Realism and Scientific Models: The Relevance of the Distinction between Epistemology and Ontology

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Summary

During the last few decades Realist perspectives within philosophy are gaining force by developing new and traditional arguments. The present article proposes that scientific models, more precisely *effective models*, provide a good example for showing important flaws in arguments regarding incommensurability or underdetermination. First, before examining examples in quantum physics and gravitation theories, a critique to skepticism is proposed. This is intended to show that a realist approach to science can be supported by scientific development. Second, we propose a defense of *Scientific Realism*. This defense is aimed to show how scientific models and theories can consistently progress if they are observed as representations that can increase their resolution when their predictions are confirmed and new elements are added to their descriptive accounts.

Resumen

Durante las últimas décadas, las perspectivas Realistas en filosofía han ganado fuerza mediante el desarrollo de nuevos argumentos y la recomposición de argumentos tradicionales. El presente artículo propone que los modelos científicos, específicamente los *modelos efectivos*, ejemplifican cómo los argumentos de la inconmensurabilidad y subdeterminación presentan importantes debilidades. Con este propósito, antes de examinar ejemplos proveídos por la física cuántica y teorías sobre la gravita-

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ción, se propone una crítica al escepticismo. Esto pretende mostrar que una aproximación a la ciencia en términos realistas encuentra sustento en el desarrollo científico. Considerando esto, y para finalizar, se propone una defensa del *Realismo Científico*. Esta defensa tiene como objetivo mostrar cómo los modelos científicos y las teorías pueden progresar consistentemente si son observados como representaciones que adquieren mayor resolución cuando sus predicciones son confirmadas y cuando se agregan nuevos elementos a sus descripciones.

Introduction

The theoretical and experimental development of science during the last few centuries has deeply impacted philosophy. The consequences of this advancement have changed the way we understand metaphysics and the theory of knowledge. And, as it can be expected from radical changes, it has brought intense debates about what is exactly the nature of this change, how many changes really are, or what is the new philosophical stance we should take. Recent philosophical work seems to be divided into two big factions. One is the old empire of Scepticism, diversely represented by idealism, positivism, or instrumentalism. On the other side, Realism has ceased its naiveté to become a strong opponent that during the last decades appears to be overwhelming sceptical positions, rapidly recovering the philosophical territory.

Our main objective in this article consists in showing why scientific theories are progressive (though not always continuous). Progression that, we argue, can be observed in the effectiveness of scientific models. At the same time, we want to argue that this circumstance supports the idea of an external world that is real and not mentally or magically produced. Therefore, physical laws, understood as natural patterns which are represented by formulations within a theory, have an ontological status. Moreover, the models devised by those theories are epistemic devices that can be distinguished from what they represent. In other words, we can consider that those models exist, but their ontological nature is a humanly-made mental representation: they are brain processes interacting to understand and represent the environment. In other words, epistemology has an ontological status too. With this in mind, we think that this conception can be sustained by Scientific Realism in a consistent way.

In the first section we will criticize scepticism, positing that its strongest arguments are circular or inconsistent. We will argue that the scientific-philosophical relationship can be better developed through a realist attitude. The two middle sections are devoted to explore how physical theories progress and how they can include older models into their frameworks. For doing this we approach models as mappings of the world that can increase their resolution when theories integrate new effective (predictive and descriptive) elements into them. Finally, we will develop a defence of Scientific Realism, position that allows us to think of science as a progressive human enterprise.

Some Inconsistencies of Scepticism

During the last three decades Scientific Realism has been reshaped and adjusted in a way that has turned it into a strong and sound perspective to approach epistemological and ontological questions. Even more, it seems to be consistent with many scientific methodologies and, in this sense, it can constitute a solid background for the understanding of scientific and epistemological models. Nevertheless, the aim of this section is not a discussion of the virtues and possible implications of a Scientific Realist stance, but the description and brief evaluation of a series of arguments that place Scientific Realism in stable ground against Scepticism. Most of these arguments emerge from the Philosophy of Science, but they concern epistemological and ontological investigations as well. And this is very relevant for the main objective of our research: explaining why clearly distinguishing epistemological and ontological categories is crucial for the understanding of scientific models and theories.

