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Axel Gelfert: *How to Do Science with Models: A Philosophical Primer*
Springer, 2016, 135 pages[1]

"Models (…) are all around us, whether in the natural or social sciences, and any attempt to understand how science works had better account for, and make sense of, this basic fact about scientific practice" (p. v).

Over the past twenty years scientific modeling has become a booming topic in philosophy of science. Axel Gelfert's book *How to Do Science with Models: A Philosophical Primer* is an up-to-date introduction to a number of hot topics as well as an original contribution to the literature. First two chapters function as an overview of the debates on the nature of models and about the way in which models represent their target systems. Anyone interested in general philosophical debates on modeling will profit from reading it as it serves as much needed coherent introduction. The remaining three chapters are different in that they offer a detailed analysis of a number of examples of actual scientific practice (chapter 3), an exciting analysis of a neglected topic, exploratory models (chapter 4), and an interesting take on the issue of a material and a theoretical dimension of models (chapter 5).

Conceptually, the book can thus be divided into two segments or approaches, one that addresses more general philosophical issues that have been vigorously debated in the literature in the recent years, the other rather specific with an eye on particular detailed examples taken from (mostly but in no way exclusively) physics. As has been common in recent years, the book is written in a style that values and pays attention to actual scientific practice. This pragmatic turn allows Gelfert to present the reader with a vast number of strategies that appear in the scientists' modeling practices. All of this makes Gelfert's book a valuable contribution to otherwise vast and disparate literature on scientific modeling.

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In the remainder of this review I will summarize the content of the chapters, focusing on both novel and interesting insights provided by Gelfert and on certain problems.

In the first chapter, Gelfert poses the question of what scientific models are. We get a nice summary of all the main contending positions which offers a great introduction for anyone new to the subject. First of all, there is a number of ways to classify different kinds of models. Thus, one can attempt to provide a typology of models (e.g. scale models, analogue models, mathematical models, theoretical models), or focus on a functional characteristics of models, for instance, on the representational aspects. Gelfert devotes some space to reviewing the models-as-analogies account of Mary Hesse, and to the syntactic and semantic view of models. He then goes on to elaborate on the fiction view of models. With a reference to Thomson-Jones, Gelfert notes that, given idealizations and abstractions, it is often the case that model systems are not instantiated in the real world, hence the "models-as-missing-systems" account. However, the practice of speaking about these kinds of model systems, as if they were instantiated, has been referred to as the face value practice. The question is, then, what is it that we speak of when we speak of a model system?

Some accounts of models take these model systems as akin to characters from novels. Against the view that model systems could be regarded as "imagined physical systems, i.e. as hypothetical entities that, as a matter of fact, do not exist spatiotemporally but are nevertheless not purely mathematical or structural in that they would be physical things if they were real" (Frigg 2010, 253), Gelfert points to models in sociology and cognitive psychology that would not necessarily be 'physical if real'. Indeed, this, for me, brings an interesting question as to what these models would be if they were real.

Although Gelfert does a good job in summarizing the debates and providing some of his own insights, he also errs on at least one occasion. When discussing the so called direct and indirect fiction view of models which is based on Kendall Walton's make-believe approach and according to which model descriptions are taken to be prescriptions to imaginings, Gelfert incorrectly places Roman Frigg into the direct fictionalist camp. Gelfert claims that "recently, more thoroughgoing *direct* views of models as fictions have been put forward, including by Roman Frigg and Adam Toon" (p. 17). But this is mistaken. As Toon says, "Frigg also draws on Walton's theory of fiction, but he advocates an indirect view of theoretical modeling (…)" (Toon 2010, 308). Furthermore, Frigg himself criticizes the direct fiction view while defending the indirect one (see Frigg & Nguyen 2016). The chapter closes with the 'challenge from scientific practice': by seeing how models are actually used by scientists, one had to either modify the semantic view or leave such a view behind and accept a 'radical heterogeneity of scientific practice'. As I noted above, it is indeed this heterogeneity that Gelfert makes vivid in his book.

Second chapter deals with the problem of scientific representation and other functions of models. Models 'stand in for' their target systems. However, by virtues of what does a model represent its target? In accord with the literature on scientific representation, Gelfert embraces the distinction between 'informational' and 'pragmatic' accounts of representation. The former concerns an objective relation between the model and the world while the latter includes the intentions of agents and the various specific uses for which models are designed.

