Chapter 2
Distributed Model-Based Science

Scientific Models Are Not Fictions

In the current epistemological debate scientific models are not only considered as useful devices for explaining facts or discovering new entities, laws, and theories, but also rubricated under various new labels: from the classical ones, as abstract entities and idealizations, to the more recent, as fictions, surrogates, credible worlds, missing systems, make-believe, parables, functional, epistemic actions, revealing capacities. The chapter discusses these approaches showing some of their epistemological inadequacies, also taking advantage of recent results in cognitive science. The main aim is to revise and criticize scientific fictionalism, also reframing the received idea of abstractness and ideality of models with the help of recent results coming from the area of distributed cognition (common coding) and abductive cognition (manipulative). The chapter also introduces the concept of epistemic warfare, later on further studied in chapter four. It will be illustrated how scientific modeling activity can be better described taking advantage of the concept of "epistemic warfare", which sees scientific enterprise as a complicated struggle for rational knowledge in which it is crucial to distinguish epistemic (for example scientific models) from non epistemic (for example fictions, falsities, propaganda) weapons. Finally a reference to new epistemological perspectives on the role of ignorance in model-based science is also provided.

2.1 Models and Fictions

Scientific models are now not only considered useful ways for explaining facts and/or discovering new entities, laws, and theories, but are also rubricated under various new labels: from the classical ones, abstract entities (Giere 1988, 2009, 2007) and idealizations (Portides 2007; Weisberg 2007; Mizrahi 2011), to the more recent, fictions (Fine 2009; Woods 2010; Woods and Rosales 2010b; Contessa 2010; Frigg

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2010a, b, c; Godfrey-Smith 2006, 2009; Woods and Rosales 2010a; Suárez 2009a, 2010), surrogates (Contessa 2007), credible worlds (Sugden 2000, 2009; Kuorikoski and Lehtinen 2009), missing systems (Mäki 2009; Thomson-Jones 2010), as make-believe (Frigg 2010a, b, c; Toon 2010), parables (Cartwright 2009b), as functional (Chakravartty 2010), as epistemic actions (Magnani 2004a, b), as revealing capacities (Cartwright 2009a). Some of the authors mentioned above are also engaged in a controversy about the legitimacy especially of speaking of fictions in the case of scientific models.

Even if the above studies have increased knowledge about some aspects of the role of models in science, I am convinced that sometimes they have also generated some philosophical puzzles and it seems to me correct (following the suggestion embedded in the title of a recent article) "to keep quiet on the ontology of models" (French 2010). Models are used in a variety of ways in scientific practice, they can also work as mediators between theory and experiment (Portides 2007), as pedagogical devices, for testing hypotheses, or for explanatory functions (Bokulich 2011), roles of models in science which are already relatively well-known in the epistemological literature. In this chapter I will concentrate on scientific models in creative abductive cognitive processes, which Hintikka considered the central problem of current epistemological research (Hintikka 1998).

I aim at substantiating my analysis of scientific models—so to speak—"in motion" also outlining the first features of my own approach in terms of what I call "epistemic warfare", which sees scientific enterprise as a complicated struggle for rational knowledge in which it is crucial to distinguish epistemic (for example scientific models) from non epistemic (for example fictions, falsities, propaganda, etc.) weapons. The characteristic feature of *epistemic* weapons is that they are value-directed to the aim of promoting the attainment of scientific truth, for example through predictive and empirical accuracy, simplicity, testability, consistency, etc.[1]

I consider scientific enterprise a complicated epistemic warfare, so that we could plausibly expect to find fictions in this struggle for rational knowledge. Are not fictions typical of any struggle which characterizes the conflict of human coalitions of any kind? During the Seventies of the last century Feyerabend (Feyerabend 1975) clearly stressed how, despite their eventual success, the scientist's claims are often far from being evenly proved, and accompanied by "propaganda [and] psychological tricks in addition to whatever intellectual reasons he has to offer" (p. 65), like in the case of Galileo: Galileo's discussions of real experiments—in the *Dialogo* but also in the *Discorsi*—become rhetorical, to confound the opponents and persuade the readers, and also to fulfil didactic needs, as contended by (Naylor 1976).

