HOW TO DO SCIENCE WITH MODELS
AXEL GELFERT

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How to Do Science with Models: A Philosophical Primer
Axel Gelfert
Dordrecht: Springer, 2016, £ 37.99
ISBN 9783319279541

The bourgeoning literature on the various aspects of models and modelling has recently spawned book-length studies that also aim to function as introductions to philosophical discussion of modelling (for example, Bailer-Jones [2003]; Morgan [2012]; Weisberg [2013]). Axel Gelfert's *How to Do Science with Models: A Philosophical Primer* fits squarely into this group. Like its predecessors, it is much more than a philosophical primer, presenting an original contribution to our understanding of scientific modelling. In particular, Gelfert pays close attention to the plurality of functions of models and their contexts of application, also highlighting the importance of their construction: '*what models are* is crucially determined by their being the result of a deliberate process of model construction' (p. 20). Accordingly, Gelfert studies several models at length, in order to identify some 'middle range' features and strategies that, although not universal, may nevertheless characterize some recurring patterns in the usage of models across disciplines.

The first two chapters are largely introductory. The first briefly reviews the earlier, and to some extent contemporary, discussion of modelling: various typologies of models offered by philosophers, the relationship of modelling to analogical reasoning, the role of models in syntactic and semantic views of theories, and models as fictions. A vast amount of material is thus canvassed within the first twenty pages of the book that may make it somewhat heavy reading for any newcomer to the philosophical discussion of modelling. For the already initiated, Gelfert's discussion contains several interesting observations, and a lot of insightfully chosen quotations, showing his characteristic way of developing arguments in dialogue with other philosophers.

Having laid out a general overview, Gelfert narrows down his focus on the philosophical discussion of scientific representation—being especially interested in the pragmatic approaches. In Chapter 2, he addresses Nelson Goodman's account of denotation and representation, and two accounts of scientific representation that have been inspired by Goodman: R. I. G. Hughes's ([1997]) DDI account of model-based representation and Mauricio Suárez's inferential account (see, for example, his [2004]). Gelfert points out that these accounts make room not only for users, but also for the mathematical and other resources that models provide for scientific research. He contrasts Hughes's and Suárez's accounts with that of Callender and Cohen ([2006]), arguing that 'the role of models in inquiry is not exhausted by their functioning as mere props for communicating mental states' (p. 33). This contrast sets the stage for the rest of the book, as Gelfert is primarily interested in how the representational means employed by models provide epistemic resources for the scientists constructing, using, and reconfiguring them.

In recognizing the plurality of models and their functions, Gelfert's effort is partly classificatory. The four types of models he discusses at length are phenomenological, causal-microscopic, 'formalism-driven', and exploratory models (Chapter 3). Gelfert's approach is case-based. The Ginzburg–Landau model of superconductivity provides an example of a phenomenological model. Gelfert shows how this model draws together a heterogeneous mix of theoretical tools in order to exhibit a number of macroscopic properties. The Ginzburg–Landau model is contrasted with Bardeen, Cooper, and Schrieffer's, which exemplifies causal-microscopic models. It depicts a possible causal mechanism by modelling the imagined processes separately, instead of giving a 'prepared description' of the phenomena as phenomenological models do. Finally, Gelfert discusses formalism-driven modelling by employing Hubbard's many-body model that makes partial use of 'first principles', yet simultaneously relies on what he calls 'mature mathematical formalisms'. Much of what Gelfert writes about phenomenological, causal-microscopic, and formalism-driven models reads as a response to Nancy Cartwright. For example, he argues against the idea that one has to either construct phenomenological models on the basis of empirical data, or rely on a few interpretative models able to render 'phenomena' intelligible. In contrast, for Gelfert, the different strategies of modelling illuminated by his case studies show that 'intelligibility can be achieved in various ways' (p. 52).

Gelfert's discussion of mature mathematical formalisms and their role in modelling is highly interesting. With mature mathematical formalisms, Gelfert refers to 'systems of rules and conventions that deploy the symbolic language of mathematics' being simultaneously connected to certain theoretical or methodological commitments (p. 55). These commitments are due to a physical interpretation of mathematical operations and constrain the various mathematically possible scenarios. Mature mathematical formalisms afford model construction in various ways, and offer 'rigorous results' in that they establish 'an exact *mathematical* relationship between certain mathematical variables' (p. 111). They can also transfer empirical warrant, Gelfert suggests, across models describing very different kinds of physical systems, due to rigorous mathematical (mapping) relations. Paul Humphreys's ([2004]) notion of a template and the work done on the semantic conception of theories would have been relevant for mature mathematical formalisms, but Gelfert does not consider them.

Perhaps the most intriguing chapter is the one on exploratory models (Chapter 4; see also Salis [forthcoming]). Gelfert introduces these models by invoking William Wimsatt's ([1987]) insight into the epistemic productivity of false models, and the discussion of non-representational models (for example, Gruene-Yanoff [2013]). Exploratory models may lack specific intended targets, instead enabling scientists to gain some qualitative understanding of a phenomenon or to obtain greater expertise in particular modelling techniques. The focus on exploratory models, argues Gelfert, 'requires moving beyond the traditional narrow focus on the representational functions and uses of scientific models' (p. 40). Gelfert's discussion is motivated by questions concerning the tacit dimension of modelling and how one gains understanding through constructing and manipulating models and simulating their behaviour in time. These kinds of activities are based on the internal resources of models that enable researchers to interact with them in exploratory ways. In order to get a firmer grasp of the notion of exploration, Gelfert follows Berlyne ([1960]) in distinguishing between specific and diverse exploration. Specific exploration, in particular, is interesting from an epistemic perspective as it focuses on specific questions, facts, or details, while divergent exploration is after novelty for its own sake. Another source of inspiration is provided by the literature on experimental exploration (Steinle [1997]). In line with discussions of experimental exploration, Gelfert comes close to claiming that exploratory models are used in situations where there is not yet a fundamental, or general, theory available.

