ARTICLE IN PRESS

Studies in History and Philosophy of Science xxx (2011) xxx–xxx

Contents lists available at ScienceDirect

Studies in History and Philosophy of Science

journal homepage: www.elsevier.com/locate/shpsa

Introduction

Model-based representation in scientific practice: New perspectives

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When citing this paper, please use the full journal title *Studies in History and Philosophy of Science*

The problem of scientific representation has been at the heart of numerous debates in the philosophy of science, and for good reason. One of the most entrenched views of science is that it gives us a by and large faithful picture of the world—indeed perhaps the most objective and accurate picture we can hope to arrive at. At the same time, we know that, especially when it comes to complex systems, even our best scientific accounts are by necessity incomplete, and sometimes present a distorted picture. In many situations, scientists need to construct models in order to be able to explain or predict anything of interest at all.

It has become customary to preface any systematic discussion of scientific models with the observation that philosophical interest in the topic has been on the rise, and that 'the philosophical literature on models has been growing rapidly over the last decades'.[1] The same could, of course, be said about many other debates in academic philosophy, and one might therefore conclude that the growing number of books and articles devoted to the topic of scientific models merely tracks the increase in professionalisation of philosophy of science as an academic discipline. Such a conclusion would be hasty, however, as it would overlook the very real increase in our overall reliance on scientific models and their numerical predictions. Scientific models, along with computer simulations, are routinely deployed across the spectrum of the natural sciences (and, increasingly, the social sciences as well). In some disciplines, scientific models have become the default mode of how to approach scientific questions.

The diversity of *kinds* of models one finds in science—toy models, theoretical models, scale models, mathematical models, material models, etc.—has attracted attention not only from philosophers, but also from historians and sociologists of science. As a result of such multi-disciplinary attention, there exists now a substantial body of case studies that describe and analyse in detail the different uses to which models have been put in specific scientific contexts.[2] At the same time, a lively philosophical debate has developed, which focuses on the representational function of scientific models and on the nature of scientific representation in general.[3] While each side frequently invokes the other in order to motivate its task, the two projects—the close-up study of individual scientific models in specific scientific contexts, and the general concern for representation as a bridge between theory and world—*de facto* often stand merely side by side with one another.

The goal of the present volume is to explore ways in which close attention to scientific practice—whether in the form of case studies or by emphasising sometimes neglected features of the practice of scientific modelling—can shed light on the philosophical issues raised by the problem of scientific representation. Instead of analysing representation as primarily an abstract relation, between a model and its target, many of the papers in this volume are based on the idea that scientific representation is, first and foremost, something that requires effort and needs to be achieved: Successful representation stands at the end of a process of scientific modelling. This marks a shift in emphasis, from abstract necessary and sufficient conditions for representation, to more tangible features of the process of modelling, such as the media and formats—both symbolic and material—in which models are specified.

The papers in the present volume draw on examples from across the special sciences. While some stock examples from physics make their appearance, many of the papers discuss cases from the biomedical sciences. Thus, John Matthewson discusses to what degree models in population biology are subject to trade-offs between the desiderata of precision, generality, and realism, and goes on to link the extent of such trade-offs in modelling to the heterogeneity of the intended target systems. Chuanfei Chin uses a case study of the medical-scientific controversy over foetal pain in order to argue for the significance of *interpretative* models—where an interpretative model aims at 'making sense' of the data,

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[1] Roman Frigg, Scientific Models. In Sahotra Sarkar & Jessica Pfeifer (Eds.), *Philosophy of Science: An Encyclopedia* (Vol. 2: N-Z; pp. 740–749). London: Routledge 2006, p. 740.

[2] For collections of in-depth case studies, see Mary S. Morgan & Margaret Morrison (Eds.), *Models as Mediators: Perspectives on Natural and Social Science.* Cambridge: Cambridge University Press 1999, and Soraya de Chadarevian & Nick Hopwood (Eds.), *Models: The Third Dimension of Science. Palo Alto*: Stanford University Press 2004.

[3] E.g., Newton da Costa and Steven French, *Science and Partial Truth: A Unitary Approach to Models and Scientific Reasoning.* New York: Oxford University Press 2003; and Mauricio Suárez, Scientific Representation. *Philosophy Compass*, 5 (2010) 91–101.

0039-3681/$ - see front matter
doi:10.1016/j.shpsa.2010.11.032

Please cite this article in press as: Gelfert, A. Model-based representation in scientific practice: New perspectives. *Studies in History and Philosophy of Science* (2011), doi:10.1016/j.shpsa.2010.11.032

and is judged by its ability to identify new meanings in the target system's behaviour, rather than by how much data about the target system is explained by its internal dynamic. Rachel Ankeny and Sabina Leonelli, in their joint contribution, provide a state-of-the-art survey of the debate about the significance of 'model organisms'. Model organisms, they argue, differ from other organisms used in experimental research in terms of their material and epistemic features, and specifically in their representational scope and representational target.

