, a reviewer pointed out that French (2003, 1474) seems to defend the idea that models may represent by themselves without any agents to the extent that he claims that “whereas intentions are typically drawn upon in art in order to distinguish ‘artistic’ objects from other kinds, this is not the case in science.” Now, I think that French’s view can be reconciled with Giere’s position in virtue of the following. When he discusses the parallels between artistic and scientific representation, French cites approvingly an insight of Budd (1993, 162) according to which ‘representation consists in the *perceived* isomorphism of structure’. To illustrate this, French goes over an example discussed by Budd (i.e., the case of the anamorphic skull in Holbein’s *The Ambassadors*) and he remarks that, though the picture is not isomorphic to a skull when one stands in front of the painting, it is isomorphic when one looks at the painting from the perspective of a spectator in an oblique position. On the basis of this insight, one could argue that what French holds is that, though it may seem that some models represent in isolation since there no actual agents who do the representing, in fact they always represent in relation to the perspective of some possible agent. [↑](#footnote-ref-9)
10. Albert Atkin (2013) characterizes the notion of index in Peirce’s theory of signs as follows: ‘If (…) our interpretation [of a sign standing for an object] comes in virtue of some brute, existential fact, causal connections say, then the sign is an index.’ Now, given that a sign functions as an index if we come to interpret it as standing for an object through some brute, existential fact, causal relations usually provide the basis for something to function as an index for Peirce (as in the case of a weathercock, which indicates the direction of the wind), but entities may also function as indexes in virtue of other brute, existential facts (e.g., topological or mereological relations). For instance, the road sign with a stylized airplane may function as an index of the direction of the airport in virtue of a topological relation between both objects and an emerged periscope may function as an index of a submerged submarine in virtue of a mereological relation between both objects. [↑](#footnote-ref-10)
11. Iranzo (2013, 67) makes this point using this specific example. In fact, Iranzo also remarks that the view that scientific representation is based on structural similarity comes in different varieties. For instance, some proposals such as those of van Fraassen (1980) and of French and Da Costa (2003) emphasize the use of structural isomorphism for scientific representation while other proposals such as that of Giere (2010) involve a more complex view that includes structural similarity but also appeals crucially to the intentions of the agents using the model. [↑](#footnote-ref-11)
12. Darwin ([1859] 2009, 129) describes his model in the following fashion: ‘The affinities of all the beings of the same class have sometimes been represented by a great tree. I believe this simile largely speaks the truth. The green and budding twigs may represent existing species; and those produced during each former year may represent the long succession of extinct species.’ This view of scientific models, according to which they represent their targets *via* some analogical or metaphorical relations, is defended in the works of Black (1962) and Hesse (1963). [↑](#footnote-ref-12)
13. For Leonelli (2008, 522), material abstraction is a process that ‘involves selecting a set of material features of *Arabidopsis* wild types as potentially interesting for research purposes, devising ways in which these properties can be incorporated into a unique specimen, making sure that specimens with those characteristics can actually be grown, and constructing a toolkit of guidelines, materials and instruments allowing researchers worldwide to grow specimens in the same way.’ [↑](#footnote-ref-13)
14. In a prior version of this article, a referee pointed out that two of the functions that a sign may exhibit (i.e., index and symbol) seem to be conflated in my discussion of Leonelli’s example. Part of the problem is that Leonelli herself does not separate clearly these two functions in her discussion of how material abstraction is used to create models of *Arabidopsis*. I have tried to clarify things by stressing that a certain specimen of *Arabidopsis* may represent some wild specimens (*qua* index) in virtue of some causal links between the organisms and that some of the features of this specimen may represent features in other plants (*qua* symbols) in virtue of a certain conventions established by scientists. [↑](#footnote-ref-14)
15. Callender and Cohen (2006, 74) illustrate this feature using the following example: ‘Can your left hand represent the Platonic form of beauty? Of course, so long as you stipulate that the former represents the latter. Then, when your dinner partner asks what you are thinking about, you can direct attention to your left hand with the reasonable intention that your doing so will activate in your audience the belief that you are thinking about the Platonic form of beauty.’ [↑](#footnote-ref-15)
16. For Liu (2015, 47), the insufficiency of mere conventional or symbolic relations to do all the main work in instances of scientific representation is illustrated using this example: ‘I have never been to Africa, yet I can acquire a good sense of what an African savannah looks like through vehicles of model representation. That is not possible if I can have access only to symbolic vehicles, even if I know and consent to all the symbols that relate to African savannahs (…)’ [↑](#footnote-ref-16)
17. Different authors use different terminology. For instance, Suárez (2003, 225) refers to a representational vehicle as the *source* of a representation in order to distinguish it from what he calls the *target* of the representation (which is the object represented). I will use here, following Callender and Cohen as well as Liu, the term ‘representational vehicle’ since the term ‘source’ does not quite convey the idea that scientific models are used as *tools* to represent certain objects. [↑](#footnote-ref-17)