To start with, it is necessary to take into account realism's oldest nemesis: the sceptical argument. We want to attack this problem using two arguments. (1) The *circularity of radical scepticism*. (2) The *slippery slope to idealism*. The first argument is intended to show how some sceptical perspectives, such as idealism or solipsism, fail to explain in non-contradictory terms how the world can be purely mentally originated. The second argument demonstrates how non well defined realism or weak sceptic positions can lead to idealism by conceding sceptical claims that are not necessarily sound. Clearly, we do not pretend to prove scepticism wrong once and for all; we just want to posit some good reasons to believe that realism represents a better perspective if we want to deal with some (or many) epistemological and ontological problems.

The first argument is not very complicated to grasp. Its main point is to show how *radical scepticism*, in a Humean formulation (or interpretation), fails to prove the spontaneous and momentary nature of impressions as disconnected from past and future. As Shimony (1947) has explained it:

> If Hume's sense impressions are strictly momentary, then there is no relation of a past impression to a present or future one. The result is that not only could we not know anything about the past, but we could not even have any idea that there is time and passage of time at all,... (p. 56).

Mario Bunge (1979) has extended Shimony's argument to show that the Humean attempt to disprove productive causation assumes the conclusion in one of its premises by saying that sense impressions are already disconnected from past and future, which makes the argument circular. One of the fundamental problems of this empiricist argument is that it conflates causation with regularity because it reduces "... the meaning of a proposition to the mode of its verification." (Bunge, 1979, p. 45) . In other words, *radical scepticism* conflates an epistemological supposition with an ontological consequence.

Sometimes this sceptical problem proposes mysterious solutions, such as the mental origin of the world (usually from a God-like or Demiurgic emanating mind) or an individual mental construction of reality (e.g. solipsism, radical-constructivism). However, this faces a greater problem: what is the source of those mental causations? Proposing a supernatural mind as a solution brings out the problem of infinite regress: a self-caused supra-mental being or an infinite chain of demiurges one causing the subsequent one (just like in Borge's poem: *Ajedrez*); clearly both are tautological solutions. Another option is to propose a solipsist perspective, that is the mind of the cogent subject creates the world. However, this would mean that the world does not exist until a particular mind creates it and it ends its existence when that mind ceases its activity; this is a clear violation of Lucretius' principle or the *genetic principle* (Bunge, 1979), which states that nothing can come from nothing (*ex nihilo nihil fit*).

We think that these arguments suffice to show that the principal forms of *radical scepticism* do not rest in sound arguments. Nevertheless, we cannot deal with causation in this article, because it would require a whole new topic. Although, causal accounts, as we have noticed, give important reasons for doubting the notion of a purely internal reality.

But, if we accept that mind is caused by a specific organization of material entities, so that minds require brains to exist, then we must face the problem of how those minds interact with an external reality that affects them. Clearly, solving the problem by proposing a direct continuity between mind and world would mean *naive realism* or vitalism. And these perspectives, especially *naive realism*, are flawed because of an obvious reason: we get things wrong constantly. Not only we make inaccurate predictions, but we do not grasp the world in a continuous and cohered way; as years of neuroscientific work have shown (Hooker, 1995; Churchland, 2010), we perceive fragmented and incomplete features of the world.

This last conclusion has incentivized some philosophers to propose that *soft scepticism* is the best solution for this problem. For instance, positivism and instrumentalism rely on this kind of sceptic position. One problem of *soft scepticism* is that it can step into a slippery slope that falls directly into idealism. Paul Churchland (2010) has suggested that this problem is originated by considering, as Locke did, that there is a one-to-one semantic relationship between a mental representation and the thing that is represented. However, it seems more plausible to think of the brain as configuring highly complex representations that are configured by the transduction of different sensorial stimuli that conform perceptual and cognitive maps of a very fuzzy environment. Because: "Contrary to the Locke-Hume picture at issue, the empirically accessible objective world does not come precarved into obvious simples." (Churchland, 2010, p. 83). Therefore, a simple sceptic doubt that states that our senses cannot be trusted always (nor completely), grounded in the wrong basis (i.e., that properties of objects cause a direct impression on our minds), might lead us to doubt any access to reality and even to doubt reality itself.

