The aims of representative practices: symmetry as a case study

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Abstract

The aim of this paper is to define a methodology that clarifies some crucial aspects of scientific representative practices. As a case study, this method explores the use of models and relates it to specific practical functions. In the first section, I emphasize the fruitfulness of a philosophical enquiry that accounts for the aims and the objectives towards which scientific practices direct their interest. Secondly, by using symmetry as a case study, I try to show that philosophy can find rich pathways of interaction with sciences, by proposing a dynamical approach to scientific representation. In the third section of the paper, I shall refer to examples that highlight the use of symmetry in current scientific representative practices. I shall conclude with some remarks on this method and its epistemological implications on our conception of objectivity and symmetry.

Keywords: scientific representation, representative practices, symmetry, models

Introduction

What we call "symmetry" refers to a rich variety (we talk about symmetries in plural) of different possible operations that inform our current scientific theories and practices. For this specific reason, symmetry is a suitable case study in order to reflect upon scientific representative practices in general. Symmetries have attracted and still attract the interest of scientists and philosophers. The huge amount of published studies allows us to investigate a wide range of scientific practices, as well as different methodologies at stake in different contexts. In expounding the aims underlying the choice of representing organic and inorganic processes by means of symmetries, the questions of the status and *reification* of symmetries in the world arise. What is the ontological status of symmetries? Are they something physical? In some cases the answer is straightforward: symmetries are just mathematical operations. In other cases, however, it is far from being unproblematic to define their status and they appear to have physical meaning, as it is in the case of Quantum systems.

The distinction between mathematical and physical symmetries still leaves the ontological question of their status open and this paper approaches this topic from a fresh perspective in order to add a small piece into the picture, by constraining symmetries as a case study into a wider framework. Symmetries in physics, engineering, chemistry and biology will be briefly reviewed and framed within the reflection upon the scientific practices in which they are involved. They will be investigated in the context of the use that science and practitioners make of them, rather than be analyzed *per se* as metaphysical entities.

In order to expound our strategy, let us consider what follows. "The most important lesson that we have learned in this century is that the secret of nature is symmetry". With this statement D. Gross (1999, p. 57) echoed the method that Hermann Weyl advanced in *Symmetry* (1952). Weyl firmly believed that our *a priori* statements in physics are grounded on symmetry. Nevertheless, the fact that symmetry can act as a canon in informing scientific theories and models, does not prove that symmetry is a secret of nature. On the contrary, they appear as a result of a complex mathematical and methodological procedure that we developed in the last century in order to classify the laws of nature and take control over phenomena.

For what concerns the question of whether symmetries correspond to actual processes in nature, if we follow upon Gross, we are tempted to agree with this. However, upon closer examination, Weyl also held a slightly different view. Symmetry (specifically in physics) does not correspond to the secret that nature is hiding; rather it appears to be one of the most powerful operations to order the interactions produced by processes that we are still trying to determine and clarify.[1]

Weyl also proposed to refer geometrical symmetry (bilateral and rotational symmetries) to certain operations that can be detected in both scientific and artistic representative practices: "Symmetry, as wide or as narrow as you may define its meaning, is one idea by which man through the ages has tried to comprehend and create order, beauty and perfection" (Weyl 1952, p. 5). The fact that we appeal to symmetry in different fields means that there are different representative practices that can employ analogous operations. If we take symmetry as being one of those operations unifying our methodology in different practices, we might discover that symmetry ceases to be a "secret of nature", and rather appears as a truth or a canon of representative practices.

However, it must be conceded that there is more than a mere analogy between the results of interactions and the operations that we perform: this analogy rests on the ground of the operation of mapping the unity of the system under analysis according to an automorphism. It would be inadequate to restrict the question of the status of symmetries to this analogy without expounding the role they play in scientific practices. In other words, to restrict our investigation to the possible kinds of symmetries that could find physical meaning is not satisfactory from both a scientific and philosophical perspective. It appears to be relevant to focus on the fact that in current scientific practices, we can detect methods that allow *the acquisition of the correspondence* between model-systems and target-systems, for instance, even if it is just in terms of an approximation, as well as in terms of a cross-check between mathematical models and measurements of actual interactions. These questions must be thought in relationship to the undeniable fact that there is an idealized

[1] Weyl believed that there is a physical process in nature that determines the success of the use of symmetry in physics in terms of prediction (see Weyl, 1952, p. 25). The perspective according to which symmetry works as a sort of regulative principle that can be supplemented by a deterministic theory via the development of physics has been endorsed by Wigner (1967). For an overview on the topic of symmetries in physics, see Brading and Castellani (2003).

status of symmetries that show their operational character together with the fact that in some specific contexts they assume physical meaning in modelling phenomena.

In order to assess the nature of these methods, I suggest to look at what scientists do when they appeal to symmetries, namely at the aims that are at stake in scientific representative practices. The fruitfulness of this approach lies in the fact that in our specific case study we detect the unifying role of symmetries, according to certain practical functions. This in turn allows us to see that symmetry help us to encompass phenomena into a system of principles and rules aiming at the unity of their representation: these principles and rules are chosen according to aims, objectives, and criteria of unification that fit the unity of the processes under analysis.

The same procedure holds for other criteria or canons that we might endorse in scientific representation. Therefore, this procedure is not just a peculiar feature of models constructed according to spacetime symmetries or geometrical symmetries. To the scientific representation employing models are to be ascribed functions that do not pertain to the mere description or denotation of target systems. We certainly find more than mere denotation, for instance, in the engineering model of a bridge performed according to robustness criteria and in general in all performance-based models that aim at explaining phenomena such as failure, cracks, and so forth.

In what follows I shall propose and discuss the reasons why our conceptions of representation and correspondence are to be re-shaped in the context of what I call a 'dynamical approach' to scientific representation. This aspect is clarified in the next section and it is the starting point of our reflections.

Part I: Scientific representation or scientific representative practices?