As Gelfert notes, any adequate account of scientific representation has to be able to account for a number of things, e.g. the fact that models serve as surrogate systems and that they often misrepresent their targets. Goodman's general views on representation are discussed, followed by a review of specific accounts of scientific representation, such as Hughes' DDI account, Suárez's inferentialist account or Contessa's interpretational account. Gelfert then points to a number of other functions that have been discussed, such as the fact that false models and incomplete models are actually epistemically valuable (Wimsatt), or that there might be non-representational uses of models (Grüne-Yanoff).

In the third chapter Gelfert presents several case studies to illustrate the strategies of model-building. Here, Gelfert argues for a middle ground between unitarism and pluralism about model-based science. He recognizes that there are multiple strategies but he also notes that some of them are actually recurring. He discusses three general types of scientific models that, nevertheless, can overlap: phenomenological models, causal-microscopic models, and target-directed models. Each type of model is suited to different purposes and to answering different kinds of questions, and each has its advantages and disadvantages.

To illustrate how these strategies are put to work in actual scientific practice, Gelfert devotes a large chunk of the chapter to providing detailed examples of accounting for the phenomenon of superconductivity. He discusses the phenomenological approach of Ginzburg-Laudau's model, the BCS microscopic model, Hubbard many-body model, and then Lotka-Volterra model for modeling population dynamics. Although the discussion gets rather technical at certain points, and thus it might prove challenging to follow the argument in depth for someone without advanced knowledge of physics, it nevertheless illustrates the main point rather well, i.e. that different modeling strategies are at play in scientific practice.

In the context of strategies of model-building, it has become customary to reference Richard Levins' work (trade-offs between precision, generality, and realism) and Gelfert is no exception here. The existence of trade-offs has been thought to be a distinctive feature of biological models, however, as Gelfert argues, many models in physics and chemistry exhibit the same trade-offs as well. In concluding remarks to this chapter, Gelfert summarizes the point with an example of climate models (p. 68):

> In other words, rather than aiming for a model that reflects every available detail of the target system, it may be preferable to have a model that makes adequate predictions primarily of those features that matter to us – say, changes in rainfall patterns in agriculturally productive parts of the world – even if it misrepresents other parts of the target system as a whole.

In chapter 4, we are presented with the notion of exploratory models. Gelfert begins by noting the importance of scientific understanding in the form of model-based understanding. This sort of understanding has an important tacit dimension: a 'feeling for' the model and the behavior of its target system which is acquired by simulation or manipulation (physical and/or symbolic). A central notion of this chapter is the notion of exploration, though. Exploration can be either 'specific' in the sense that it "converges upon a specific question, fact, detail, or 'missing link'" (p. 75), or 'diversive' which is not directed at a specific object or a question. Experimenting as well as modeling concerns both senses of exploration which Gelfert well documents on a number of examples.

These exploratory tasks can be aimed at forming and stabilizing certain conceptual frameworks, and in some cases, a tentative proposal of an operational definition is a prerequisite to an intelligible experiment. Based on the last point, Gelfert claims that concepts may play an exploratory role in a similar way to experiments. Although suggestive, it seems to me that this claim would have benefited from further arguments. Be as it may, Gelfert's main interest lies with exploratory models. He takes minimal models (e.g. in ecology, physics, and social sciences) to be instances of this category, the exploratory models. Minimal models, as he sees them, are intended as tools for investigating certain model systems which do not refer to any particular real world systems, nor make precise quantitative predictions. One might object that Gelfert should have at least mentioned the fact that the term 'minimal model' has been used in rather different senses in the literature, however, his main concern is not with the variety of the meanings of the term, but rather with the fact that at least some of the usage illuminates well the notion of exploration.

He then goes on to further illustrate the importance of explorative models by showing four different functions these models may have: they serve as starting points of research, as proof-of-principle demonstrations, they generate potential explanations, and they explore the suitability of the target. Gelfert thus highlights the exploratory function of scientific models and puts the notion of exploratory models on a par with other important kinds of models such as predictive and explanatory models.

In chapter five, Gelfert first devotes space to differing accounts of scientific models. Models-as-mediators account stresses certain autonomy of models from both theory and data and highlights the fact that models are often constructed by using various tools. Models have also been construed as epistemic tools, as concrete artefacts, built by specific representational means and constrained by their design (i.e. a given design allows answering certain questions and serving certain purposes but not others). Gelfert wants to go a step beyond the 'models as tools' which he sees as too passive – he wants to stress their active role.