Notwithstanding this rejection of scepticism, we do not believe that reality can be accessed directly. According to our present perspective, reality should be understood in terms of a highly complex world that can be represented in different degrees, representation that can be improved through technological development and scientific advancement. Our best theories can be understood as mappings of the world, not completely different from our perceptual or day-to-day (manifest) mappings of our immediate environment. We can refine those maps, including scientific representations which are developed through a collective process of assessing and comparing the accuracy and resolution (fine-grainedness) of those models and theories. Through the next two sections we will exemplify this by showing how physical models and theories progress and how, when they improve, they can express a more detailed representation of the world.

Effective Models in Quantum Physics and the Refining of Representations

Throughout the last years Models in physics have been perfected and now they can show or represent aspects of our physical reality in a more detailed form. This characteristic progress of science can be observed in both models and theories. Here we present some examples of this progressive improvement in physics. Contrarily to some perspectives (usually unscientific) that regard Quantum Physics as an example of a reality that is discontinuous and undefined, we want to show that the development of Models in Quantum Physics supports two relevant assertions in favour of Scientific Realism. (i) The discussion about scientific continuity cannot be homologated to the problems of continuity in the physical reality; once again: ontology cannot be fused with epistemology. (ii) The relevant question for scientific theories is the one regarding the preservation of features: new models can keep features of old models as long as the new refined theory can repair inaccurate references or explanations. In this sense, physics (and other sciences) can integrate old models to new ones in an homomorphic way. A new theory or model can increase its granularity: new theories are more fine-grained when compared to old theories. If old models are not radically wrong, they can be integrated into the new proposed representations.

Now, let us consider Bohr's model of the atom and its further refining by successive theories. During the beginning of the twentieth century, Niels Bohr postulated a very simple model of the atom: electrons as point particles orbiting the nucleus in discrete levels. This model represents the electron as moving through specific energy levels (quantization). However, something that this model could not explain was the phenomenon of *spontaneous emission*. This phenomenon can be resumed in this way: in some exited atoms, electrons in different states tend to decay, that is in some moment of time electrons "fall" into *lower energy levels* emitting quantas of light. Even though this model did not give us an explanation of how the physics behind the process work, it did give us a sufficiently good picture (representation) of how electros behave and are distributed in relation to the atom. Furthermore, it has introduced to us a new perspective on quantization regarding the level of atomic dimensions.

The electronic transition was not understood until the advent of Quantum Field Theory (*QFT*), or *second quantization* (Baym, 1968; Maggiore, 2005). Thus, only with the development of QFT, physics came to understand the underlying mechanism of spontaneous emission; albeit for doing that it is was not necessary to threw away Bohr's representation. In this new approach, we understand particles as manifestations of fields in spacetime, and electron's transition is explained by some interaction between both electron quantum field and electromagnetic *vacuum quantum field*. This shows the difference between a model that can *describe* and a model that can *explain* a physical phenomenon (Etkina et al., 2005). Therefore, a model that effectively describes a physical property or entity does not necessarily explains its behaviour. Though this does not mean that a descriptive model cannot be subject to further refinement by new theories or models that can explain better some of its elements. Thus, that model can be integrated into a more fine-grained picture of the physical reality that both old and new models try to describe and explain.