These tricks are very useful and efficient, but one thing is the *epistemic* role of reasons scientist takes advantage of, such the scientific models I will illustrate in this chapter, which for example directly govern the path to provide a new intelligibility

[1]In this perspective I basically agree with the distinction between epistemic and non-epistemic values as limpidly depicted in Steel (2010). In chapter eight I will illustrate how, in recent times, various kinds of what I call epistemic irresponsibility are precisely jeopardizing the efficiency of these "epistemic weapons".

of the target systems at hand; another thing is the *extra-epistemic* role of propaganda and rhetoric, which only plays a mere—positive or negative—ancillary role in the epistemic warfare. So to say, these last aspects support scientific reasoning providing non-epistemic weapons able, for example, to persuade other scientists belonging to a rival "coalition" or to build and strengthen the coalition in question, which supports a specific research program, for example to get funds.

In sum, I will illustrate that there is no substantial need of reframing—in the new complicated lexicon of fictions (and of the related metaphors)—what is already well-known thanks to the tradition of philosophy of science. We have to remorselessly come back to Newton's famous motto "hypotheses non fingo", which has characterized for centuries the spirit of modern science: "I have not as yet been able to discover the reason for these properties of gravity from phenomena, and I do not feign hypotheses. For whatever is not deduced from the phenomena must be called a hypothesis; and hypotheses, whether metaphysical or physical, or based on occult qualities, or mechanical, have no place in experimental philosophy. In this philosophy particular propositions are inferred from the phenomena, and afterwards rendered general by induction" (Newton 1999, p. 493).

2.2 Models Are Not Fictions. The Inconsistency of the Argument of Imperfect Fit

Should scientific models be regarded as works of fictions? At the beginning of the previous section I said that models, both in scientific reasoning and in human perception, are neither mere fictions, simple surrogates or make-believe, nor they are unproblematic idealizations; in particular, models are—when we adopt a perspective informed by the distributed cognition framework—never abstract, contrarily to the received view. Let us outline in this section the first problem, related to the *fictionalist* nature of models. I will return to this problem in Sect. 2.3, in which also the problem of the *abstractness* of models will be deeply illustrated: as for now we can note that, in a philosophical naturalistic framework, where all phenomena and thus also cognition, gain a fundamental eco-physical significance, models are always material objects, either when we are dealing with concrete diagrams, physical or computational models, or when we face human "mental models", which at the end "are" particular, unrepeatable, but ever-changing configurations and transformations of neural networks and chemical distributions at the level of human brains. Indeed, defending in this chapter an interdisciplinary approach we are simply re-engaged in one of the basic tenets of the philosophical mentality, now enriched by a naturalistic commitment, which acknowledges the relevance of scientific results of cognitive research.

If, ontologically, models are imaginary objects in the way objects of fictions are imaginary objects, I cannot see them as situated in any "location" different from the brain, so that they are imaginary in so far as they are just "mental" models. As Giere contends:

> In spite of sharing an ontology as imagined objects, scientific models and works of fiction function in different cultural worlds. One indication of this difference is that, while works of fiction are typically a product of a single author's imagination, scientific models are typically the product of a collective effort. Scientists share preliminary descriptions of their models with colleagues near and far, and this sharing often leads to smaller or larger changes in the descriptions. The descriptions, then, are from the beginning intended to be public objects. Of course, authors of fiction may share their manuscripts with family and colleagues, but this is not part of the ethos of producing fiction. An author would not be professionally criticized for delivering an otherwise unread manuscript an editor. Scientists who keep everything to themselves before submitting a manuscript for publication are regarded as peculiar and may be criticized for being excessively secretive (Giere 2009, p. 251).

Moreover, to consider models as fictions would destroy the well regarded distinction between science and science fiction. This attitude can present cultural dangers: is science just a matter of fictions? Both kinds of fictions (scientific and literary) certainly provide insights on something "real", that is they aim at *representing* aspects of the world (for example *War and Peace*, Giere says, provides insight into the "human condition") but often various genres of literary fictions are simply finalized to entertain. Even if both contain imaginary objects, the processes that govern their formation and what from them is derived are very dissimilar, as I will further describe in Sect. 2.3. Representation in science is always related to criteria of scope, accuracy, precision and detail—Giere says—and further notes: "Remember the many models that were proposed and rejected in the race for the double helix because they failed adequately to represent the structure of DNA molecules. In the realm of fantasy, such criticisms are not appropriate. It is no criticism of the Harry Potter novels that there is no community of genuine wizards. Nor is it a criticism of War and Peace that its main characters did not exist" (Giere 2009, p. 252). The fact that a scientific model, relating to the "real" world, seems to be a fiction—that is to say, the fact it does not perfectly fit to any real system—does not authorize us to regard the overall model as a work of fiction, because it does not function like a work of fiction such as novels or so.

