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Scientific Understanding and the Explanatory Use of False Models

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Abstract

In model-based sciences, like biology, models play an outstanding explanatory role. In recent times, some authors have shown how the notion of understanding could shed light on the analysis of explanation based on models. This notion has attracted growing attention in philosophy of science. Three important questions have been central in the debate: (1) What is scientific understanding?; (2) is understanding factive, i.e., does understanding presuppose or imply truth?; and (3) can understanding be objective? I will outline and assess the main answers to these questions and I will support my personal contribution to question number 2 and 3.

Introduction

From Droysen and Dilthey until today, it has been common practice in the philosophy of social sciences to consider the notions of 'understanding' (*Verstehen*) and 'explanation' (*Erklären*) as alternative and even opposite scientific methodological approaches. The historicist and hermeneutic schools held that natural sciences look for causal explanation of phenomena, whereas human and social sciences

(*Geisteswissenschaften*) should instead look for the understanding of the meaning of human actions and social phenomena in general. Understanding was viewed in this context as a form of grasping and interpreting the meaningful content of some human actions or mental processes, including the meaning that social actors attribute to their actions. The proposed model for this grasping was the comprehensive reading of a text. It is possible to understand the meaning, the aim, or the motivation of a human action in the same sense we can understand the meaning and the aim of a previously unknown written document. This research method is supposedly restricted to social sciences because there is no meaning, aim, or motivation to be interpreted inside the realm of natural phenomena. The behavior of physical entities does not seem to be meaningful at all and certainly there is no point in trying to make empathetic sense of it (Bransen 2001).

Nevertheless, this contrast makes use of a very narrow sense of the term 'understanding'. Not only human products or attitudes (actions, intentions, inferences, ideas, works of arts, discourses, etc.) can be understood, but also objective situations, functions, working mechanisms, relationships, etc. And all of these later items are located among the objects of study of physical and biological sciences (Salmon 1998). We can achieve a comprehensive insight into the meaning of an action, but also into the homeostatic mechanisms that keep the temperature in mammals constant; or into the DNA self-replication process and the grounds of its semi-conservative character. Thus, despite what has usually defended the hermeneutic tradition, it is also possible to achieve an understanding of natural phenomena, and there is no reason to restrict scientific understanding to social sciences. Indeed, the broad acceptance of this fact has contributed to a renewed interest in this topic in current philosophy of science. There have been in the last few years a number of illuminating attempts to clarify the notion of understanding such as is used in the context of natural sciences. It would not be excessive to say that the discussion concerning the role of understanding in natural sciences, and particularly the assessment of its epistemic virtues, is one of the hot topics in the field.

Now then, in the philosophy of (natural) science, understanding has been usually seen as an aim or a consequence of a (good) scientific explanation, and not a methodological alternative to causal explanations. Philip Kitcher expressed clearly this position when he wrote three decades ago: “a theory of explanation should show how scientific explanation advances our understanding.” (Kitcher 1981, p. 508). In general, the explicit aim of the majority of the proposed theories about scientific explanation has been to satisfy this requirement.

But there has been an additional important change in the focus of the present discussion about scientific explanation. It has been remarked repeatedly that, in many fields, scientists develop explanatory tasks by means of models, instead of laws, theories, or elaborated arguments. In biological sciences this is a well known fact. Such sciences are model-based with various models frequently used with an explanatory function. And in this regard, a surprising variety of accounts has been proposed to cover all the possible modalities this function can offer when it is carried out by a model: structural explanation, simulacrum explanation, mechanistic explanation, equilibrium explanation, causal model explanation, contrastive explanation, explanation by exemplification, explanation by de-idealization, explanation by concretization, explanation by relaxation, and so on. All of them, of course, have been illustrated with suitable examples.[1]

The polysemy of the term ‘model’ is one of the main obstacles to a comprehensive approach. In biology, for example, ‘model’ can designate as diverse things as concrete organisms (e.g. Drosophila melanogaster); material objects representing other entities in a simplified form (e.g. molecular models made out of plastic and metal); paradigmatic solutions to an empirical problem (e.g. lac operon model); theoretical and idealized interpretations of the structure and working mechanisms of some biological entities or processes (e.g. the lipid bilayer model of cell membrane, the key-lock model for the enzymatic action, McArthur and Wilson’s equilibrium model for island biogeography, Mitchell’s model of oxidative phosphorylation); sets of equations describing some aspect of the behavior of a complex biological system (e.g. Lotka-Volterra model of interspecific competence, Michaelis-Menten kinematic model to determine the velocity of the enzymatic action, or Levins’

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[1] cf. McMullin 1978, Cartwright 1983, chap. 8, Sober 1983, Wimsatt 1987, Machamer, Darden and Craver 2000, Elgin and Sober 2002, Plutynski 2004, Bechtel and Abrahamsen 2005, Odenbaugh 2005, Marchionni 2006, Craver 2006, Darden 2008, Hindriks 2008 and 2013, Weisberg 2007a, Bokulich 2011, Kennedy 2012.

metapoblational model); simulating computer programs (e.g. Thomas Ray's model Tierra in Artificial Life); etc. Moreover, not every model is devised to explain a phenomenon. Sometimes, as in the case of a scale model, its function is merely to illustrate or exemplify features of another entity. In addition to explanation and exemplification, models perform many other functions in science (e. g. they can be used as auxiliary elements in experimentation, manipulation or teaching; as a source of surrogative reasoning; as heuristics for getting new hypotheses or for guiding the analysis of alternative possible scenarios; as tools for prediction; as devices for calculating or for making some ideas more precise; as proofs of the possibility of existence, etc.). Demetris Portides (2008, p. 385) has pointed out that most of these meanings of the term 'model' are linked to the ideas of representation and idealization. But even this lowest common denominator can be accomplished diversely by models (cf. Morrison 1999, and Weisberg 2007b).