In what follows I shall advance the 'dynamical approach' to scientific representation, according to which, in different sciences, principles and rules are chosen according to aims, objectives, and criteria of unification that select and inform the unity (or a specific type of unity among others) of the processes under analysis, even if the resulting models are just an approximation of these processes (be these data or phenomena as target-system). Before dealing with this approach, I shall expound the reason why it is more appropriate to talk about representative practices instead of representation, and why our conception of representative practices should consider the aims and the objectives towards which they direct their interest.

The expression 'representative practices' might recall Sorrell's (2004) or Lynch and Woolgar's (1990) works. The present perspective, however, does not approach the subject sociologically or from a Peircean stance. Nevertheless, it recognizes the framework of the social human activity that informs both scientific and artistic representative practices. My claim is that the aims and the objectives pertaining to these practices cannot be isolated from the use of model-systems and specific practical functions. These aims and objectives are part of model-systems, because, in informing them, they allow the "acquisition of the correspondence" with a target system.

This observation might open interesting perspectives, if applied to the current debate on scientific representation in the philosophy of science.

The richness of this debate offered several answers to the constitution of model-systems informing scientific representation. Most of these answers, as far as I can see, assume that this is a debate concerning the actuality, the possibility or the impossibility of a certain relation of correspondence between model-system and target-system, be the latter referred to data or phenomena.[2]

Since models are one of the most fundamental tools used in sciences, I shall briefly refer to the current debate in the philosophy of science in order to frame the close relationship between models and their practical functions and to highlight how the aims directing modelling can be encompassed into a dynamical approach to the question of scientific representation. I shall distinguish my position from others by referring to the expression ‘scientific representative practices’, meaning the process of the aim-directed modelling entailing practical functions.

A. Framing the question

The debate concerning the status of scientific representation and the role played by models is object of extensive studies. Interestingly, some of them investigated the presence or the exclusion of the link between scientific and artistic representation. Callender and Cohen (2006), for instance, suggested that while there is no special problem about scientific representation, there is a general question involving representation, be it scientific or artistic. However, Callender and Cohen still share the same view advanced by the prominent participants to the mainstream debate: they are still endorsing a view according to which representation is a relation and involves a notion of correspondence. Also they maintain that this correspondence is grounded on arbitrary stipulation, even if they rightly proposed not to treat representation *per se*.[3] I maintain that the distinction between art and science does not rely on operations as they are in themselves, rather on the way in which they are performed according to the aims that we ascribe to them: geometrical symmetry, for instance, can be used in scientific practices and in art as well. Albeit distinguished, art and sciences pertain to the same domain as being products of human social activities, and both scientists and artists interact, in very different ways, with the institutions.

[2] Within the debate on scientific representation, models received special attention. Giere claims that there is a “similarity” between a model and the world (Giere 1988, p. 81), depending on the intentions in designing and the use of the model performed by scientists (Giere 1992, pp. 122-123). Another claim is advanced by French, who identifies the relationship between model and the real world as partial isomorphism (French 2002). Other introduced the normative aspects in dealing with representation (Morrison 2006), as well as the interconnection of the representational and explanatory features of models (Morrison and Morgan 1999).

[3] See Callender and Cohen (2006, p. 15): “In particular, we propose that the varied representational vehicles used in scientific settings (models, equations, toothpick constructions, drawings, etc.) represent their targets (the behavior of ideal gases, quantum state evolutions, bridges) by virtue of the mental states of their makers/users. For example, the drawing represents the bridge because the maker of the drawing stipulates that it does, and intends to activate in his audience (consumers of the representational vehicle, including possibly himself) the belief that it does”. The weakness of this point is highlighted by Frigg (2010).

Specifically, sciences are directed towards explicit or implicit aims, most of the time subordinated to the interests of political and economical institutions (in both the public and the private sector). It is undeniable that there is a strong link between our models and scientific theories, which are produced by complex activities, and our social practices, namely the fields and different activities in which we exert our knowledge, we acquire skills, we make experience and we set up the advancements for future development and research. Sciences are thus related to applications that transform the organization of our lives in the society.

Nevertheless it would be far from a mere epistemological perspective to highlight the tasks linked to these interests. The question that should be raised here is the fact that due to this inevitable commitment to the social sphere and to the necessity of manipulation and control, scientific representative practices employ models that add something more to the model-descriptions.

As Frigg (2010) argued “model-descriptions usually only specify a handful of essential properties, but it is understood that the model-system has properties other than the ones mentioned in the description. Model-systems are interesting exactly because more is true of them than what the initial description specifies; no one would spend time studying model systems if all there was to know about them was the explicit content of the initial description. It is, for instance, true that the Newtonian model-system representing the solar system is stable and that the model-earth moves in an elliptic orbit; but none of this is part of the explicit content of the model-system’s original specification”.[4] We might observe, however, that this difference in instantiation between model-descriptions and model-systems depends on the aims attributed to the latter (albeit they are not to be identified with them) that are linked to concrete applications and to the aims of scientific representative practices in the human social organization (this is quite evident in the case of engineering practices or research in nanotechnology).

Different ways of representing phenomena in sciences (but this holds in art as well) can share common characteristics, as the studies of Stegeman (1969), Callender and Craig (2006), and Frigg (2010) show. However, it can be shown that these representative practices also differ according to the different aims that are, so to speak, ‘attached’ to the operations performed in their domains: the use of the model-system counts to mark this difference. This basic observation also holds within the same scientific domain when a mathematical model is related to a model system, which entails much more than the first model from it descends.