In addition, there is a group of models developed to study systems in physics. They are based on the assumption that we cannot see all the details of a system. In this sense, when we study a process or system through a model, that model has a specific *resolution* which is understood as incomplete but increasable. This type of models are called *effective models*, because they are explicative though they show a limited or coarse-grained picture of the studied process. One popular effective model, usually considered a prototypical example of this type of models, was proposed during the decade of 1930 by Enrico Fermi. This model was constructed to explain the beta decay; namely, a neutron decaying to a proton, electron and electronic antineutrino (Langacker, 2010).

$$n \longrightarrow p + e + v_e$$

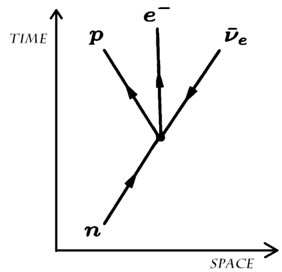

Fig.1: Beta minus decay explained according to Fermi's model.

In Fermi's model we understand the decay process diagrammatically as a point-contact interaction (see Fig.1). This model proposes a point-like interaction between the four particles involved in this reaction. The mathematical model of this process, represented diagrammatically by Fig. 1, was very successful for describing some parameters involved in the decay process. Nevertheless, the model has a limited energy-range of validity (Langacker, 2010). Therefore, Fermi's theory cannot tell the full story.

In the Intermediate Vector Boson Theory, the four-particle interaction was eliminated (Yukawa, 1935; Schwinger, 1957). Instead, it was assumed that the process was mediated by a spin-1 particle, analogous to the photon in the Quantum Electrodynamics Theory (Langacker, 2010). However, the intermediate bosons W^-, which participate in the beta decay were assumed to be very massive (compared to the energies of the experiments) and electrically charged. This new proposal is depicted in Fig. 2, and the model behind it is the Electroweak Interaction Model, which for some energy limits tends to behave as the process represented in Fig. 1. The electroweak model is part of the Standard Model (SM), the model of electroweak and strong interactions. Nowadays it is the paradigmatic model for representing interactions of elementary particles. It is important to say that SM agrees to an exceptional level with the experimental data, showing that models and experimentation are highly consistent. Nevertheless, there still are some unexplained phenomena; for example: dark matter, matter-antimatter asymmetry, neutrino oscillations, or the hierarchy problem. Surprisingly, these issues can make us think that SM is an effective theory as well. That is not a wrong interpretation, because these unexplained phenomena tell us that SM has limited resolution; resolution that might be improved by future representations.

Fig. 2: Beta minus decay explained according to the electroweak effective model.

What we have shown in this section is how the improvement of effective models works. Effective models in particle physics are so important, and have been played such a prominent role, due to their simplicity. As we have said above, this type of models work with certain limited resolution. Usually in physics the resolution of a model is referred as the *degrees of freedom* of a system. These degrees of freedom can be understood as the dynamical variables of a specific model. Hence, If we want to increase the resolution of a representation we need to develop a theory capable of producing models which include more variables that can depict the new observed details. And this can give us information of the existence of substructures present in a specific physical system. In the case of Fermi's model we have observed the process not considering the underlying degree of freedom, the particle W^-, that mediates the interaction point (where the decay occurs). Differently, a more complete theory, such as the Electroweak Model, explicitly includes this degree of freedom. This new degree of freedom coincides with the particle W^-, because this particle establishes the necessary relationships that can include the variables absent in Fermi's model[3]. Therefore, models that include more degrees of freedom are more fine-grained representation of physical reality.

These models have been used in Particle Physics, Condensed Matter, Statistical Mechanics, General Relativity and Hydrodynamics. Nowadays, the success of Quantum Field Theories (QFT), such as the Standard Model of particle physics, permits us to consider other possible extensions of the model based on the same ground. For example: Supersymmetry, Technicolor, or Grand Unified Theories. For sure, both *representational models* and *effective models* have played a very important role for the understanding of physical reality in different areas. And it seems probable that in the future they will aid us again in improving the deepness of our *observations* (direct or indirect) of nature.

Gravitation and the Non-Exclusion of Old Theories

There is another remarkable example of this process of improvement in physical theories. Newton's theory of gravitation, proposed during the

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[3] Considering this, these degrees of freedom are variables that can be associated to real physical objects and their behaviours. These are not mere epistemological devices, but structures, parameters and (why not) individuals that have an ontological status: they are a constitutive part of reality.