Finally, I strongly agree with Giere that "In fact, the argument from imperfect fit to a functionally fictional status for models proves far too much" (Giere 2009, p. 254), because it is typical of every cognition the involvement of ideal categorization and schematization, so that most of what everyone thinks and perceives should be regarded as fictional:

> It seems to me that the assimilation of scientific models to works of fiction presupposes an exaggerated conception of nonfiction. On this conception, a genuine work of nonfiction has to provide "the truth, the whole truth, and nothing but the truth". Thus, the realization that scientists are mostly in the business of constructing models that never provide a perfect fit to the world leads to the unwarranted conclusion that scientists are in the business of producing fictional accounts of the world (cit.)

Mizrahi (2011) seems to support—in the linguistic perspective about the role of "facticity" in scientific cognition—a similar point of view about the coherence of seeing scientific "idealized" models as "quasi-factive": "[…] if [scientific] understanding is (quasi) factive, then we can attribute this sort of cognitive success to scientists when they employ idealizations, such as the Ideal Gas Law, precisely because they mirror the facts to some extent. That is to say, in the case of the Ideal Gas Law, it is precisely because of the agreement between the predictions of the gas laws and the behavior of gases (under specified conditions of temperature and pressure) that we attribute cognitive success to scientists in this case. Otherwise, it seems, we would say that scientists don't understand the behavior of gases at all".

The problem is that models help reach success in experimental outcomes, because they instead fit to designated aspects of the world:

> […] the view that scientific models are ontologically like works of fiction in being imaginary creations not only does not uniquely support fictionalism, but is compatible with a moderate realism. There is nothing in this notion of a scientific model that prevents identifying elements of models with things traditionally classified as "unobservable". On the other hand, as discussed earlier in this chapter, some elements of models may not be identified with anything in the world (cit., p. 256).

(Mizrahi 2011)

I confess that I would not encourage epistemologists to engage in debates about "realism" against "fictionalism", or about problems like "is fictionalism compatible with realism?" etc. (Suárez 2010), because the adoption of these old pre-Kantian categories is in my opinion philosophically sterile. After all, the same discussions about a privileged *level* of reality (able to demarcate everything else, for example "fictions") could be easily substituted by an equally coherent view about the consistency of various *levels* of reality, where the referents of fictions could be easily included.

It is not that "fictions provide inferential shortcuts in models; and the fact that this is the main or only reason for their use distinguishes them as fictional" (Suárez 2010, p. 239), even if Vaihinger would agree with this functionalist perspective on fictions.[2] Indeed, even if it is not decisive to say "that the inferential characterisation provides a way to distinguish precisely scientific from non-scientific uses of fiction", models used in non-scientific practices may also trigger inferences, and the problem here is more fundamental. In science, models are not used and intended as fictions, they are just labeled as fictions because of a juxtaposition of some recent philosophers of science, who certainly in this way render the scientific enterprise more similar to other more common modes of human cognition: after all fictions are ubiquitous in human cognition, and science is a cognitive activity like others. Unfortunately science never aimed to provide "fictions" at the basic levels of its activities, so that the recent fictionalism does not add new and fresh knowledge about the status of models in science, and tends to obfuscate the distinctions between different areas of human

[2] Suárez's approach to scientific models as fictions is actually more sophisticated than it may appear from my few notes. Basically, Suárez does not defend the view according to which models are fictions: even if he defends the view that models contain or lead to fictional assumptions, he explicitly rejects the identification of models and fictions, preferring instead to stay "quietist" about the ontology of models, and focusing rather on modeling as an activity—see in particular his introduction to the 2009 Routledge volume he edited entitled *Fictions in Science* (Suárez 2009b).