Furthermore, same phenomena can be ‘represented’, or better, modeled, in a different way by the engineer and the physicist (see section III example 4, when the engineering model is insufficient to fit the aims of the target-system, engineers appeal to physical model-systems), but same phenomena can be described or explained on the ground of different models, depending on the chosen aims. For example, in the case of a bridge one can perform the analysis concerning lateral and vertical vibrations on the ground of a numerical model. Engineers can do it, by endorsing a prescriptive or a performance-based approach or both of them. The design, thus, can proceed via models that are empirically informed, by taking into account human behavior in interacting with a structure, or via the application of physical or biological models that show, as a result, the behavior

[4] Frigg (2010, p. 102).

analogous to the processes of interest. Scientists from different fields also propose different considerations of causal laws, depending on the use of a scientific model that they chose to endorse. Same laws assume or lose relevance depending on the context in which they are used and produce a representation of the processes at stake directed towards aims (again see section III example 4, where from the virtual works principle descend two completely different models of physical systems and engineering models in the FEM, with inevitable consequences on the 'representation' of the target system). Finally, an interesting example is offered by Hughes (1997) "DDI" theory of representation, which identifies three elements pertaining scientific representation from an epistemological perspective: elements of "denotation", "demonstration", and "interpretation". Hughes suggested that "if we examine a theoretical model with these three activities in mind, we shall achieve some insight into the kind of representation that it provides" (Hughes 1997, pp. 329; 335). The present perspective, as far as what I call "practical functions" of scientific representative practices are concerned, is close to Hughes' stance. The problem thus concerns how we represent something, namely what counts in the present approach are the activities and the functions that we associate to the aims of modelling phenomena.

B. Philosophy and scientific representative practices: the dynamical approach

The concept of scientific representation gives us the chance to ask two main questions concerning 1) the possible ingredients of scientific reasoning and scientific representation and 2) the ways in which we produce and/or reproduce our scientific knowledge and representative practices.

I am interested in the second aspect rather than in the first attempt, which is related to a metaphysical and ontological perspective that I call 'the static approach' to scientific representation. We should start considering the idea of abandoning what I call a 'static' idea of representation.

Current debates on scientific representation and idealization descend from one of the most intricate philosophical questions, namely the possibility of any correspondence between thought and reality, and truth and reality. Even if the terms of the debate focus on data, models and scientific theories, the question of the possible relationship among them and its justification is far from being solved and is still drawn in terms of correspondence, no matter whether it is complete, incomplete or impossible (to these three terms we can refer the realist, antirealist and skeptic positions).[5]

Correspondence is a result of a complex process of manipulation, unification and acquisition, rather than an assumption, and the mere concept of representation does not explain the dynamics of this process. Philosophy seems unable to resist the temptation of reflecting upon the concept of representation *per se* and to assume its relation with a theory of correspondence (or non-

[5] The history of philosophy might help us in this case. It is not by chance that for modern philosophy, from Descartes onwards, the term "representation" and its definition played a crucial role. By the end of the Seventeenth Century, representation had become a fundamental problem in epistemology, in natural philosophy, and in mathematics. In each of these fields, we can identify crucial topics that re-emerge in subsequent developments of the philosophy of science and epistemology. In 1780s Immanuel Kant tried to undermine the problem, by establishing that representation is a 'general mark' in logical terms: it is so general and vague that the problem of a theory of knowledge should concentrate rather on the operations of the mind and forget about the correspondence-theory problem involving the mere concept of representation (*Vorstellung, repraesentatio*).

correspondence). For instance, Frigg defines representation as follows: "Representation then is the relation between a model-system and its target-system".[6] He follows upon Callender and Cohen when he claims that "It has been pointed out variously—and in my view correctly—that, in principle, anything can be a representation of anything else".[7]

Therefore, at present, the concept of representation is one of those concepts that we cannot easily abandon, because it offered a rich source for reflection and invested the crucial epistemological problem of correspondence that engaged philosophers of science in the last decades, as well as philosophers in the last four hundred years.

However, what if we change the conception of representation and correspondence underlying the studies on scientific representation? We might find perhaps that, even in the case of one of the most debated cases, the case of symmetry, our enquiry can find fruitful pathways of interaction with sciences.

In order to reach this goal, I shall present and discuss the practical functions that are present in the use of symmetries. For each of these functions there are aims directly linked to the use of symmetry in different sciences. The aims that accompany our scientific representation in practice consist in:

a. Definition of properties
b. Classification
c. Manipulation
d. Finding of conserved quantities
e. Selection of necessary rules

The next step consist in showing that these aims are not at all arbitrary, but respond to necessary tasks of scientific practices that profoundly influence the organization of our life once they are applied to specific fields.

Part II: Symmetry in context

In this section I expound the nature of the dynamical approach to scientific representation and relate the use of symmetries to aims and practical functions. Even if it might appear at first sight that what follows consists in a mere review of case studies and examples, the reader will immediately notice that the thesis advanced in the previous section is tested and shows the extreme flexibility of the dynamical approach. While this first section aims at detecting the practical functions attached to our models, the last section will include the aims of scientific representative practices and by relating them to the practical functions, will directly embody the methodology of a dynamical approach to these practices.

[6] Frigg (2010, p. 99).
[7] Frigg (2010, p. 99).

I have already highlighted the high prominence of symmetry as a suitable case study, given its wide use across sciences. Furthermore, I emphasized that symmetry embodies the role of a canon or a rule, which is not taken from experience, but is mathematically constructed: it is an operation. Those who believe that models are set-theoretic structures identified symmetry with a property of the relation or the structure: models are structures and they are composed mathematical or set-theoretic entities.[8] In these models, what counts consists in relations whose properties derive from reflexivity, transitivity, symmetry and so forth. I shall present now an alternative approach to deal with symmetry and scientific representation.[9]

If we look at the practical implications of scientific representation, namely if we consider the dynamics at stake in scientific representative practices that employ different kinds of symmetries, we find that the aims are incorporated into the model system, which is not constituted by simple extensionally defined relations (see example B and section III example 4).[10] The second point that the structuralist approach misses is that symmetry (a part from its mathematical formulation confined within its definition of automorphism) is not a relation that can be referred to objects without including properties that pertain to the specific system under analysis and that in some cases take into account not only the material properties of the objects, but also human behavior (as it is in the case of the performance-based approach and risk analysis of structures in civil engineering). With regard to this observation, it seems relevant to point out that in numerical models, for instance, qualitative variables or semi-quantitative variables can always be made quantitative through random assignment. However, this implies a complex process and cross-check methods according to the aim associated to the model: modelling depends on the aims of the representative practices at stake. As far as I can see, this complex activity would be missed by focusing on the mere extensional characterization of relations. Moreover, as we shall see in this section, symmetry appears more as an operation at stake in scientific representative practices, which does not exhaust the activity of modelling systems and processes. For this reason, a dynamical approach should be preferred, since it can be further enriched by features expounded by a static

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[8] Van Fraassen (1980), Da Costa and French (1990).