He then focuses on yet another important aspect of models when he says that "for a model to be successful, more is required than that it stand in the right sort of objective relationship to its target system" (p. 117). He adds that "a successful model should enable such learning, by making relevant information about its target accessible to us – not only in principle, but in a sufficiently salient way, such that a reasonably skilled user would be able to draw relevant inferences about the target system from interacting with the model via the representational means it employs" (p. 117). In order to capture this relation between models, model users, and their targets, Gelfert suggests distinguishing between degrees of *immediacy*, which concerns "the phenomenology of our interaction with the representational means deployed by a model" (p. 118), and degrees of *directness*, which pertains to the relation between the model and the target.

Following up on the presented distinction Gelfert draws on yet another distinction originally due to Don Ihde (taken from the philosophy of technology), one between embodiment relations and hermeneutic relations. Embodiment relations concern technologies that interact with our perception and body, whereas hermeneutic relations concern the need of interpretation. Examples include: glasses, telescope, or car-parking (embodiment relations); and measuring or computing apparatus, or graphical chart belong properly to the category of hermeneutic relations. The difference is then further clarified in the following way: "Both the printed map and the handheld telescope are visual technologies of sorts; but whereas in the case of a telescope, we can 'become one with' and, through skilled embodied use – as an extended self, we might say – look through it at the world, in the case of the map the representational medium itself occupies the focal point of our attention:

when we read a map, we are looking at the map, not through it at the world" (p. 122).

We have learned that there is an incredible heterogeneity of model-elements, and this heterogeneity "often entails that some parts of a model may be continuous with our ordinary sensory modalities, whereas others require significant interpretation" (p. 124). Gelfert applies this distinction to the context of models, and, furthermore, he highlights that both kinds of relations are often at play at the same time:

> An engineer designing a new type of aeroplane might begin by constructing a model that has the appearance of the full-scale aircraft, including its geometrical proportions, only to find that not all relevant properties (such as drag, weight, friction etc.) scale proportionately with size; in such cases, one would need to suspend immersive engagement with what looked to be a good stand-in for the target system and 'read' the model in a more detached way: for example, by taking measurements, making appropriate modifications (e.g. adjusting the relative wing size), or adding further elements (e.g. additional background assumptions) to it. Working with models often requires such 'switching' between embodied and hermeneutic modes of interaction. This leads to the second modification of my general claim: not only do scientific models support different types of user-model-target relations, but they often *enable* their users to switch back and forth between them. (p. 124).

To further illustrate this point Gelfert presents us with two more examples. The first one is the Phillips machine which is a machine built from water tanks, levers and tubes, and which serves as an analogue model of macro-economy. The materiality of the Phillips machine "is key to how the machine models economic processes" (p. 125), but interpretation is required as well – one needs to have a good grasp of the economical concepts. The second example is that of modeling proteins. Before the dawn of advanced computer technology scientists were constructing material models of proteins to find out about their structure. Figuring out the three dimensional structure of proteins is difficult because it cannot be straightforwardly predicted from a sequence of amino acids because, in Gelfert's words, "a sequence of amino acids will 'fold' into the most energy-efficient three-dimensional structure, yet determining this structure involves running numerically demanding simulations which, in turn, requires the extensive use of computer technology" (p. 126). Thus, we see an important 'hermeneutic' element involved in the process. Nowadays, however, sophisticated programs have been developed that allow their users to manipulate 'virtual' atoms, followed by rendering of the most probable structure of a protein, all this in real time. As a result, we get more of the 'embodiment' element, a 'feeling for the molecule'. Gelfert closes by noting that "models, then, are not simply neutral tools that we use at will to represent aspects of the world; they both constrain and enable our knowledge and experience of the world around us: models are mediators, contributors, and enablers of scientific knowledge, all at the same time" (p. 127).

From the very beginning Gelfert has argued that searching for a unified account of scientific modeling is a fool's errand. Indeed, as Gelfert argues, given the various roles and uses of scientific models there will not be any such unified account, ever. What we have been given is a plethora of well documented cases of scientific modeling which show how colorful and multifarious the actual practice is. Gelfert is also to be applauded for opening new philosophical issues to work on such as the role of exploratory models. Anyone interested in the up-to-date research on the philosophy of scientific modeling is well recommended to read this book, as well as anyone interested in the scientific practice more broadly.

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