18. In particular, Liu (2015, 48) argues that, while some may be reluctant to separate epistemic vehicles from symbolic ones since some objects often seem to play both roles, the distinction is justified since they play both roles in different contexts as the following example shows: ‘The double helix model of DNA as a model showing the relevant structure of the molecules is rarely used as a convenient symbol in the context of scientific research and pedagogy. When it is used as a symbol, it is used as a symbol of a great scientific achievement; and then, and usually only then, is a fully realized replica of the model (…) necessary to be placed somewhere to do the job of a scientific representation.’ [↑](#footnote-ref-18)
19. The fact that this model was devised and constructed by its builders to represent a portion of the real world is underscored by Weisberg (2013, 1-3), who writes: ‘The Corps recognized the benefits that the Reber plan might bring to the area, but it was certain that damning the bay would have serious, unintended consequences. It recognized that a battle of words would not be advisable in advising regional authorities; it needed hard data. But how such data be collected without actually building the dams and risking harm to the bay? Its solution was to build a massive hydraulic scale model of the San Francisco bay.’ [↑](#footnote-ref-19)
20. The primary indexical role of the San Francisco bay model is further highlighted by the fact that the model had to be *calibrated* so that it could to be used effectively to represent the tidal flows. For further discussion of this, see section 4 below. [↑](#footnote-ref-20)
21. In virtue of this, one of the advantages of adopting the Peircean framework that I present and defend here is that we don’t need to make a distinction (as Frigg does) between different kinds of representation. On my view, there is just one relation of representation that admits different grounds (iconic, indexical or symbolic) and that may hold between different items. [↑](#footnote-ref-21)
22. The term ‘epistemic’ that Barberousse and Ludwig use is potentially misleading since models may be used produce knowledge even if they do not tell us what the world is like. In virtue of this, I prefer the terminology (as well as the associated distinction) that Shech (2015, 3464) puts forth in the following passage: ‘Scientists routinely use representational structures such as models to make inferences about the world (epistemological aspect) and to tell us what it is like (ontological aspect).’ Though both aspects are usually deployed in tandem while building and employing scientific models (since one usually draws inferences from what there is in the world, as a reviewer pointed out in a previous version of this article), I believe that it is important to distinguish them because they correspond to different functions: an inferential one and a descriptive one. The importance of separating these functions can be further supported by considering the fact that statisticians traditionally distinguish inferential statistics from descriptive statistics. [↑](#footnote-ref-22)
23. I am very grateful here to a reviewer who suggested presenting my position in these terms. [↑](#footnote-ref-23)
24. One of the best examples of this trait of scientific models is provided by Prandtl’s hydrodynamical model of a liquid with a very thin boundary layer, which is amply discussed by Morrison (1999, 53-60). [↑](#footnote-ref-24)
25. I will explain below what all these terms, which *are termini tecnici*, mean and how the conditions they impose are met by the account I presented here. [↑](#footnote-ref-25)
26. The following passage from Kralemann and Lattman (2013, 3402-3403) shows that, if one adopts the view they propose, scientific models turn out to be intentional objects with both reference and specific semantic contents: ‘models are signs which represent something else, i.e., their objects; nonetheless they do not act as signs by themselves, but only when they are made to do so by an interpretative act of a subject that pursues a specific objective and who explicitly or implicitly chooses a theoretic or linguistic context including a frequently semantically coded prior knowledge, which in the concrete act of modeling connects the model with a specific semantic content, i.e., its interpretation.’ [↑](#footnote-ref-26)
27. Peirce (NEM, IV, 353) ‘(…) in all reasoning there must be something amounting to a diagram before the mind’s eye and the act of inference consists in observing the relation between the parts of that diagram that have not entered yet into the design of its construction.’ [↑](#footnote-ref-27)
28. This last point by Shech is important since it echoes a rather plausible claim made by Łukasiewicz (and mentioned in Giedymin 1986, 198), which is that the search for the universal laws of nature (which is presumably one of the tasks of science) could be compared to the deciphering of a coded message when the code is unknown. [↑](#footnote-ref-28)
29. It is important to make a clarification here: in a sense, all models misrepresent their targets since they are all built using both abstraction and idealization, which involve willful and explicit distortions or omissions. However, this does not prevent us from judging some models as more ontologically faithful than others since, as Shech (2015, 3480) observes, ‘faithfulness and accuracy are matters of degree’. [↑](#footnote-ref-29)
30. A reviewer has pointed out that, though the Peircean framework that I articulated here is interesting, I have not done enough to show that Peirce's conception of signs is strong enough to carry the epistemic roles that scientific models must fulfill in the practice of science –roles which include, not only representation, but also learning and testing hypotheses (e.g., Downes 2011). Undertaking this project is beyond this paper. However, I think that the framework has the resources to develop an account of other epistemic roles that models have –in particular, of how scientists develop and choose models to learn. In the case of learning, the gist of the argument would be the following: granting that models are signs, we can in principle explain how they are used by scientists to learn by reflecting on how toddlers make doodles and combine them in different ways to learn and recall information, since doodling appears to promote learning according to psychological research. For more details on the connection between doodling and learning, see Andrade (2010). [↑](#footnote-ref-30)