[9] I follow here Frigg´s observations on the structural realist stance: "This definition of isomorphism brings a predicament to the fore: an isomorphism holds between two structures and not between a structure and a part of the world per se. In order to make sense of the notion that there is an isomorphism between a model-system and its target-system, we have to assume that the target exemplifies a particular structure. The problem is that this cannot be had without bringing nonstructural features into play". This point is clearly shown in the case of engineering model-systems, where even the material of the structure (i.e. wood, steal etc.) and the shape of the structural elements play a crucial role in modelling.

[10] I endorse here once again Frigg's criticism of this view: "For what follows it is important to be clear on what we mean by "individual" and "relation" in this context. To define the domain of a structure it does not matter what the individuals are—they may be whatever. The only thing that matters from a structural point of view is that there are so and so many of them. Or to put it another way, all we need is dummies or placeholders. Relations are understood in a similarly "deflationary" way. It is not important what the relation "in itself" is; all that matters is between which objects it holds. For this reason, a relation is specified purely extensionally, that is, as class of ordered *n*-tuples and the relation is assumed to be nothing over and above this class of ordered tuples. Thus understood, relations have no properties other than those that derive from this extensional characterization, such as transitivity, reflexivity, symmetry, etc. This leaves us with a notion of structure containing dummy-objects between which purely extensionally defined relations hold".

approach to scientific representation, but still has the advantage of capturing the complexity of the processes under analysis, by including the activity of data and model interpretations. I shall start with examples of symmetries in geometrical objects and their possible use in chemistry in order to highlight the present perspective, and I shall briefly refer in examples B) and C) to symmetries in physics.

A- Examples of symmetries in geometrical objects are given by symmetries of transformations as rotations and reflections that leave geometric objects **invariant**. Symmetries of geometric objects are relevant in sciences, as shown in the case of a molecule with tetrahedrical symmetry. The CH_4 (methane molecule) has the form of a tetrahedron and the symmetry of the molecule usually determines some of the physical and chemical properties of the substance (for example the band structure that it shows in Infrared and Raman spectroscopy).[11] We infer that if a molecule possesses inversion symmetry, this cannot have an electric dipole moment. Put in a different way, there is a point $\vec{p}$ such that the molecule is invariant under

$$\vec{x} \mapsto 2\vec{p} - \vec{x}.$$

In this case we define invariance and an actual property, by acquiring a correspondence between what we can find in nature and the rules of symmetry that we follow in order to be oriented in practical experience. The aims associated with this practical function consists in manipulating and classifying physical bodies for further applications.

B- Transformations of space and time that leave the equations of motion invariant constitute another example that is extremely helpful to show how we incorporate aims in scientific representative practices. For Newtonian physics these symmetries are the transformations forming the Galilei group, which is a 10 dimensional Lie Group:

1) $\vec{x} \mapsto \vec{x} + \vec{x}_0$ spatial translations

2) $t \mapsto t + t_0$t time translations

3) $\vec{x} \mapsto \vec{x} + \vec{v}_0 t$ relative movement at constant velocity

4) $\vec{x} \mapsto R_0 \vec{x}$ spatial rotations

These symmetries are extremely relevant in physics, because we associate the aim of **finding** conserved quantities to the symmetries of the equations of motion, according to a practical function of prediction.

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[11] Coates (2000, pp. 10815–10837).

For relativistic physics the equations are invariant under *Lorentz transformations* (which also are a 10 dimensional Lie Group). The translations and rotations act the same way as in the Galilei group, but the transformations that relate reference systems that are moving with constant velocity relative to each other act differently. Consider the equation:

$$\Box\phi(t,x,y,z) \equiv \left(\frac{1}{c^2}\frac{\partial^2}{\partial t^2} - \frac{\partial^2}{\partial x^2} - \frac{\partial^2}{\partial y^2} - \frac{\partial^2}{\partial z^2}\right)\phi(t,x,y,z) = 0$$

By assuming that Lorentz invariance is a fundamental symmetry of nature, then the form, which the equations of motion for the various matter fields and forces can take, is severely **restricted**. The practical function of prediction operates here in synergy with the practical function of restriction (see example C). Furthermore, we can detect the practical function of prediction, by considering *Noether's Theorem*, which establishes that, if in a theory there is a continuous *n*-parameter family of symmetries, then there are *n* conserved quantities. If the equations of motion for a field are invariant under time translations, there is a conserved energy density for this field. The scientific representative practice at stake here is one of the most relevant for models in physics and is directly linked to the **practical function of prediction** that we ascribe to scientific theories and models in general.

C- Gauge symmetries that leave local equations of motion invariant are **restrictive** in terms of the equations of motion that they allow. Gauge symmetry plays a crucial role in the foundation of the Standard Model, given that the fundamental interactions (electromagnetic, weak and strong) are symmetric *under* a certain gauge symmetry: gauge symmetry dictates the form of the interactions and in doing so it allows to perform the practical function of **restricting** the equation of motion to be used in a certain scientific theory and in model-systems. Also it allows us to construct a system of interaction to classify phenomena at high energy scales.

It must be noticed that in scientific representative practices three practical functions emerge from these examples:

In case A we have the dominance of the function of **invariance**: we generally attribute objectivity to this function in order to **define properties of the processes under analysis**, **classify** and **manipulate** them for further aims.[12]

In case B we have the dominance of the function of **prediction**: symmetry is of a fundamental significance in order to 1) **find conserved quantities of a system** independently from its degree of complexity, and 2) **incorporate phenomena** into a system via implemented classification (see case C).