Interestingly enough, some authors (e.g., Knuuttila and Merz 2009, Leonelli 2009) have evidenced that the close link between explanation and understanding is particularly visible and revealing in the explanatory use of models. Given the linguistic character of most scientific explanations, it could even be defended that understanding phenomena is a primary and more direct aim of the model building than explaining. From this point of view understanding, far from being a by-product of scientific explanation, in many circumstances it is only because the model lets us explore and understand the details of a particular phenomenon that a scientific explanation of it can be devised. The mere understanding of the phenomenon through the model might be considered in some occasions as such an explanation, as with some models in population genetics. It could be said that these models explain because they provide a genuine understanding of the phenomena. Understanding might be seen then as the primitive target and explanation would be derivative. But whatever the case may be, it is quite clear that the enhancement of understanding is a basic aim to be pursued when a model is used for explanatory purposes. Whether or not it is feasible in some specific occasions to understand a phenomenon without having an explanation of it, or *vice versa* (for a discussion, see Lipton 2009, Gijsbers 2013, Strevens 2013), understanding is in itself a valuable epistemic goal of empirical sciences and models are a powerful device to meet it.

In order to develop the topic of scientific understanding by means of explanatory models, three relevant questions immediately arise and call for an answer. First of all, it is necessary to have a precise notion of what ‘understanding’ means in this context. Secondly, while scientific models admittedly contain many false assumptions, it has been held that understanding is “factive”, i.e. that it presupposes or implies the truth of the involved beliefs. It is necessary, then, to clarify to what extent and in what circumstances the “factivity” of understanding should be maintained. Thirdly, understanding has been accused of been devoid of any epistemic value due to its irremediably subjective character. Therefore, if we accept that the understanding of phenomena is a central aim of the use of scientific models, we are obliged to respond to this objection. In what follows I will expose and assess the main answers these questions have received over the last years, and I will defend a personal approach to the second and third question. The next section enumerates some attempts to define the concept of ‘understanding’. I will opt for Catherin Elgin’s definition because it gathers in a simple form some important aspects of scientific understanding. In the following section I will defend that understanding is not factive as far as the use of models is concerned, since, indeed, false models are good devices for understanding phenomena. To this effect, I will distinguish four types of false models according to the role that falsehoods play in their explanatory function. In the final section, I will suggest some criteria to decide whether a model provides or not a genuine (not merely subjective) understanding of phenomena. For this purpose, it will be convenient to separate what I call ‘contrastive models’ from the other kind of models that for want of a better word I call ‘representative models’.

What does understanding (a natural phenomenon) mean?

It is not a simple task to provide a unifying characterization of scientific understanding. As with models, understanding comes in a number of disparate sorts. For example, a distinction has been made between propositional understanding (‘understanding that’ or ‘understanding why’ something is the case) and objectual understanding (understanding a phenomenon, an objective situation, a subject matter, a theory, a mechanism, an event, an action, a state of facts, etc.) (Kvanvig 2003, pp. 190-

191). This last sort of understanding has awakened a special interest in contemporary philosophy of science and will also be my focal point here.

The difficulty of finding a satisfactory characterization of this complex and varied notion is widely acknowledged. Some even think this is a task doomed to failure. It has been claimed in an influential work on this topic that "it seems to be impossible to give a single universally valid definition of the notion of scientific understanding" (de Regt, Leonelli and Eigner 2009, p. 2). Nevertheless, this difficulty has not impeded many definitions to be proposed in recent years. Michael Friedman (1974, p. 15) holds that "science increases our understanding of the world by reducing the total number of independent phenomena that we have to accept as ultimate or given". For Schurz and Lambert (1994), understanding a phenomenon implies knowing how the phenomenon fits into one's background knowledge. For de Regt and Dieks (2005) understanding is to have an intelligible theory of the phenomenon, that is, a theory T about which scientists in a given context can recognize qualitatively characteristic consequences of T without performing exact calculations. Kuorikuoski (2011) thinks that understanding is the ability to make correct counterfactual inferences on the basis of received knowledge and to perform effective actions with them. Strevens (2013) contends that a person has a scientific understanding of a phenomenon if and only if she grasps a scientific explanation of that phenomenon. Gijsbers (2013) considers that we understand a domain D of phenomena if we know which connections exist among such phenomena. Khalifa and Gadomski (2013) prefer to say that understanding a phenomenon lies in knowing the phenomenon and knowing an explanation of it achieved through reliable explanatory evaluation. Wilkenfeld (2013) defines it as the capacity for carrying out useful representational manipulation. This list of characterizations is only a sample, but it clearly shows that an agreement about the definition of 'understanding' is far from being reached. Some think that it is a kind of knowledge; others think it's a skill; others that it's a mere subjective experience; others a capacity for something (making new inferences, mental manipulation, constructing models, effective action); etc.