18th century. Newton's work was the first theoretical approach aimed to understand the behaviour of terrestrial objects (such as falling rocks or pulleys) and the behaviour of celestial objects (objects outside earth) under a unified conception. This theory had a huge predictive success: it could predict the movement of almost all the planets around the Sun, the Coriolis Effect, the Tidal Forces, and many other physical phenomena (Goldstein et al., 2001). However, it could not explain the precession of Mercury, or the deflection of light near a massive object. Later, during the first decade of the 20th century, Einstein postulated the General Theory of Relativity, which changed our fundamental conception of space and time. This theory explained the phenomena that Newton's theory could not, and it managed to include Newton's theory into its own theoretical space as well (against the incommensurability thesis).

With this in mind, when we observe General Relativity under some conditions, such as slow velocities or weak and time-independent gravitational fields, we recover Newton's theory (Carroll, 2004). Therefore, if we consider Newton's theory as included into Einstein's theory, it is not incorrect or illegitimate to think of a system without forces or of geometry of spacetime as guiding the movement of objects that are evaluable in terms (using the formulation) of Newton's theory. We can perfectly think of the parabolic movement of a rocket on earth as following a geodesic movement in a curved spacetime (i.e., in the surface of the earth, we are actually living in a curved spacetime). Hence, Einstein's theory changed our vision of the world; we replaced the idea of forces with the conception of a geometric spacetime. By doing this, it was possible to explain some phenomena that Newton's theory could not, but it did not explained away all its concepts.

Through this new Einsteinian conceptual framework we have developed new notions of spacetime, the evolution of our universe, and the properties of the macroscopic world (such as black holes, gravitational waves, gravitational lensing, singularities, or the causal structure of spacetime). Nevertheless, this does not mean that we have to despise Newton's representations. Differently from many precedent examples of failed theories, Newton's theory has not lost explanatory power due to General Relativity, but it has been included into an improved interpretation of spacetime's properties and phenomena. Every theory, up to date, has a limit of possible explanations and descriptions. Some of those explanations or descriptions can be related to inexistent entities or parameters. If those are explained away by a new theory the other reliable theoretical assumptions present in the old theory that still can explain or describe under specific conditions are not less valid, but just special cases of the new theory.

Therefore, the evolution of our theoretical frameworks does not imply that old ideas are contradictory or inconsistent, it only shows that old models were just partially accurate or inaccurate in some specific respects. For instance, as Newton's laws still work at low speeds in spacetime, Einstein's theory can be understood as an enlargement of the old Newtonian models. This more fine-grained representation of physical reality enlarges our knowledge (it does not erase the old and builds a new one from scratch), and permits us to understand new phenomena, previously undetected or overlooked. It is important to keep in mind that to the present date we have two "big theories" which explain much of both the microscopic (Quantum Mechanics) and the macroscopic (General Relativity) world. However, these theories are not compatible at all, if new proposed theoretical models, such as *Quantum Gravity*, will unify these theories in a continuous way or they will radically change our conception of physics remains unknown. But what we can do say is that this does not mean that these theories have to be understood as completely dispensable, whatever the change produced by a new theory could be.

More Claims against Scientific Realism?

Finally, we want to devote our last section to reinforce our perspectives on Scientific Realism. We have already argued against scepticism, because we think it encourages an attitude towards scientific research that is not consistent with the development of theories and models; as we have shown through the last two sections. Nevertheless, there are more critic assessments of Scientific Realism that come from different grounds. In our present view, the strongest of these critiques is posited by Structural Realism. The core claim is that Scientific Realism cannot deal with Instrumentalist arguments, such as those of incommensurability or underdetermination, because it treats unobservables as metaphysical fundamentals. Structural Realism proposes two solutions. One says that the arguments for realism should be stated in epistemological grounds, because the only element that can be preserved from one theory to another is structure. More specifically: they preserve mathematical formulations (Worrall, 1989). The other one states that Realism can deal with ontological claims only if the nature of reality is considered to be purely structural; so there would be no good reason to think that we can ever find definite individuals in the world (Ladyman, 2014; Floridi, 2011). As we can see, both positions have the same problem: they step too close to the slippery slope to idealism.