[12] Note that symmetry is not to be completely identified with invariance as pointed out by Roman (2004, p. 6).

In case C we have the dominance of the practical function of **restriction**: symmetry allows the **selection of necessary rules** and principles to be used for further tasks within the framework of a specific theory and at the same time it informs its systematic and unified character.

Part III: Symmetry and scientific representative practices

In this last section, I shall refer to examples that highlight the use of symmetries in different fields as aim-directed scientific representative practices. I try to show that the dynamical approach to the question of scientific representation can highlight the complexity of current practices. What emerges in this section is the fact that depending on the aims embodied by models, different kinds of symmetries can be endorsed. I shall present four cases that might be read as being interconnected when interpreted as transitions of goal-directed modelling processes from one stage to a more complex one.

1. When dealing with models concerning the behavior of s*nowflakes and crystals*, the practical function of classification is clearly displayed by using geometrical symmetry. The symmetry is "injected" in physical bodies to easily compare them with other samples. However, as shown in the X-ray and atomic force diagrams, geometrical symmetry allows an approximation, but not a pure correspondence between the model and the physical object. This idealization is directed towards aims of comparison, classification and intervention.

2. One of the most intriguing cases to investigate concerns the application of *Lie Groups* to the structure of *Hydrogen atom*. Scientists insert operators to make it symmetrical in both the relativistic and non-relativistic case for the purpose of prediction and explanation that would be otherwise impossible to achieve by means of geometrical symmetry. This aspect is clearly pointed out by S. Singer.[13] Her analysis focuses on how to make predictions about the numbers of each kind of basic state of a quantum system from only two ingredients: symmetry and the linear model of quantum mechanics. This method has wide applications in crystallography, atomic structure, classification of manifolds with symmetry and other fields. Also, as shown by S. J. Weinberg (2011), it is possible to generate SO(4) symmetry from Lie algebra in the methods for analyzing the hydrogen atom. Through the use of dynamical symmetry scientists provided a new approach to the "accidental degeneracy" of the hydrogen atoms energy levels and explained it. Further applications of this model in physics can be found in Vibron Model Description of molecules, the Interacting Boson Model of the Atomic Nucleus, the SU(3) classification of hadrons, and the Bose–Einstein condensates of spinor and tensor bosons. The hydrogen atom model inspires current studies in genetics and biology, as we shall see in the next example.

3. One of the most well-established model-systems is the *DNA Structure (Helical Symmetry)*. The reason why we use helical symmetry in modelling DNA structure has obvious practical implications in terms of description of the processes of its replication in order to intervene and manipulate them. We can perform dodecahedral rotation or privilege the axial view of DNA double helix, according to the aim of intervening on it and easily identify the processes of a certain

[13] Singer (2005, pp. 283-296).

interest in simulations and test. As R. Sinden (1994) argued, two-dimensional and three-dimensional nuclear magnetic resonance (NMR) data of DNA in solution provided three-dimensional coordinates for the position of individual atoms in DNA, with the result that the picture that emerges is one of an extremely variable helical structure, not at all uniform and monotonous. Furthermore, the secondary structure of DNA can assume myriad alternative or non-B-DNA forms (which are the most common models used since 1960s and derived from X-ray diffraction analysis).[14] The classical model is *de facto* insufficient when the evolution of the genetic code is considered. In genetics, scientists prefer to employ a pseudo-orthogonal (Lorentz like) symmetry in stochastic modelling, in order to 'represent' a genetic network. In this way, models of gene expression are linked to the practical function of prediction of processes involved in the secondary structure of DNA. This practical function was weakened in the classical model. Rather, as I claimed in the previous example, the study of the energy levels of hydrogen atoms and the definition of degeneracy applied to them played a crucial role in developing models, which in turn are *analogically* applied to genetics:

> "The notion of degeneracy is profoundly related to that of symmetry. Degeneracy means invariance; in the present case, it means that the codon to amino acid assignment is invariant under the replacement of codons by synonymous ones. And invariance means symmetry, in the sense that one can build transformation groups that keep invariant certain properties. This kind of connection between symmetry and invariance can be seen in the spectrum of the hydrogen atom: this is a system with an obvious rotational symmetry, implying that states with the same azimuthal angular momentum quantum number *m* will have the same energy".[15]

Scientists may refer to an algebraic approach in modelling the evolution of the genetic code: a current code is generated by a dynamical symmetry breaking process, starting out from an initial state of complete symmetry and ending in the observed final state of low symmetry. In both cases, symmetry plays a decisive role: in the first case, it is a characteristic (invariant) feature of the dynamics of the gene switch and its decay to equilibrium, whereas in the second, it provides the guidelines for the evolution of the coding.[16] It is possible to identify in this procedure the practical functions of invariance, prediction and restriction associated to the use of symmetry in scientific representative practices. The following passage clarifies these aspects and we can detect in the scientists' words the operations they performed, according to the practical functions and the aims associated to their practice:

> "But symmetries may be much less obvious than in this case; they may be hidden! And there are many examples where the spectrum of a molecule or atom is a testimony of some hidden symmetry. Thus if we look at the genetic code from this point of view, *as if* it were some kind of spectrum, we face a straightforward question: is the degeneracy pattern of the code the expression of some hidden symmetry?

[14] Sinden (1994, pp. 3; 32).
[15] Ramos, Innocentini, Forger, Hornos (2010).
[16] See Ramos, Innocentini, Forger, Hornos (2010).