I do not aspire to put my own definition on the map. Instead of increasing the collection of plausible definitions, I think it is better to select among the many already proposed one good enough for our aims. I judge Catherine Z. Elgin's definition (Elgin

2009, p. 327) elegant, comprehensive, and clarifying, and therefore I will assume it here. This is her proposal:

> [U]nderstanding is a grasp of a comprehensive general body of information that is grounded in fact, is duly responsive to evidence, and enables non-trivial inference, argument, and perhaps action regarding that subject the information pertains to.

Besides its simplicity and accuracy, one of the main qualities of this definition lies in its usefulness to see how scientific models are used in explanatory functions and how this use allows us to understand some phenomena. Actually, it includes both the theoretical and the practical aspect of scientific understanding. On one hand, understanding is described as a mental grasp of information that enables us to infer new interesting consequences about phenomena. On the other hand, this mental achievement makes possible to act on the phenomena –including mental manipulation. According to this characterization, understanding is manifested in a double capacity: the capacity for further reasoning on the phenomena under scrutiny and the capacity for successful manipulation of the same. And, supposedly, both aspects are closely entangled in the practical strategy of model-based sciences (Godfrey-Smith 2006).

Understanding (via) false models

As for the second question –whether or not understanding presupposes the truth of the beliefs held about the understood phenomena–, Jonathan Kvanvig (2003, chap 8), among others, has defended an affirmative answer. For him, to say that a person understand *p* requires that *p* be true. As I said above, he distinguishes between propositional understanding and objectual understanding. The first lies in understanding that something is the case, or in other words, in understanding a proposition describing something. The second lies in understanding an object (a phenomenon, a situation, a language, etc.). According to Kvanvig, in order to understand a proposition, the proposition must be true; and similarly in order to understand an object, the beliefs about this object must be (mostly) true as well.

However, this claim does not fit well with the frequent use of false models in science. In spite of its current use in philosophical literature, many persons still have misgivings about the expression ‘false models’. Models do not seem to be true or false in a strict sense. In the first place, usually they are not linguistic entities, and in their formal and rigorous usage ‘true’ or ‘false’ are metalinguistic predicates applicable only to linguistic entities. Secondly, models themselves do not state anything about reality unless they are supplemented by what Ronald Giere (1999) named ‘theoretical hypotheses’. These hypotheses declare that the real system is similar to the model in some respects and to some degree. They would be true or false, but not the model as such. And thirdly, in general, models present a lot of idealizations (and abstractions) that neglect or distort important aspects of the real world, and make of any model system something unavoidably fictional. Thus, the hypothetical system described by a scientific model usually is unreal and idealized. There are no ideal gases, perfect pendulums, completely isolate populations of predators and preys, or infinite populations of random-mating individuals. They are only useful imaginary hypothetical entities; i.e., fictional constructs created for the sole purposes of research. For sure, we can generate some “fictional truths” with them, and in this sense some propositions are true or false inside the model (e.g. in the Copernican model of the universe, the statement ‘planetary orbits are circular’ is true). But these fictional truths are not literal truths about the real world, because they do not refer to any actual trait, but to a fictional one (cf. Godfrey-Smith 2009, Frigg 2010, Contessa 2010). In as much as the model as a whole is just an idealized fictional representation of this sort, it is neither true nor false with regard to a real target system.

Nevertheless, models can be judged true or false in a broader and indirect sense. Similarly to the maps, they can be also interpreted as accurate or inaccurate representations of real-world features. A map is a partial, perspectival, simplified, conventional, historically contingent and indefinitely perfectible representation of a territory and of some its geographical items (railways, restaurants, monuments, etc.). A model is also a representation of something else; it stands for a real target. Once we take into account the current reading conventions and the different aims and interests that the map-maker could have pursued, a good map must show some interesting and contextually useful structural similarities with the territory represented, and must preserve the significant relations between its parts or elements. These preserved relationships make possible that the surrogative reasoning carried out through the map (such as ‘If I’m in Toledo, I have to take this road to arrive to Madrid’) lead to correct consequences concerning the actual traits of the territory. If this condition is not fulfilled in a satisfactory degree, it is not preposterous to say that the map is misleading, inaccurate, incorrect, or –at least in extreme cases– simply false. A map of Spain in which Madrid is located between Málaga and Toledo, or the Guadalquivir River flows into the Bay of Biscay, would be not only an inaccurate map, it would be a false map *tout court*. Otherwise, if the condition of preserving the significant structural relationship is met, the map could be estimated as roughly accurate or approximately true (see Kitcher 2001, chap. 5, and, for a different opinion, Sismondo and Chrisman 2001). In the same way, bearing in mind the purpose for which a model has been put forward by scientists, it is to be expected that such a model provide faithful descriptions of some interesting and relevant properties of the target system in that context. Hence, a very unrealistic, incomplete or counterfactual model, a model that does not share enough relevant properties with its target system or that fails to refer to its real properties could be considered false (for a discussion and some important clarifications, see Chakravartty 2010 and Mäki 2011). In fact, due to the mentioned idealizations constitutive of many models, some authors think that these models cannot be but false. Highly idealized scientific models are false in the sense that they do not –and cannot– offer an accurate representation of the real target system.