cognition, such as science, religion, arts, and philosophy. In the end, "epistemic fictionalism" tends to enforce a kind "epistemic concealment", which can obliterate the actual gnoseological finalities of science, shading in a kind of debate about entities and their classification that could remind of medieval scholasticism.[3]

2.3 Models Are Distributed

At the beginning of the previous section I advanced the hypothesis that models, both in scientific reasoning and in human perception, are neither mere fictions, simple surrogates or make-believe, nor they are unproblematic idealizations, and I also specifically contended that models are never *abstract* or *ideal*, contrarily to the received view: they do not live—so to say—in a kind of mysterious Popperian *World 3*. Let us deepen this second problem concerning the abstract and ideal nature of models in scientific reasoning.

First of all, within science the adopted models are certainly constructed on the basis of multiple constraints relating to the abstract laws, principles, and concepts, when clearly available at a certain moment of the development of a scientific discipline. At the same time we have to immediately stress that the same models are always *distributed* material entities, either when we are dealing with concrete diagrams or physical and computational models, or when we face human "mental models", which at the end are indeed particular, unrepeatable, and ever-changing configurations and transformations of neural networks and chemical distributions at the level of human brains. In this perspective we can say that models are "abstract" only in a special cognitive sense, that is as "mental models", shared to different extents by groups of scientists, depending on the type of research community at stake.

I contend that the so-called "abstract model" can be redescribed in terms of what Nersessian and Chandrasekharan (2009) call *manifest model*: when the scientific collective decides whether the model is worth pursuing, and whether it would address the problems and concepts researchers are faced with, it is an "internal" model and it is manifest because it is shared and "[…] allows group members to perform manipulations and thus form common movement representations of the proposed concept. The manifest model also improves group dynamics" (Chandrasekharan 2009, p. 1079). Of course the internal representation presents slight differences in each individual's brain, but this does not impede that the various specific representations are clearly thought to be "abstract" insofar as they are at the same time "conceived" as referring to a unique model. This model, at a specific time, is considered "manifest", in an atmosphere of common understanding. Nevertheless, *new* insights/modifications in the internal manifest model usually occur at the individual level, even if the approach to solve a determinate problem through the model at stake is normally shared by a

[3]I will reconsider the demarcation problem in Sect. 3.2.1 of the following chapter.

specific scientific collective: the singular change can lead to the solution of the problems regarding the target system and so foster new understanding.[4] However, new insights/modifications can also lead to discard the model at stake and to build another one, which is expected to be more fruitful and which possibly can become the new manifest model. Moreover, some shared manifest models can reach a kind of stability across the centuries and the scientific and didactic communities, like in the case of the ideal pendulum, so that they optimally reverberate the idea of high "abstractness" of scientific models.

If we comply with a conception of the mind as "extended", we can say that the mind's guesses—both instinctual and reasoned—can be classified as plausible hypotheses about "nature" because the mind grows up *together with* the representational delegations[5] to the external world that the mind itself has made throughout the history of culture by constructing the so-called cognitive niches.[6] Consequently, as I have already anticipated few lines above scientific models are always distributed. Indeed, in the perspective of distributed (and embodied) cognition (Hutchins 1999) a recent experimental cognitive research (Chandrasekharan 2009) further provides deep and fresh epistemological insight into the problem of the role of models in the dynamics of scientific reasoning. The research illustrates two concrete external models, as functional and behavioral approximations of neurons, one physical (in-vitro networks of cultured neurons) and the other consisting in a computational counterpart, as recently built and applied in a neural engineering laboratory.[7] These models are clearly recognized as external systems—external artifacts more or less intentionally prepared and manipulated, exactly like concrete diagrams in the case of ancient geometry—interacting with the internal corresponding models of the researchers,

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[4]The analytic literature on scientific models has recently clearly acknowledged both the role of scientific models in extended/distributed cognition but also their related capacity to favor "understanding". The increase of explanatory inferential ability—which favors understanding—can in turn be broken down along different dimensions of explanatory power: non-sensitivity, precision, factual accuracy, degree of integration, and cognitive salience: "The explanatory power of the model, and consequently the amount and type of understanding it can provide, amounts to the number and importance of these inferences it enables. [...] Understanding the model and understanding with the model should be kept" (Kuorikoski and Ylikoski 2015, p. 3834). Toon (2015, p. 3874) too exploits extended cognition to propose a new gracious view of the nature of understanding: "Understanding is not always in the head. Instead, it involves brain, body and world". Finally, on the problem of degrees of understanding of phenomena and its relationship with explanationist and manipulationist interpretation cf. the rich (Kelp 2015, p. 3794).