This promptly suggested performing what we may call ‘the search for symmetries in the genetic code’. […] Lie group theory provides a well-developed mathematical machinery for modelling symmetry in biological systems. It provides not only a quantitative framework but also leads to biological insights about the processes that are modelled, as shown by the examples presented in this review. *In the stochastic model for a two-state gene, symmetry has practical implications*: the eigenvalue of the diagonal operator characterises the dynamics of the gene switch and the affinity between the regulatory protein and the gene operator site, whereas the non-diagonal operators connect the probability distributions of the two states. In addition, noise analysis leads to the conclusion that fast switching genes give rise to Poissonian distributions whereas slowly switching genes have broader or bi-peaked distributions. In the algebraic model for the evolution of the genetic code, possible pathways for this evolution arise naturally, but are strongly restricted. The picture of evolution by a stepwise incorporation of new amino acids *fits perfectly* with that of dynamical symmetry breaking. The Klein symmetry that has remained preserved can serve as an underlying principle that has conducted the evolution of the standard code as well as that of non-standard codes. In the modelling of gene networks, group theoretical tools can be useful for the search for a composition rule between two or more genes. Another feature is the possibility to model single genes that present more than two levels of regulation. The construction of a dynamical system for the evolution of the genetic code is also a possible future application of group theoretical methods in biology”.[17]

As it appears from this passage, we cannot detach a model system from its specific use. Moreover, as I have previously pointed out, what we call “correspondence” in representing phenomena is nothing else but a process of fitting aims of scientific representative practices. The process of acquisition of the correspondence embodied in the model system is acquired by following a rule (Klein symmetry in this case) that allows the composition of standard code and non-standard codes. The endorsement of the abovementioned model based on the group theoretic approach is informed by the aim of reproducing a rule for the evolution of the genetic code. Therefore, its mathematical model shall reflect this aim and the resulting model system incorporates necessarily the practical functions of invariance, prediction and restriction pertaining to the use of symmetries. On the ground of heuristic considerations, scientists analogically construct the unity of the processes under analysis. This definition seems to be valid for model systems both referred to target-systems and actual phenomena.

4. The aspects expounded in natural sciences and pertaining to scientific representative practices may well be found in engineering also. *Symmetry in engineering modelling* can be detected in the Finite element method (FEM). FEM is a technique originally developed for numerical solution of complex problems in structural mechanics. In the FEM, the structural system is modeled by a set of finite elements connected at points (or nodes). Elements may have physical properties, such as thickness, coefficient of thermal expansion, density, Young’s modulus, shear modulus and Poisson’s ratio. It is also possible to model straight or curved one-dimensional elements with physical properties such as axial bending and torsional stiffness. In engineering the use of this kind of elements aims at modelling the behavior of cables, braces, trusses, beams, stiffeners, grids and frames that in turn can be parts of more complex structures. The elements are placed at the

[17] Ramos, Innocentini, Forger, Homos (2010).

centroidal axis of the actual members. This allows engineers to model only half of the elements via axial symmetry in such a way that the analysis time is significantly reduced, as well as the cost. There is clearly a utilitarian function attributed to geometrical symmetry here. Indeed, the introduction of FEM has substantially decreased the time to take results to the production line. Through improved initial prototype designs using FEM testing and development have been accelerated and productivity increased.

FEM has radically improved both the standard of engineering designs and the methodology of the design process in many applications. For example, in spice-compatible circuits and system simulators, it can be used a combination of analytic and numerical approaches in the FEM that generates other models to consider more complicated effects. In “Behavioural modelling for heterogeneous systems based on FEM descriptions”, J. Haase, S. Reitz, and P. Schwarz have shown that model-description are incorporated into model-systems to fit and predict the behavior of a certain structure. The combination of these models into one model-system is determined by the laws at stake (in the specific case, a generalization of Kirchhoff’s Current Law) that regulate the unity of the process under analysis. The method of incorporation of two or more model-descriptions into one model-system allows the use of analytical FEM formulas for the construction of behavioral models, to derive behavioral models with fixed numerical values for components from FEM descriptions, and the implementation of models in different languages (MAST, HDL-A, VHDL-AMS). This methodology employed in engineering encompasses geometrical symmetry in the FEM, and use it for constraining relations among structural components and to restrict the variables in mathematical models when the performance-based approach is endorsed. The latter operation seems to point towards an account of models different from the structural realist stance. Moreover, this last example confirms that the use of a model (be it a model-description or a model-system) makes the difference in scientific practices for the definition of the models-system itself that should account for complex actual processes.

What is really intriguing from the present perspective is that, despite of its high flexibility, FEM modelling depends on the numerical model and the aims engineers pursue. Even if it might seem at first that this kind of modelling is suitable for a semantic and structuralist account of models, it can represents a challenge to an account of models as structures related by partial isomorphism or partial homomorphism. If we have to account, for instance, for gusset plates buckling we appeal to the FEM. Now, in a structural realist stance, the mathematical model would be partially isomorphically mapped into sub-models (or sub-structures). But in the FEM there would be more than these relations. The mathematical model appears to be rather the result of a process for the prediction of the behavior of the system/object (see Fig. 1). Furthermore, in practice, engineers can modify the sub-models through an error-controlled model, which is not mapped into the mathematical model. The final model-system entails models that can be independent of each other, or just indirectly dependent.

Furthermore, the mathematical model does not entail the exact relationships of displacement modeled to account for the actual buckling of a gusset plate (it must include, for instance, thermal coefficients depending on the material and the shape of the gusset plate). In the FEM coefficients referred to empirical properties of the elements influence the model and are embodied in structural codes (such as the EUROCODES). The elements are positioned at the mid-surface of the actual layer thickness, and to do so, one does not rely on the mathematical model only. This is the case also for torus-shaped elements used to solve axis-symmetric problems, such as thin, thick plates, shells, and solids that may have cross-sections. Now, the behavior of nodes is modeled according to nodal (vector) displacements or degrees of freedom, which may include translations, rotations, and, for special applications, higher order derivatives of displacements.