This view is in need of further qualification though, for it is well known that at every turn scientists derive from these high idealized models and from other kind of false models a lot of useful and substantial true consequences about the characteristics and behavior of their targets. The interesting point is, then, that false models can be used under certain conditions to get a revealing insight into the working mechanisms or into the causes of actual phenomena. As it was said before, false models are frequently used as tools for providing scientific understanding. When this happens, they constitute what Elgin (2012) has called “felicitous falsehoods”. An adequate understanding of these false models can yield an adequate understanding of the target systems. Some authors, like Hindriks (2008), Morrison (2009a) and Kennedy (2012), are more radical and they have argued –convincingly, in my opinion– that it is precisely in virtue of the model’s inaccuracies or falsities –and not despite them– that it explains or provides understanding.

I think a helpful step in order to see how these falsehoods can be felicitous ones and so facilitate a scientific understanding of phenomena is to distinguish several types of false explanatory models. Because, actually, models can be false in several different ways and this is not irrelevant to their use. I outline here a classification which does not pretend to be exhaustive, but that could be used as a guideline.[2] I will distinguish between (1) adjustable models, (2) template models, (3) non-referential models, and (4) contrastive models. Let us dwell a bit upon the differences:

(1) *Adjustable models*: They are false models susceptible of improvement through a progressive process of de-idealization or concretization, leading to describe the phenomena in specific situations with greater accuracy and realism. The ideal gas law ($PV = nRT$) is a good example. It comprises an idealization assuming that molecules are perfect elastic particles with negligible volume and that there is no attraction or other interaction between them. In the normal range of temperature and pressure this law remains valid, but not in scenarios with very high temperature and pressure. However, the van der Waals' equation introduces two corrections; one to reflect the volume of molecules and another to take into account the attraction between them. This law is then a refinement of the previous one. It contemplates more particular features of the real gases and is valid also for high pressures:

$$(P + n^2a/V^2)(V - nb) = nRT$$

Volterra model for a population of predators and preys could be cited as another exemplary case. It states that the dynamic of interactions between the two species in this type of population can be suitably described by two simple equations. If D is the density of predator population and P is the density of prey population, then the growth rate of prey would be

$$dP/dt = rP - aPD,$$

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[2] The three first items in this typology can be seen somewhat like a simplification of Wimsatt's (1987) classification of false models.

and the growth rate of predator would be

$$dD/dt = haPD - mD,$$

where r is the instant growth rate *per capita* in the prey population, a is a measure of the rate of capture for each predator, h is a measure of the efficiency in the transformation of the energy obtained from the captured preys in the production of new predators, and m is the specific mortality or migration rate of predators. Anyway, this elegant model makes a number of idealized assumptions. It supposes that the only restriction to the prey growth is the existence of predators, so that in absence of predators the prey population would grow indefinitely. It is easy to correct this false assumption by introducing a new factor in the equations. Let K be the carrying capacity of an environment, that is, the maximum population size of preys that the environment can sustain, then the equation for the prey population growth rate would be

$$dP/dt = rP(1 - P/K) - aPD$$

That new factor replaces an exponential growth for a more realistic logistic growth. And this replacement leads to important changes in the dynamical behavior of the system; namely, the constant oscillations of the populations' size produced in the first system are gradually cushioned until reaching a steady state, or simply they do not appear any more. And a similar correction is feasible in order to take into account the mere fact that any predator has a limit in its capture rate (cf. Rodríguez 1999, pp. 274-287).

(2) *Template models*: They are models describing a non-existent ideal situation from which actual systems deviate to some degree due to the influence of several causal factors to be empirically determined in each case. Hardy-Weinberg's model fits in this sort of models. It is in fact a case of "neutral model", in Wimsatt's sense (Wimsatt 1987). Neutral models in evolutionary biology are models without natural selection. They try to describe a situation in which natural selection plays no significant role. But Wimsatt extends the idea to any "baseline model that makes assumptions that are often assumed to be false for the explicit purpose of evaluating the efficacy of variables that are not included in the model" (Wimsatt 1987, p. 27). And he adds: "the use of these models as «templates» can focus attention specifically on where the models deviate