[5]Representational delegations are those cognitive acts that transform the natural environment in a cognitive one.

[6]I introduced this concept in the previous chapter, Sect. 1.4.1.

[7]An analysis of the differences between models in biology and physics and of the distinction between natural, concrete, and abstract models from a traditional epistemological perspective is illustrated in Rowbottom (2009). A comparison between experiments as commonly thought to have epistemic privilege over simulations provided by models is given by Parke (2014). The importance of the different roles played in science by thought experiments, simulations, and computer simulations is further studied in El Skaf and Imbert (2013), taking advantage of a unique conceptual framework.

and they aim at generating new concepts and control structures regarding target systems.[8] I have to note that manipulative abduction—that is reasoning to hypotheses I have introduced in Sect. 1.3 of the previous chapter—also happens when we are more or less unintentionally *thinking through doing* (and not only, in a pragmatic sense, about doing). This kind of action-based cognition can hardly be intended as completely intentional and conscious.

The external models in general offer more plasticity than the internal ones and lower memory and cognitive load for the scientist's minds. They also incorporate constraints imposed by the medium at hand that also depend on the intrinsic and immanent cognitive/semiotic delegations[9] (and the relative established conventionality) performed by the model builder(s): artificial languages, proofs, new figures, examples, computational simulations, and so new "affordances" etc. I have more deeply illustrated the concept of cognitive delegations to external artifacts in (Magnani 2009, chapter three, Sect. 3.6), stressing how formats also matter in the case of external hypothetical models and representations, and how they provide different affordances and inferential chances, cf. (Vorms 2010). Roughly speaking affordances—a concept famously introduced by Gibson (1979)—present to humans and animals various opportunities for action.[10]

It is obvious that the information (about model behavior) from models to scientists flow through perception (and not only through visualization as a mere representation—as we will see below, in the case of common coding also through "movements in the visualization [which] are also a way of generating equivalent movements in body coordinates" (Chandrasekharan 2009, p. 1076).

Perception persists in being the vehicle of model-based and motor information to the brain. We see at work that same perception that Peirce speculatively analyzed as that complicated philosophical structure I illustrated in my book on abductive cognition.[11] Peirce explains to us that some basic human model-based ways of knowing, that is *perceptions*, are abductions, and thus that they are hypothetical and withdrawable.[12] Moreover, given the fact that judgments in perception are fallible but

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[8]Thomson-Jones (2012) too acknowledges, even if in the framework of an analytic scenario, not indebted to cognitive science, the importance of "concrete" models, and establishes a novel and useful distinction between mathematical and non-mathematical models together with the concept of "propositional model".

[9]The semiotic (iconic) status of models—in general—has also been extensively acknowledged by the recent analytic literature, cf. for example Kralemann and Lattmann (2013), who amply illustrate a Peircean-based approach. As also observed by the authors, the semiotic theory of models seems to contribute to the solution of the "ontological puzzle" of models.

[10]Actually the concept is much more complicated also illustrating its relationship with abductive cognition and cognitive niches..

[11]The complicated analysis of some seminal Peircean philosophical considerations concerning abduction (which refers to all the cognitive processes that lead to hypotheses), perception, inference, and instinct, which I consider are still important to current cognitive and epistemological research, is provided in Magnani (2009, Chap. 5).