In Gelfert's view, exploratory modelling has been alluded to by philosophers, but not systematically addressed. He attributes the lack of discussion of exploratory modelling to philosophers' tendency to frame questions concerning models in terms of their truth or falsity. Referring to Wimsatt, he asks, 'what is it that makes *some* false models more successful than the others', and seeks an answer in their suitability for exploratory purposes. Again, Gelfert's approach is taxonomical; he specifies four different exploratory functions that models can have (without intending these functions to exhaust the exploratory uses of models). Exploratory models can function as starting points, proofs of principle demonstrations, potential explanations, and vehicles for inquiry into the suitability of a target. As an example of proof of principle models, Gelfert briefly discusses (Volterra's version) of the Lotka–Volterra model. Indeed, Volterra used the model to determine whether the observed oscillations in the interacting predator and prey populations could be explained by the internal dynamic of the two populations alone (Knuuttila and Loettgers [forthcoming]). But this does not mean that the model could not be used as a potential, or even actual, explanation, a point that is not explicitly addressed by Gelfert's discussion of exploratory models. What this shows is how difficult it is to talk about functions without making them the properties of the models themselves. Yet, the 'same' model can be appropriated for different purposes, making it a multifunctional artefact. Finally, in discussing the use of models to explore the suitability of a target, Gelfert makes the important point that one should not approach modelling as an activity proceeding either from theory to phenomena or vice versa. The idea of co-construction of theory and phenomena comes very close, but Gelfert chooses the philosophically less adventurous route of viewing models as '*in search of* empirical phenomena' (p. 94).

The recognition that modellers employ vastly different strategies leads Gelfert discuss trade-offs in modelling. The question is whether the trade-offs between generality, precision, and realism are necessary or unavoidable (Levins [1966]). Gelfert's answer is (hesitantly) negative, but he grants that the more heterogeneous ensemble of systems the target covers, the more difficult it is to increase both precision and generality at the same time. Accordingly, such trade-offs might be more endemic to biology, since biological systems are less homogeneous among themselves, being complex adaptive systems. Should such heterogeneity in targets then provide a demarcation criterion distinguishing physical sciences from the biological ones, as suggested by Orzack and Sober ([1993])? Although Gelfert does not deny that there are differences between biological entities and some fundamental entities studied by physics, he suggests that instead of starting from 'presumed ontological differences between the research objects of various scientific disciplines', one should instead look at the differences in scientific practice across fields when explaining the pervasiveness of trade-offs (p. 65). Gelfert notes that physicists have tended to direct their attention to homogeneous systems that can be characterized by a small number of parameters in a range of circumstances. But this need not be the case, argues Gelfert, pointing at cases like granular media, quasicrystals, and colloids. Finally, he discusses 'fingerprint effects' in mesoscopic systems that are sample-specific but reproducible. He insightfully observes that in modelling such phenomena, the primary goal is no longer the explanation of 'the actual behavior of a specific system *as an instance of* a general class of target systems' (p. 66). Technological and computational developments have made it possible to model phenomena at an ever greater resolution, removing the need to attribute sample-specific features to noise or idiosyncracies of experimental arrangement.

In the final chapter, Gelfert discusses models as enablers of scientific knowledge-building, using accounts of models as mediators (for example, Morrison and Morgan [1999]; Morgan [2012]), and models as epistemic artefacts or tools (for example Knuuttila [2011]; Boon and Knuuttila [2009]). In line with Boon and Knuuttila, he stresses how the specific construction of a model and the representational means in their various modes and media both constrain and enable scientific reasoning. In order to distinguish his approach from theirs, however, he characterizes their account as relying on seeing models as passive tools. This interpretation seems to be based on the connotations of the word 'tool', rather than on what Boon and Knuuttila ([2009]) argue in their study of the Carnot model, which details how the model enabled its own further construction and the subsequent development of thermodynamic theory. It is precisely the recognition of the epistemic resources that models as representational artefacts embody that motivates the artefactual account. These resources can be put to many uses, and they facilitate and guide further research. Hence it seems fair to say that the novelty of Gelfert's account does not lie in presenting an active account of models in contrast to passive accounts that view models as docile tools. Gelfert expands on and extends the existing accounts with his theoretical and conceptual articulation of the epistemic functioning of models. Such articulation is evident in Gelfert's examination of exploratory models and mature mathematical formalisms, as well as in his intriguing closing discussion of user–model–target relations.

In conclusion, *How to do Science with Models: A Philosophical Primer*, published in the Springer Briefs in Philosophy, is indeed brief—but only in relation to its ambitious scope. It is an innovative examination of several topics that merit further work from philosophers of science interested in scientific representation and modelling. For such work, Gelfert has provided fruitful conceptual tools and theoretical analyses.

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