from reality, leading to estimations of the magnitudes of the unincluded variables, or to the hypothesis of more detailed mechanism of how and under what conditions these variables act and are important” (p. 28). The Hardy-Weinberg model establishes that the gene frequencies of a panmictic and infinite population not subject to natural selection, mutation, or migration, remain constant across the generations. Let us suppose that there are two possible alleles for a certain locus in the genetic pool of this population; the allele *A*, with an initial frequency *p*, and the allele *a*, with a frequency *q*. If so, the frequencies in the equilibrium state of the genotype *AA*, *Aa*, and *aa* will be p^2, 2pq, and q^2 respectively. Virtually, no real population meets these criteria, but precisely what the model aims to bring out is the fact that any deviation from the equilibrium-frequencies founded in the real measured gene frequencies must be explained by the intervention of one or several of the excluded factors (natural selection, mutation, migration, genetic drift due to the small size of the real population, not-random mate, etc.). In that case, it would be pointless to de-idealize the model, for its function is not to understand the working of a real system in simplified situation, but to fix the point beyond which some evolutionary force must have been acting. As Sober (1984, p. 23) explained some years ago, this model describes a “zero-force state”. Another illustrative example of this kind of models would be R. A. Fisher’s sex ratio model. Fisher’s model explains why under a variety of conditions the stable (adaptive) proportion of males and females in biological populations is 1:1. If the actual sex ratio in a population departs from this proportion, there must be some cause of this disparity to be found. The populations of certain species of invertebrate parasites, for instance, usually contain a higher number of females than of males. These populations live in isolated habitats, where the mixture with other populations is very unusual, and the individuals have to reproduce very quickly. Then, the mate competition is merely local, e.g. only against the rival individuals staying in a host. Under these circumstances, the action of natural selection favors a female-biased sex ratio. The same thing happens with a polyginous species, the Scottish red deer *Cervu smegalocerus*, in which the more dominant females are better fed and their offspring grow up to become stronger than the average. These dominant females tend to have more sons than daughters (Ridley 1996, pp. 307-312).

(3) *Non-denotative models*: They are irremediable false models, since the model postulates entities, properties or mechanisms that fail completely to refer. There is nothing in the real target system able to be designated as the element denoted by the

main elements of the model. For this reason, unlike the two previous kinds of models, they cannot be considered even approximately true. Sometimes, but not always, such models are used only to save the phenomena, like the Ptolemy's epicycles. Other times, like in the case of caloric or the electromagnetic ether, these models are the ones that simply fail to denote the real features of phenomena. This kind of models, inasmuch as they are not identical to other false models, has been comparatively unattended. Three notable and interesting exceptions are Morrison (2009b), Elgin (2010a), and Toon (2010). Morrison analyses in detail Maxwell's ether model as an illustrative example of how a fictional mechanism can provide information and yield useful predictions. She contends that there are a number of ways these models might accomplish this task, hence a careful analysis is required in each case. Elgin explains that these models are not fictive, like the ideal gas model, but defective. Unlike fictive models –which do not try to denote any real object–, these non-referential models purport to denote an actual target system, but in fact this system does not exist in the real world. In the case of fictive models there are real target systems that share with the model some of the properties exemplified by it. This does not happen with the non-denotative false models. They cannot share any property with the target system because this target does not exist at all. For his part, Toon states that not always these models try to represent an actual object; sometimes the intended target system is explicitly a non-existent object, e.g. a model of a bridge not yet built, or a ball-and-stick model of unreal atomic configurations.

(4) *Contrastive models*: With some exceptions in this last case, these three previous types of false models are built to fit somehow with their target, or, in other words, they are models built to represent (some aspects of) a real-world target system. But there is another type of false models not encompassed by the mentioned types. They are models explicitly formulated to represent imaginary target systems. There would be no actual system that could be considered to be represented (even approximately) by them. But although the represented system is a completely fictional one, it is proposed however in order to understand some real phenomena. Sometimes these models can even be in conflict with the accepted scientific laws. And, unlike other models based on ideal non-existent model systems (ideal gas, perfect pendulum, infinite populations), in this case, it is the dissimilitude or the contrast between the model system and the real-world phenomena that has the burden of the explanatory function and casts light on the

workings of these phenomena. As Weisberg states, “insofar as we can understand why do not exist [the phenomena described by the model], we will have gained a better understanding of phenomena that do exist” (Weisberg 2007a, p. 223). For that reason, these models can be designed as ‘*contrastive models*’ (Diéguez 2013). A good example would be –in my opinion– Laurence D. Hurst’s (1996) model to explain why usually there are only two sexes in nature. Hurst offered a mathematical model for a population of isogamous protists in which there are three mating types. The model shows, among other things, that unless the costs of finding a mate are high, this population and other populations of organisms with gametic fusion should evolve towards two mating-types or sexes, and therefore, that organisms with gametic fusion and more than two sexes should be rare in nature. More recently, but along the same lines, Tamás Czárán and Rolf Hoekstra (2004) constructed a model showing that, under usual conditions, “a population consisting in two mating types can displace a pan-sexual population which is otherwise similar to the mating types in all other respects” (p. 7). A species or population is pan-sexual if every sex cell of the organisms which make it up can potentially fuse with any other sex cell. In a similar way, a model developed by Michael Bonsall (2006) indicates that, unless that numerous and complex physiological innovations were introduced, diploid zygotes have higher fitness optima than triploid zygotes (i.e., zygotes produced by the fusion of three types of gametes). In these three examples, the propounded models deal with three or more mating-types. With the exception of fungi and a few rare organisms,[3] this is an unreal situation, so that the models do not aim to match any actual system. However, they show that these unreal modeled systems are instable or have lower fitness than a two mating-type system. In this sense, they provide some understanding concerning the widespread existence of this kind of reproductive modality. From the point of view of their explanatory use, these models diverge from others in an important issue; what can be named as their *representational intentions* are not the same. An ideal gas is an idealization of real entities: ordinary gases. As a model, the ideal gas tries to map onto any real gas in a real context. On the contrary, three-sex species are not idealization about anything real, but fictions not accessible by means of simplification or abstraction carried out on real systems.