[12]A detailed treatment of this issue is given in the article "Vision, thinking, and model-based inferences" Raftopoulos (2017), published in the *Handbook of Model-Based Science* (Magnani and Bertolotti (2017)).

indubitable abductions, we are not in any psychological condition to conceive that they are false, as they are unconscious habits of inference. Hence, these fundamental perceptual model-based ways of cognizing are constitutively intertwined with inferential processes. *Unconscious* cognition enters these processes (and not only in the case of some aspects of perception—remind the process, in scientific modeling, of "thinking through doing", I have just quoted above at p. 38), so that model-based cognition is in this case typically performed in an unintentional way. The same happens in the case of emotions, which provide a quick—even if often highly unreliable—abductive appraisal/explanation of given data, which is usually anomalous or inconsistent. It seems that, still in the light of the recent results in cognitive science I have just described, the importance of the model-based character of perception stressed by Peirce is intact. This suggests that we can hypothesize a continuum from construction of models that actually *emerge* at the stage of perception, where models are operating with the spontaneous application of abductive processes to the high-level model activities of more or less intentional modelers ((Park 2012, 2017), and (Bertolotti 2012)), such as scientists.[13] Finally, if perception cannot be wrong, given the fact that judgments in perception are fallible but indubitable abductions, as I have just illustrated, then these judgments should not be regarded as *fictional*.

2.4 Perception-Action Common Coding as an Example of "On-line" Manipulative Abduction

The cognitive mechanism carefully exploited and illustrated in (Chandrasekharan 2009) takes advantage of the notion of *common coding*,[14] recently studied in cognitive science and closely related to embodied cognition, as a way of explaining the special kind of "internal-external coupling", where brain is considered a control mechanism that coordinates action and movements in the world: we can see this process as an example of "on-line"—where the interplay between internal and external aspects is fundamental—manipulative abduction. Common coding hypothesizes

[13] On the puzzling problem of the "modal" and "amodal" character of the human brain processing of perceptual information, and the asseveration of the importance of grounded cognition, cf. Barsalou (2008a, b).

[14] "The basic argument for common coding is an adaptive one, where organisms are considered to be fundamentally action systems. In this view, sensory and cognitive systems evolved to support action, and they are therefore dynamically coupled to action systems in ways that help organisms act quickly and appropriately. Common coding, and the resultant replication of external movements in body coordinates, provides one form of highly efficient coupling. Since both biological and nonbiological movements are equally important to the organism, and the two movements interact in unpredictable ways, it is beneficial to replicate both types of movements in body coordinates, so that efficient responses can be generated" Chandrasekharan (2009, p. 1069): in this quoted paper the reader can find a rich reference to the recent literature on embodied cognition and common coding.

> […] that the execution, perception, and imagination of movements share a common representation (coding) in the brain. This coding leads to any one of these three (say perception of an external movement), automatically triggering the other two (imagination and execution of movement). One effect of this mechanism is that it allows any perceived external movement to be instantaneously replicated in body coordinates, generating a dynamic movement trace that can be used to generate an action response. The trace can also be used later for cognitive operations involving movement (action simulations). In this view, movement crosses the internal/external boundary *as movement*, and thus movement could be seen as a "lingua franca" that is shared across internal and external models, if both have movement components, as they tend to do in science and engineering (Chandrasekharan 2009, p. 1061).

Common coding refers to a representationalist account, but representation supports a motor simulation mechanism "which can be activated across different timescales—instantaneous simulation of external movement, and also extended simulations of movement. The latter could be online, that is, linked to an external movement (as in mental rotations while playing Tetris, see (Kirsh and Maglio 1994)), or can be offline (as in purely imagined mental rotation)" (Chandrasekharan 2009, p. 1072). Furthermore:

1. given the fact models in science and engineering often characterize phenomena in terms of bodies and particles, motor simulations are important to understand them, and the lingua franca guarantees integration between internal and external models;
2. the manipulation of the external models creates new patterns that are offered through perception to the researchers (and across the whole team, to possibly reach that shared "manifest model" I have illustrated above), and "perturbs" (through experimentation on the model that can be either intended or random) their movement-based internal models possibly leading "[…] to the generation of nonstandard, but plausible, movement patterns in internal models, which, in combination with mathematical and logical reasoning, leads to novel concepts" (cit., p. 1062);
3. this hybrid combination with mathematical and logical reasoning, and possible other available representational resources stored in the brain, offers an example of the so-called multimodality of abduction. Not only both data and theoretical adopted hypotheses, but also the intermediate steps between them—i.e. for example, models—can have a full range of verbal and sensory representations, involving words, sights, images, smells, etc. and also kinesthetic and motor experiences and feelings such as satisfaction, and thus all sensory modalities. Furthermore, each of these cognitive levels—for example the mathematical ones, often thought as presumptively *abstract* [does this authorize us to say they are fictional?]—actually consists in intertwined and flexible models (*external* and *internal*) that can be analogically referred to the Peircean concept of the "compound conventional sign", where for example sentential and logical aspects coexist with model-based features. For Peirce, *iconicity hybridates logicality*: the sentential aspects of symbolic disciplines like logic or algebra coexist with model-based features—iconic. Indeed, sentential features like symbols and