Algebraic tools, such as the theory of groups that dictate the symmetric structure of the mathematical model certainly are the results of a mapping process, but the latter is not related to models taken in themselves, rather homeomorphism and monomorphism, but the same holds for homo-morphism, are nothing but goal-oriented functions for validation and verification of both approximated models (which are sub-models of the mathematical model) and the goal-oriented mathematical model (see Fig. 1). The latter does not simply entail the approximated structures, but as a model-system include more than these relations and structures: it is goal-oriented. The semantic stance claims that models are to be reconstructed as ordered n-tuples of sets: a set of objects; a set of properties, quantities and relations over these objects; and a set of functions on the quantities. The structural realist stance (French and Ladyman 1999; Bueno et al. 2002) advanced the thesis that in the semantic theory of models we may determine their nature by looking at partial isomorphism or partial homo-morphism as shaping the relation between mathematical theories and the world, more specifically between models and models of the world. According to our previous definition, this 'static' approach should not be discussed within the context of the dynamical approach to scientific representation. However, since this stance claims that partial isomorphism or partial homo-morphism and a theory of models as structures can enrich and clarify scientific practices, a response is in order. A partial isomorphism requires that for all R_i in the set of relations defining the model, R_1(xy), iff , $R_1^{'}(f(x)f(y))$ and R_2(xy), iff $R_2^{'}(f(x)f(y))$, so that every definite assertion of the first model must hold in the second as well. Suaréz and Cartwright (2008) highlighted that this approach leads us to admit that there is no way to leave behind parts of the first model in moving to the second; whatever the first model definitely asserts—either that the relation definitely does hold or that it definitely does not—must still hold in the second model. Moreover, according to another structural approach (Bueno et al. 2002) the relation between mathematical theories and the world could be often read in terms of partial homomorphisms. Given two models taken as partial structures, a partial homomorphism holds between them in such a way that objects in the second model can possess relations that are lacked in the first. According to Suaréz and Cartwright (2008), this is still not sufficient to capture the fact that there may be relations positively ascribed to objects in the old model that one wishes to deny in the new. What counts from our present perspective is the fact that in engineering practices, there are criteria according to which the new model possesses relations lacked in the first one or that are denied in the new one. As Stein et al. (2004) show, there are goal-oriented error estimates or bounds that inform a mathematical reference model, albeit indirectly. Now, depending on the external error controlled model, the homomorphism is mapped for validation from a hierarchical approximation to the goal-oriented mathematical model.

It is true that between models isomorphism (non necessarily always partial) can be detected, but, as the case of FEM clearly shows, it is for validation purposes, and presupposes an error controlled model and a numerical method, which are not directly referred to the goal-oriented mathematical model, albeit they cannot be read off the complex modelling process of a certain system.

Model-systems including sub-models, or ‘sub-structures’ can follow upon symmetry or asymmetry conditions that are exploited in order to restrict the size of the domain, and to predict the structural behavior of an object, by determining displacement compatibility along the element edges, particularly when adjacent elements are of different types, material or thickness. Compatibility of displacements of many nodes can usually be imposed via constraint relations imposed to nodes on symmetry axes, however, when it is not feasible, a (third) physical model that imposes the constraints may be used instead. In the model-systems the elements’ behaviors capture the dominant actions of the actual system, by adding something more (elements’ shape, empirical constraints, and so forth) to the mathematical model. Furthermore, it must be noticed that in the performance-based approach in engineering the mathematical model is not presupposed in the model system, rather is used as a goal-oriented framework for double-checking the consistency of some constraints that have been chosen according to physical laws, numerical methods, and so forth. If the structural realist position aims at highlighting some of the possible relations that are at stake in sub-models, and just one stage of a complex process, then I might find it consistent. However, if, on the contrary, it aims at revealing the dynamics of modelling as a process, it appears to fail.

Conclusion

From the previous discussion descends that we use symmetries in our scientific practices by associating them to practical functions of invariance, prediction, and restriction in order to control and further manipulate models and their associated phenomena. We intervene and manipulate certain processes according to an order that is dictated and controlled by functions, operators and so forth, in order to predict part of the behavior of a process under certain transformations that leave it invariant. However, given that models include the operations of our scientific representative practices, they also include the practical functions and the associated aims that inform the model-systems. It does not mean, however, that a physical object is the product of a mere arbitrary construction, nor that model-systems are just structures. It is rather clear that when we adopt specific representative practices in sciences, particularly by using symmetry (or asymmetry) in modelling, we are pursuing specific aims depending on the functions of invariance,[18] prediction and restriction. Representing in sciences is never independent of aims. Applications and problem solving strategies reveal this crucial aspect.

[18] Though, as I tried to show, there is not a perfect correspondence between symmetry and invariance.

For this reason, I cannot agree with Frigg on that "the intrinsic nature of a model-system does not depend on whether or not it is so used: representation is extrinsic to the medium doing the representing".[19] We have seen how the dynamical approach to the question of scientific representation allows us to deal with crucial elements that are disregarded by current interpretations.

From the present perspective, as it emerged in the case of symmetry, there is something more to be added to our conception of representation, especially scientific representation. The latter cannot be read in terms of mere correspondence or as a relation. As I tried to show, the use of the term 'representation' is ambiguous, because it prevents us from seeing the dynamics underlying scientific processes and from explaining the fact that we use specific scientific tools to predict and anticipate phenomena, whose unity is incorporated and captured by model-systems and their results. The concept of scientific representative practices is an ideal substitute for the concept of scientific representation, because it entails the reference to the way in which we order and restrict data, laws and phenomena, not only in a descriptive, but also in an explanatory way. A desirable account of scientific representative practices looks at the purposes that we may inject into models via the performance of practical functions. I suggested that this account should be considered as a 'dynamical approach' to the question of scientific representation. In the specific context of this paper, I have shown that to expound the reasons why we use symmetries in sciences means to deal with a certain conception of objectivity as invariance (see Part II, example A), and, according to the proposed view, the question of objectivity can be inserted in the context of a dynamical approach to representative practices. Objectivity is linked to practical functions and aims of scientific representative practices: the more the results of a model-system fit the aims at stake (such as explaining the failure of a bridge or the replication of DNA by comparing two double-helix structures) and show consistency, the more the operations and functions they are attached to acquire objectivity. Objectivity ceases to be read in terms of correspondence and becomes a process that includes the operations we perform, as well as their aims.