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[3] The ciliated protozoan *Tetrahymena thermophile* is one of these rare organisms. It has seven mating types. Some eusocial insects, like ants of the genus *Pogonomyrmex*, have a three-sex reproductive system.

We are now ready to bring into focus the question about the factivity of scientific understanding. First of all, we must distinguish between understanding a phenomenon by means of a model and understanding the model itself. When we consider the case of understanding *a* model itself, understanding seems clearly not factive. We can obviously understand false models, e.g. Ptolemy's model of planetary motions can be understood by any dedicated student of the history of astronomy. In a similar way, we can understand false propositions, like 'Spain is an island', or propositions that are not literally true, but only "true in fiction", like 'the books of chivalry drove Don Quixote crazy' or 'all the vortex in electromagnetic ether spin in the same direction'. Furthermore, we can understand what an ideal pendulum is, or what an ideal gas is, although there is no ideal pendulum and no ideal gas in the real world. This is a trivial fact usually admitted by those who defend the factivity (or quasi-factivity) of understanding. What they rather emphasize is that things are not the same when we turn our attention to the understanding of an objective situation or a phenomenon. In that case, it seems that the phenomenon to be understood cannot be a spurious phenomenon. Following Kvanvig's suggestion, it would not be feasible to understand that *p* is the case if *p* is not the case indeed. It would be senseless to say that 'John understands why sugar never dissolves in water' or that 'Mary understands how the rain dance produces rainfall'. It also seems that you cannot understand the cause of something if your beliefs about this cause are outright false. You will fail to understand why your car broke down if you erroneously believe that the cause is a defect in the carburetor whereas the real cause is a problem with the spark plug cables. And, what is more interesting here, some of these authors hold that the understanding of a false model does not involve the understanding of the modeled phenomena. "One might understand –writes Kvanvig (2009, p. 342)– the model or theory itself, as when one understands phlogiston theory. One does not thereby understand combustion, however".

Now then, it is a very strong position to demand factivity to any form of scientific understanding. *Pace* Kvanvig's statement, sometimes we can understand the behavior of a real target system –like a gas– or imaginary systems –like a three-sex species of animals– by means of models containing a large number of false suppositions. And in this use of models, falsities are neither peripheral nor dispensable.

Let us see in a more detailed way how the different false models we have distinguished realize this function.

Adjustable models are idealized and abstract representations of a target system. However, these idealizations and abstractions, as explained, are not impediments to the correct understanding of the behavior of phenomena, rather they are tools to achieve it. Adjustable models allow us, for example, to foresee how the target system would change if some initial conditions were different. They give some relevant answers to the frequent demands of counterfactual information about the behavior of the target system in a variety of circumstances. On the other hand, as Elgin (2004 and 2010a) states, these models exemplify some of the most significant properties of the target system and make easier for us the analysis of the relations and interactions of these properties. As she writes (Elgin 2004, pp. 126-127),

> No real gas has the properties of the ideal gas. The model is illuminating though, because we understand the properties of real gases in terms of their deviation from the ideal. In such cases, understanding involves a pattern of schema and correction. We represent the phenomena with a schematic model, and introduce corrections as needed to closer accord with the facts. Different corrections are needed to accord with the behavior of different gases. The fictional ideal then serves as a sort of least common denominator that facilitates reasoning about and comparison of actual gases. We ‘solve for’ the simple case first, then introduce complications as needed.

Thus, adjustable models lead to a better understanding of real phenomena insomuch as the processes of de-idealization and concretization yield to better predictions and analyses. These processes, by contrast, are not so relevant in the case of template models, even though they provide understanding in an analogous way. They are used as a resource to detect the reasons of the departure of real systems from an ideal situation. Insofar as these reasons are figured out, we reach a better understanding of the target-system’s working circumstances, as well as of the factors that modify and shape it. With regard to contrastive models, they work in another way, but not very dissimilar. Unlike the adjustable models –and in some sense, also the template models–, where it is the similitude with the real target system what is interesting, in the case of contrastive models, it is the dissimilitude what has the burden of the explanatory function and casts light on the workings of the target system. They answer to the contrastive question ‘why *p* rather than *q*?’, and therefore they let us understand –for example– why there are only two sexes rather than more.[4]

Non-denotative models display more difficulties. Whether or not these non-denotative models are able to yield some sort of understanding is a complex and debatable matter. On the one hand, it could be argued that they do not constitute a basis for a genuine understanding at all. They would be simply cases of misunderstanding. It is true that the Ptolemaic astronomy was useful for navigation and to predict eclipses, but in fact epicycles are not even remotely connected with the actual mechanisms that cause planetary motions. Therefore, they cannot give us a genuine understanding of these motions. And the same would be applicable to the phlogiston chemistry and to Maxwell’s ether model. Wimsatt (1987, p. 30) seems to adopt this position when he writes: “Will any false model provide a road to the truth? Here the answer is just as obviously an emphatic «no!». Some models are so wrong, or their incorrectness so difficult to analyze, that we are better off looking elsewhere”. But, on the other hand, it could also be argued that this kind of models can provide a defective but valuable understanding of the phenomena. At any rate, they are better than simple ignorance. From an instrumentalist or a constructivist point of view, these models have made possible a certain degree of control over the phenomena or have contributed to set up some interesting possible world, so, although they cannot be seen as approximately true representations of reality, they were useful devices in our practical and cognitive handling of the world. Apparently, knowledge and understanding do not follow the same epistemic rules. A false knowledge is no knowledge at all, because knowledge must be true by definition. Understanding, in contrast, does not seem to be a so dichotomous issue. A false understanding (a misunderstanding) can be somewhat a kind