Demetris Portides, in his study of the shell-model of nuclear structure, offers a new perspective on the distinction between theory-driven and phenomenological models. At a general level, the representational status of a model depends on its capacity to function as a source of knowledge and its ability to postulate and explain underlying mechanisms that give rise to the observed behaviour of its target. More specifically, his paper attends to the theoretical activity of constructing the nuclear shell-model with spin-orbit coupling, arguing that both the processes of construction and their accompanying rationale are vital parts of phenomenological models and of the latter's representational capacity. Models of the nucleus also make their appearance in Margaret Morrison's contribution, where they provide an interesting foil for other areas of physics, such as hydrodynamics, which are likewise characterised by the coexistence of many different models for the same system. However, unlike in the case of, say, the study of turbulent flow, in the case of nuclear physics this leads to irreconcilable theoretical difficulties that impose epistemic and methodological burdens that resist resolution by a variety of philosophical strategies, including perspectivism, paraconsistency, and partial structures.

Several of the papers in this volume pay close attention to the way in which models are constructed, encountered, and constrained by general features of how they present themselves to cognitive agents. In order to function as sources of knowledge, or as representational devices, models must be specified in a way that makes them cognitively accessible. As Marion Vorms argues in her contribution, any approach that takes the concrete practices of scientists seriously, must pay proper attention to the cognitive interactions between agents and the representational devices they reason with and manipulate. This applies equally to simple mathematical models (e.g., the harmonic pendulum) and to complex material models, such as Watson and Crick's original model of the DNA double helix. Even in 'simple' cases, the information contained in a model cannot be accessed unless given in some particular format. Axel Gelfert, in his contribution, argues that 'mature mathematical formalisms' play a special role in the process of constructing models and gaining knowledge on their basis. As mathematical formalisms undergo a process of elaboration, enrichment, and entrenchment, they come to embody theoretical, ontological, and methodological commitments and assumptions. Since these are enshrined in the formalism itself, they are no longer readily obvious to either the novice or the proficient user. At the same time as formalisms constrain what may be represented (and how), they also function as inferential and interpretative resources.

Tarja Knuuttila offers a sustained critique of the 'representational approach', according to which models give us knowledge because they represent their supposed real target systems. This approach, she argues, is overly restrictive as regards the epistemic value of modelling, since it neglects the actual representational means with which scientists construct models. On the proposed alternative view, models are to be regarded as *epistemic tools.* This amounts to an acknowledgment of their status as concrete artefacts that are built by specific representational means and are constrained by their design in such a way as to facilitate learning from them by means of construction and manipulation.

Gabriele Gramelsberger takes as her starting point the observation that many complex models are nowadays encountered primarily in the medium of programming code. By analysing a snippet of code of a general circulation model (GCM), of the kind used in current global climate models, she describes coded numerical models as instances of a new symbolic form of research, which—in a way that is foreshadowed in the work of Ernst Cassirer—dissolves object-oriented reference into a relation-centred mode of analysis. The case of climate modelling is especially instructive, given that atmospheric models belong to the oldest numerical models in science, with roots in the deterministic tradition of early modern physics, yet nonetheless provide a good illustration of a new, symbolically and computationally mediated form of research. The historical origins of scientific models, which continue to inform our conception of the practice of scientific modelling, are at the heart of Mohd Hazim Shah's contribution. By relating the scientific and philosophical discussion about models—'from Tycho Brahe to technoscience'—to the cultural-emotive significance of scientific knowledge, he attempts to show how contrasting intellectual temperaments and outlooks have not only shaped historical controversies, but remain with us today, for example in the form of entrenched philosophical debates such as the realism/anti-realism debate in the philosophy of science.

Several of the authors (Chuanfei Chin, Axel Gelfert, Mohd Hazim Shah, Tarja Knuuttila, John Matthewson, Demetris Portides) first presented versions of their papers at a workshop on 'Model-Based Representation in Scientific Practice', held at the National University of Singapore (NUS), on 5–6 September 2008, with financial support from the Ministry of Education, Republic of Singapore, and the Faculty of Arts and Social Sciences at NUS (via an AcRF Tier 1 grant, WBS R-106-000-016-112). The fruitful and constructive atmosphere at this meeting gave rise to the idea of editing a volume based on selected papers from the workshop, together with additional invited papers. Many individuals contributed, in one way or another, to the success of the workshop and subsequently helped with the editing of the present volume and with general advice. I am grateful to all of them, in particular Rosna Buang, Jeremy Chong, Stephen John, Tarja Knuuttila, Wendy Parker, Anjana Supramaniam, Peter Vickers, and Michael Weisberg.