conventional rules[15] are intertwined with the spatial configuration, like in the case of "compound conventional signs". Model-based iconicity is always present in human reasoning, even if often hidden and implicit. It is from this perspective that [sentential] syllogism and [model-based] perception are seen as rigorously intertwined. Consequently, there is no sharp contrast between the idea of cognition as perception and the idea of cognition as something that pertains to logic. Both aspects are inferential in themselves and fruit of sign activity. Taking the Peircean philosophical path we return to observations I always made when speaking of the case of abduction: cognition is basically *multimodal*;

4. it is the perturbation I have described above that furnishes a chance for change, often innovative, in the internal model (new brain areas can be activated creating new connections, which in turn can motivate further manipulations and revisions of the external model): it is at this level that we found the scientific cognitive counterpart of what has been always called in the tradition of philosophy and history of science, scientific imagination.[16]

It is worth to note that, among the advantages offered by the external models in their role of perturbing the internal ones, there are not only the unexpected features that can be offered thanks to their intrinsic materiality, but also more neutral but fruitful devices we can use "as they stand", which can be for example exemplified thanks to an analogy between models and externalized mathematical symbols and their so-called "semantic opacity": "Apparently the brain immediately translates a positive integer into a mental representation of its quantity. By contrast, symbols that represent non-intuitive concepts remain partially semantically inaccessible to us, we do not reconstruct them, but use them as they stand" (De Cruz and De Smedt 2011). For example, it is well-known that Leibniz adopted the notation dx for the infinitesimals he genially introduced, and called them *fictions bien fondées*, given their semantic paradoxical character: they lacked a referent in Leibnizian infinitesimal calculus, but were at the basis of plenty of new astonishing mathematical results. Indeed to confront critiques and suspects about the legitimacy of the new number dx, Leibniz prudently conceded that dx can be considered a fiction, but a "well founded" one. The birth of non-standard analysis, an "alternative calculus" invented

[15]Written natural languages are intertwined with iconic aspects too. Stjernfelt (2007) provides a full analysis of the role of icons and diagrams in Peircean philosophical and semiotic approach, also taking into account the Husserlian tradition of phenomenology.

[16]In a perspective that does not take into account the results of cognitive science but instead adopts the narrative/literary framework about models as make-believe, Toon (2010) too recognizes the role of external models in perturbing mental models to favor imagination: "Without taking a stance in the debate over proper names in fiction, I think we may use Walton's analysis to provide an account of our prepared description and equation of motion. We saw […] that these are not straightforward descriptions of the bouncing spring. Nevertheless, I believe, they do represent the spring, in Walton's sense: they represent the spring by prescribing imaginings about it. When we put forward our prepared description and equation of motion, I think, those who are familiar with the process of theoretical modelling understand that they are to imagine certain things about the bouncing spring. Specifically, they are required to imagine that the bob is a point mass, that the spring exerts a linear restoring force, and so on" (p. 306).

by Abraham Robinson (Robinson 1966), based on infinitesimal numbers in the spirit of Leibniz's method, revealed that infinitesimals are not at all fictions, through an extension of the real numbers system $\mathbb{R}$ to the system $\mathbb{R}^*$ containing infinitesimals smaller in the absolute value than any positive real number.

De Cruz and De Smedt call this property of symbols that represent non-intuitive concepts and remain partially semantically inaccessible to us "semantic opacity". It renders them underdetermined, allowing further creative processes where those same symbols can be relatively freely exploited in novel contexts for multiple cognitive aims. Semantic opacity favors a kind of reasoning that is unbiased by those intuitive aspects that possibly involve stereotypes or intended uncontrolled interpretations, typical of other less opaque external models/representations.