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[4] Paul Humphrey sees here a limit for the explanatory use of this kind of models. They could provide understanding, but not explanation. He writes: “here, then, is perhaps where one part of the boundary between explanation and understanding lies. Although it can enhance our scientific understanding to explore models that violate the laws of our universe, such models cannot be used in explanations. A well-known example involves the conditions under which life can emerge in the universe. The ‘how possibly?’ questions investigated in the neighbourhood of anthropic principles add to our understanding of how life might have emerged if the laws had been different, but answers to them cannot explain life as it arose in our universe” (Humphrey 2006, pp. 42-43). The three examples I mentioned show, however, that Humphreys’ scruples are exaggerated and that these models can have sometimes an explanatory function.

of incipient or imperfect understanding, and can be judged in a later period as the first incorrect step in a way leading to the current genuine understanding of phenomena.

Then, a balanced judgment on the role of non-denotative models would demand an extensive historical analysis. Of course, we cannot do it here, but we can remind some well-known few things that will help to contextualize the issue. Ptolemaic planetary models meant a real progress in the understanding of the structure of the universe respect to Eudoxus and Calippus models and to the Aristotelian spheres model. Assuming that one of the main functional characteristics of a scientific model is carrying out surrogative reasoning about its target (Swoyer 1991, Suárez 2004, Contessa 2007), we must acknowledge that Ptolemy's models fulfill reasonably well this function when they were put forward. It is probably true –although some historians dissent– that they were proposed as mere mathematical models to calculate the position of planets, not as physical models trying to represent the working mechanisms of the cosmos. At least, they were commonly interpreted in this way during the Middle Ages. But Ptolemy's models were able to generate some consequences concerning the changes in the brightness of the planets, their apparent retrograde motions, the variation in their velocity on the background of the ecliptic, the absence of stellar parallax, and so on.

However, from the contemporary perspective, we see this set of models as flatly false representations of reality –not as approximate truths (but see Niiniluoto 1999, p, 192)–, and we tend to consider them unable to provide any genuine understanding of planetary motions. They cannot give an answer to most of the questions that might be raised from the present knowledge perspective about these motions. Their representation of them differs completely from ours. We could not accept this representation without refusing almost all of our scientific knowledge about the Solar System and about physics. Thus, few persons would probably be prepared to accept that Ptolemaic models supply some form of understanding of the functioning of the universe.

For its part, likewise epicycles, or phlogiston, or caloric, Maxwell's ether is a fictional entity (although some scientists, like the British physicist Oliver Lodge, believed at some point in its real existence, as was the case with epicycles, phlogiston, or caloric as well). But we are probably less reticent to admit it played a fundamental role in the understanding of physical phenomena. The mechanical model of the electromagnetic ether had an extremely valuable function in the articulation of Maxwell’s electromagnetic theory. So, from our current perspective, it is reasonable to think that its contribution to the development and advance of this theory justified its use, independently of its failure to denote a real-world system. It facilitated the calculations, guided ulterior researches, had a heuristic value, and was a very useful device for surrogative reasoning and in deriving some mathematical relationships. It led Maxwell, for instance, to the conclusion that the light must be itself a kind of electromagnetic wave, since transversal waves were transmitted in ether at the speed of light (cf. Harman 1982, chap. 4, although see Chalmers 1986 for a contrary point of view). But Maxwell attributed to it basically an illustrative and auxiliary function, without intending to reflect anything real, and finally his theory –the field equations–dispenses with the model.

What makes so different the way we contemplate Ptolemaic epicycles models and Maxwell’s ether model in reference to their role in our understanding of natural phenomena? I think that a good indication to elucidate this question can be found in this reflection by Margaret Morrison (2005, p. 170):

> Given that many models cannot be evaluated on their ability to provide realistic representations, we need to focus less on the distinction between “heuristic” and “realistic” models, and instead, emphasize the way in which models function in the development of laws and theories.

A clean-cut difference between Ptolemy’s epicycle model and Maxwell’s ether model is precisely that the later was a useful device in the development of laws and theories nowadays accepted, but not the former. Accordingly, it could be stated that we understand real phenomena by means of non-denotative models only if these models were useful in the development of laws or hypotheses that could be justified by currently accepted scientific theories.

The (desirable) objective character of scientific understanding

The question concerning the objectivity of understanding was controversial from the very beginning of the discussion. Hempel (1965) famously held that understanding is a merely psychological or pragmatic matter; a notion to be attributed only to subjective states of individuals, and consequently a relative and non-generalizable concept. Unlike explanation, an account of understanding necessarily involves a subject. The feeling of understanding, however strong it may be, does not imply a genuine understanding. This thesis has been held by J. D. Trout (2002) as well. Trout argues that a "sense or feeling of understanding" is by no means a reliable indicator of the truth of a scientific explanation and it is neither necessary nor sufficient for good explanation. The more significant evidence adduced by Trout in support of his claim are the experiments carried out by cognitive psychologists showing the common human biases due to overconfidence and hindsight mistakes.