Indeed, when Structural Realism proposes that the only thing we can know of the world are individuals instantiating a structure, they are just a few steps far from stating that we can only know a general structure of the world but neither its individuals nor their properties or relationships (Psillos, 2001). Moreover, some versions of Structural Realism think of the world as pure structure, arguing that reality is ontologically structural (Ladyman, 2014). And this is not far from informationism: reality is nothing but information, namely related data[4]. Thus, if we want to take a realist stance, we should not rush into conclusions that a priori and radically negate possibilities to our knowledge. In this sense, knowing the relational properties of scientific objects does mean a specific knowledge of those objects (i.e. how they relate and the relationships they have established). Thus, there is no good reason to think that indirect observation of physical objects through those relationships cannot lead to know other types of properties that are non-relational.

With this in mind, it is easy to see that Structural Realism concedes too much to instrumentalism. For instance, it concedes that we can establish truth-topic proposition in the case of observable data or evidence, but not in the case of unobservables. But this is plainly wrong, and the reason is quite simple: if we cannot trust our theoretic and technological measurement instruments, then we have no reason to trust our cognitive maps and our sensorial organs either. Because, the only difference between these two pairs is that the first one is produced by social interactions and culture, and the latter is the result of evolution; and both are mechanisms for exploring the world. Even more, our observations are generally theory-laden:

> ...All the scientific evidence we have points to the view that perception is itself an activity essentially cognitively similar to theory construc-

4 This can be observed in Floridi (2011), where he congruently argues in favor of Informational Structural Realism. However, he fails to notice that a dichotomy between observable and unobservable objects is unsound, and it presents very difficult problems. In other words, he partially steps in the slippery slope to idealism; particularly when he asserts that it is possible to obtain mind-independent information and that those related data might be the basic components of the basic structure of the world.

> tion; the mind forms the "best" model it can of the scene before it on the basis of memory, stored information processing methods, and current information input. (Hooker, 1995, 118).

Hence, redeploying our cognitive maps in order to accommodate new evidence into previously established conceptual frameworks requires a significant effort of comparing different frameworks and developing new ones (Churchland, 2010). This can be noticed, for example, when a person goes to live to a different country that has a different currency, and she has to re-adapt her estimations about her monthly budget to the new country's different cost of life. This process is difficult, because she thinks of her expenditures as part of a map that represents the relation of prices in her old country, such as the cost of food, health, or transport. Previous knowledge has to be contrasted with new evidence.

In addition, this implies that theory-ladeness is part of our evaluation of evidence. We can observe evidence that is not strictly accurate, and our inferential evaluation of it can lead us to trustworthy results. "The evidence is never certain, and our justified confidence in it may change. After we infer the generalization, our confidence in each of our data will improve, since it will inherit additional support from the inferred generalization." (Lipton, 2004, 204). But this story does not go very differently for unobservable objects. As we have argued previously, our technological instruments aimed to detect and measure some inaccessible aspects of reality perform a mapping that can allow us to infer properties of those objects that can go beyond their mere relationships. Under this light, the problem of underdetermination seems to be a weaker nemesis of Scientific Realism.

Most of the strength of the underdetermination argument rests in a syntactical assessment of theoretical propositions. But the fact that our inferential practices allow improvement shows that treating theories as single propositions is not necessarily the correct approach. The classical answer to this problem is treating theories as theoretical-sets of Tarski-style formulations. This permits the evaluation of single propositions (e.g. a principle) in a truth-topic way without the need of committing the reliability of the whole theory. However, this position has its flaws as well, the most notorious can be noticed when theories are considered as linguistic propositions, forgetting that they are complex cognitive frameworks[5]. If we opt for a non-propositional account, then we can deal with the problems of reference in a better way. For instance, we can appeal to a non-linear notion of reliability that considers theories as dynamical and complex frameworks. Epistemic models of the world can be better understood as maps where the relationship between representation and represented is homomorphic (Hooker, 1987; Churchland, 2010). This means that we can achieve better representations if we increase representational resolution, just as we have shown in the previous two sections.