Peirce too was clearly aware, speaking of the model-based aspects of deductive reasoning, that there is an "experimenting upon this image [the external model/diagram] in the imagination",[17] where the idea that human imagination is always favored by a kind of prosthesis, the external model as an "external imagination", is pretty clear, even in case of classical geometrical deduction: "[…] namely, deduction consists in constructing an icon or diagram the relations of whose parts shall present a complete analogy with those of the parts of the object of reasoning, of experimenting upon this image in the imagination and of observing the result so as to discover unnoticed and hidden relations among the parts" (Peirce 1931–1958, 3.363).

Analogously, in the case at stake, the computational model of neuronal behavior, by providing new chances in terms of control, visualizations, and costs, is exactly the peculiar tool able to favor manipulations which trigger the new idea of the "spatial activity pattern of the spikes" (Chandrasekharan 2009, p. 1067).

2.5 Model-Based Ignorance

An interesting issue recently introduced in the epistemological debate is concerned with the role of ignorance in cognition and its relationship with scientific modeling.[18] Elliott (2012, p. 333) notes that Alfred North Whitehead (Whitehead 1925) was already completely aware of the abstracting role of scientific models generated by the need of focusing only on specific features of a phenomenon. Whitehead said that scientists and philosophers tend to assume that their simplified abstractions adequately capture all the nuances of the phenomenon and dubbed this mistake

[17] It is not surprising to find in recent analytic academic articles about models in science the reference to the concept of imagination: for example Levy nicely stresses that modeling is not only the representation of target phenomena, but is also intimately linked to the imagination, "[…] we utilize the imagination as a means of describing and reasoning about a real-world object. […] models are imaginative descriptions of real-world phenomena" (Levy 2015, pp. 791 and 797). Also Meynell (2014, p. 4149) stresses the imaginative role of those particular kinds of models that are the thought experiments.

[18] On ignorance and epistemic irresponsibility see Chap. 8, Sect. 8.5.

the "Fallacy of Misplaced Concreteness", because it is characterized by the false assumption that abstractions accurately mirror all the details of concrete phenomena.

Gross, treating the problem of modeling in multiple scales in biology usefully observes that

> The process of what I have called "selective ignorance" leads to decisions as to what is included in constructing or utilizing a model, and what is left out. Indeed, part of the art of modeling is choosing what to exclude and what to include. This art involves general decisions of model type: conceptual, quantitative, physical (e.g., real, such as a physical model for an animal to evaluate heat-loading), and biological (including animal models used for experiments, cell lines, and tissue cultures). The question focused upon here concerns whether there are some general methods to evaluate the utility of these quite different forms of models (Gross 2013, p. 74).

We know that scientific models are created *ad hoc* (that is they are creatively abduced) or simply chosen (through selective abduction) from an encyclopedia of pre-stored ones. Indeed it is important to note that this cognitive process is characterized by an activity of model evaluation that regards epistemological utility with respect to the scientific objectives of a model—and the criteria for model adoption and acceptance—which are not always explicit and may vary from highly quantitative to qualitative: "Models are constructed for a diverse array of objectives including: *descriptive*, in which the model is intended to summarize a set of observations; *mechanistic*, in which the model is intended to explicate patterns based upon hypothesized mechanisms; *predictive*, in which the model is applied to predict system response perhaps to alternative treatments; and *control*, in which the model is used to manage the system perhaps based upon some optimization criteria and constraints. These are often not independent since many models are hierarchical in structure, with some mechanistic components based upon descriptive submodels" (Gross 2013, p. 75).

Further, model evaluation can be characterized by some model *testing*, using statistics or comparison with other models, but also by model *flexibility* (how the model may be applied to disparate problems), *feasibility* (how model is easily available for the application at stake), and *applicability* (how the model parameters may be quickly estimated). Given the fact developing scientific models needs considerable effort, it is not frequent to see them criticized in scientific papers, also because this would be a threat to the cohesion of the collective of scientists that work in the lab; not only, many models are computational and their complexity is an obstacle to criticisms, because it is difficult to know or to detect their internal ways of functioning, also on the part of peers and reviewers.

What is important to note at the end of this chapter is that scientific models not only are ways of abstracting and idealizing. They are also triggers of selective ignorance: the abduction of a certain scientific model inclines research in a specific direction, they hide some aspects or prevent the acquisition of relevant information (a simple example is represented by their constraining data collection to guide theory development in a certain direction) (cf. (Elliot 2012)).

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