The concept of representative practices certainly tells us that we look at permanent properties, primary properties as relations of invariance of/in a certain system, but also that this is not the whole story. As I tried to show, it is with the identification of other crucial practical functions and the aims that we associate to models that we can give a more satisfactory account of scientific practices,[20] and then throw a fresh light on the use of symmetries in sciences. Conclusively, scientific representative practices (that refer to something more than a mere mapping,

[19] Frigg (2010, p. 99). Frigg's perspective is closer to what I called the 'static approach' to scientific representation, dealing with the "intrinsic nature" of model-systems and the ingredients of scientific representation. The disagreement does not concern his arguments, which I find consistent with his perspective, but rather it is due to the different approach I endorse.

[20] Furthermore to investigate these practices from a dynamical perspective means to analyze the relationship between scientific and artistic representative practices also, because they depend on the same ground: **human social activity**. In scientific representative practices we relate the operation of symmetries to images, to visualization, qualitative and material properties, as it is in the case of lattices, molecule models, snowflakes etc. Now, these 'representations' turn out to be beautiful as well. We often experience the paradox that in representing something for scientific purposes, it finally turns out to be part of another representative approach, or better representative practice, which pertains to art. We have still to explain why and how this is possible.

partial isomorphism or partial homo-morphism) are portrayed as aim-directed processes of ordering phenomena or laws according to a chosen rule embodied by models that must respond at least to one of the three abovementioned functions: invariance, prediction, and restriction. Although it is far from being complete, the proposed approach to scientific representative practices ties together the practical functions and the aims associated to the processes of acquisition of the correspondence between model-systems and target-systems. Further discussion concerns the ground of the agreement on the use of certain models and the interpretations of different results descending from scientific practices. More importantly, the present approach, perhaps, entails the possibility of re-defining or abandoning the concept of correspondence in the current debate on scientific representation. But this is another question that deserves further discussion.

Bibliography

Brading K. and Castellani E. *Symmetries in Physics*. Cambridge: Cambridge University Press, 2003.

Bueno, O., French, S., Ladyman, J. *On representing the relationship between the mathematical and the empirical*. In: *Philosophy of Science* (2002), 69: 497–518.

Callender C. and Cohen J. *There Is No Special Problem About Scientific Representation*. In: *Theoria* (2006), 55: 7–25.

Coates, J. *Interpretation of Infrared Spectra. A Practical Approach*. In: Meyers, R. A. (Ed.). *Encyclopedia of Analytical Chemistry*. Chichester: John Wiley & Sons Ltd., 2000: 10815–10837.

French, S., Ladyman, J. *Reinflating the semantic approach*. In: *International Studies in the Philosophy of Science* (1999), 13: 103–121.

Frigg, R. *Fiction and scientific representation*. In: Frigg, R. and Hunter, M. (eds.) Beyond mimesis and convention: representation in art and science. Dordrecht: Springer, The Netherlands, 2010: 97-138

Gross, D. *The triumph and the limitations of quantum field theory*. In: Conceptual foundations of quantum field theory. T: Y: Cao (ed.) New York and Cambridge: Cambridge University Press 1999, 56-67.

Hartmann, S. and Frigg, R. *Models in science*. In: Zalta, Edward N., (ed.). Stanford: The Stanford encyclopedia of philosophy. Stanford University 2006.

Hughes, R. I. G. *Models and Representation*. *Philosophy of Science* 64 (1997), Supplement: 325–336.

Lynch M, and Woolgar S., *Representation in scientific practice*. MIT Press, 1990.

Morgan, M. and Morrison, M. (eds.). *Models as Mediators: Perspectives on Natural and Social Science*. Cambridge: Cambridge University Press 1999.

Ramos, A.F., Innocentini, G.C.P., Forger, F. M., Hornos, J.E.M., *Symmetry in biology: from genetic code to stochastic gene regulation in Systems Biology*. In: IET 4 (2010): 311 – 329.

Roman, P., *Why Symmetry?* In: *Symmetries in Science* XI. B. Gruber, G. Marmo, N. Yoshinaga (eds.). Dordrecht: Kluwer, 2004.

Sinden, R., *DNA Structure and Function*. San Diego, CA: Academic Press, 1994.

Singer, S., *Linearity, Symmetry, and Prediction in the Hydrogen Atom: An Introduction to Group and Representation Theory*. New York: Springer 2005.

Sorrell K. S., *Representative Practices: Peirce, pragmatism, and feminist epistemology*. New York: Fordham University Press, 2004.

Stegeman, B. *The Art of Science*. The Journal of Aesthetics and Art Criticism Vol. 27, No. 1 (Autumn, 1968): 13-19.

____*Science as Art*. In: A Bulletin of the Atomic Scientists, April (1969): 27-30.
Stein, E., Rüter, M., Ohnimus, S. *Adaptive finite element analysis and modelling of solids and structures. Findings, problems and trends*. In: *Int. J. Numer. Meth. Engng* (2004), 60:103–138.
Suaréz, M. Cartwright, N. *Theories:Tools versus Models*. In: Studies *in History and Philosophy of Modern Physics* (2008), 39: 62–81.
Van Fraassen, B. *The Scientific Image*. Oxford: Oxford University Press, 1980.
_____*Scientific Representation: Paradoxes of Perspectives*. Oxford: Oxford University Press 2008.
Weinberg, S.J. *The SO(4) Symmetry of the Hydrogen Atom*. 2011, available at (http://hep.uchicago.edu/~rosner/p342/projs/weinberg.pdf).
Weyl, H. *Symmetry*. Princeton: Princeton University Press, 1952.
Wigner, E. P., *Symmetries and Reflections*. Bloomington, IN: Indiana University Press, 1967.

Fig. 1 Sequence of physical structures, mathematical models and numerical methods similar to the one proposed by Stein et al. 2004. Note that models related through partial isomorphism would be just a small part of the process underlying the goal-oriented mathematical model.