As our main objective is to argue in favour of the representational efficacy of scientific models, we want to discuss their implications for the cultural-linguistic level as well. For doing this we want to establish a clear distinction between the nature of representational procedures and what is represented. Bunge (1979) has argued that one of the most important things is to make a clear distinction between laws as natural patterns and laws as scientific formulations. In this sense, laws at a first level have an ontological character, they are patterns of interaction between natural entities[6]. On the other hand, laws at a second level consist of a formal representation of those patterns, so one first-order-law can be represented by many different second-order-laws. Furthermore, Bunge (1979) establishes a third distinction, or third-order-laws: the experimental application and subsequent cultural transmission of a formal law (second level) that is evidenced by experience. The most relevant proposition in this distinction is that second and third level laws have to be comprehended at an epistemological level.

This distinction allows us to give a philosophical assessment of our previous claims. First, even when we evaluate reality by comparing the

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[5] Churchland (2010) has proposed a three-level process of learning, where only the third level, which is the configuration and transmission of knowledge in a social and cultural space, can be regarded as producing properly linguistic representations. Churchland's second-level learning is based on the redeployment of cognitive maps or representations that are configured through a first-level learning process characterized by Hebbian learning. This posits a knowledge-representation system of the brain not as a logic-formal structure, but (more plausibly) as a vector-activation space of neural connections.

[6] Frigg & Hartman (2012) have argued that realists have not given an account of laws within models. Here we present Bunge's (1979, 2010) account that is an explanation of laws from a Scientific Realist position. Also, a Scientific Realist answer to empiricism that does give an account of laws can be found in Hooker (1995). So, it seems that there are realist accounts that consider laws as part of nature and not as purely epistemic elements that can only be found within models.

maps we conform of it, because we have no direct access to the world (healthy scientific scepticism), we can trust some of those representations more than the others. Second, this is based on the possibility of an abductive process of knowledge evaluation (or inference to the best explanation) that is present even in our day-to-day experiences. Third, it is possible to decide which of those models are better regarding their predictive success (when data is not fudged), and their descriptive and explanatory merits; namely prognosis is the best test for diagnosis and etiology (Bunge, 1979). Finally, we can understand the plausibility of this process only if we consider that an independent external reality is what is being represented and observed by the construction and evaluation of these models.

Conclusions

Scientific models and theories have shown huge progress throughout recent history. We have used the examples of particle physics and gravitation, but we think that this progress can be observed in other sciences as well. For instance, it can be seen in the improvement of biological evolutionary theories, or in the progression of many psychological topics and concepts through neuroscientific research. One of the fundamental characteristic of theoretical progress is that despite some theories can contradict each other, the most functional and accurate theories tend to embrace and enlarge representational models of the past through a new and more general framework. And this means that our picture of reality, at least regarding some aspects of it, is more accurate than before: it is represented through more fine-grained models which assist us in improving and cohering our day-to-day image of the world.

With this in mind, it is highly relevant to consider that ontology not only precedes but also embeds epistemology. Our minds depend on a previous history of physical-chemical and biological change that occurs at an ontological level. Our epistemological adventures are an expression of that history. However, we have the possibility of reconfiguring and transmitting our cognitive representations, and thanks to cultural development we can improve them through academic discussion and technology. For this reason it is important to make a clear distinction between ontology and epistemology. This is, fundamentally, a philosophical task. But as this task allows us to evaluate (among other things) the plausibility and testability of theories and their models, it is highly relevant for science as well. Even more, this distinction not only establishes a solid footing for the development of different types of models, from visually-imaginary to logical-mathematical, but it also aid us in assessing and examining the reliability and accuracy of those models.

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