An early reply to Hempel's position was formulated by Michael Friedman (1974, p. 8):[5]

> [A]lthough the notion of understanding, like knowledge and belief but unlike truth, just is a psychological notion, I don't see why it can't be a perfectly objective one. I don't see why there can't be an objective or rational sense of 'scientific understanding', a sense on which what is scientifically comprehensible is constant for a relatively large class of people.

More recently, Elgin (2010b) makes a similar point:

> Even though human subjects understand, it is not obvious that their accomplishment should be characterized as subjective. To see this we might note that understanding is closely related to knowledge. Although knowledge involves belief, no one is inclined to say that knowledge is merely psychological, not epistemological. No one holds that whether *s* knows that *p* is subjective. Why should understanding be different? Knowledge is related to justification, which typically relies on tacit background beliefs. But although people may think they know because they consider their justification and background beliefs adequate, they can be wrong, even if they satisfy the standards of their own epistemic community. If knowledge is not keyed to the standards of a particular, historically situated epistemic community, why should understanding be?

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[5] For an insightful reply to Trout's paper, see de Regt (2004).

> Why shouldn’t we say that our predecessors thought they understood the motions of the planets, just as they thought they knew that the earth was motionless, but in both cases they were wrong?

I have dealt with this problem elsewhere (Diéguez 2013), and I will sum up my position here.

For a start, I think it is important to draw a line between contrastive models and representational models, since they constitute two different strategies to reach scientific understanding. Contrastive models, as we have seen, are false models that allow us to understand a real system by showing why some situations related to this system are impossible or very improbable in normal circumstances. Representational models are models explicitly designed to represent after all a real target system. The other three types of false models we have presented –adjustable models, template models, and non-denotative models– belong to this last class.

This distinction makes it easier to find criteria for genuine understanding. In fact, this distinction is necessary because, in view of their diversity of aims, the criteria cannot be the same for both types of models. These criteria could be interpreted as tentative indications to decide when a scientific model is able to provide genuine understanding, and not a merely subjective feeling of understanding, to an informed individual. For the case of contrastive models, I would now suggest a very simple quality criterion of genuine understanding:

> A contrastive model gives us a genuine understanding of the behavior of the real system if the contrast between the consequences derivable from the model and the real target system can reveal how an interesting characteristic of the behavior of the real system might depend on the presence or absence of certain circumstances which are respectively absent or present in the model, or if the model shows how its unrealistic assumptions are hypothetically unstable and for this reason the opposite conditions prevailing within the real system tend to arise.

Thus, if the entities of the model, or its properties, are unrealistic, but the casual mechanisms postulated by the model are analogous to those of a real system, it would be possible to learn about the limits and potentialities of these causal mechanisms and, therefore, about their operations in the real system. The function of this first kind of model is certainly closer to instruments for exploring the world than to faithful representations of reality.

As for representational models, things are more complex because they are much more used in science and they offer a greater diversity. However, it is possible to pick out some criteria which might be used as indicators of a spurious sense of understanding. Since representational models make some realistic assumptions about the target system, I think these criteria must be focused on the methodological and epistemic resources that could strengthen the reliability of these assumptions. Using Weisberg's (2007a) terminology, they can be interpreted as minimal "representational fidelity criteria".

A representational model provides a genuine understanding of the target system if:

(1) the analogies between the model and its target are not weak or scientifically unfounded;

(2) it does not formulate oversimplifying abstractions which exclude relevant functional factors, i.e., factors which are necessarily constitutive of the behavior of the target system;

(3) it does not make extremely unrealistic and useless idealizations, that is, idealizations which are so far removed from the real conditions of the modeled system that they do not help to see how the behavior of this system varies under the action of usual causal factors or under certain manipulations;

(4) it does not postulate a pseudoscientific ontology; i.e., it does not postulate entities or processes incompatible with the current state of science;

(5) the postulated mechanisms offer analogies with the mechanisms that are working in the real system;

(6) its predictions about collateral phenomena do not fail systematically.

I think these criteria highlight typical deficiencies which go against the possibility of a faithful representation and increase the arbitrariness of the model. The more these criteria are unfulfilled, the less accurately the model represents the target system. It is reasonable to think that these deficiencies make it more probable that the surrogate inferences carried out with the model are too misleading or uninformative. Detecting some of these deficiencies is, then, a good reason to conclude that an initial sense of understanding caused by the model does not correspond to a genuine understanding of the target system. But if these deficiencies are not detected and the criteria are met, we can be confident that the sense of understanding in such a case is not merely a subjective feeling.

Conclusions

False models are excellent devices to get a scientific understanding of natural phenomena. Taking into account the different ways they can pursue this goal, it can be distinguished between adjustable models, template models, non-denotative models and contrastive models. All of them involve falsehoods which are necessary to the explanation of the behavior of the target system and to the understanding of the nature of real-world phenomena. Therefore, understanding, unlike knowledge, is not factive. It does not presuppose that the majority of the beliefs involved in the state of understanding must be true. Finally, understanding is not irremediably subjective. Some reasonable contextual criteria can be chosen in order to tentatively assess when a feeling of understanding corresponds to a genuine understanding.

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