Exploratory Models and Exploratory Modeling in Science: Introduction

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That science is more than the unilinear application of general theories to specific empirical circumstances is, one hopes, no longer something that is controversial or requires detailed argument. To be sure, there were times when devising universally applicable theories was seen as the most worthy task of science, with less lofty activities such as experimentation and scientific modeling being relegated to the underbelly of "proper science." Arguing for a pluralistic recognition of the diversity of scientific practices, methods, and goals, might—at least on the pages of this journal—amount to preaching to the converted. Yet, once the diversity and heterogeneity of science is acknowledged, the real work only starts: for, the task of systematizing the manifold ways in which science proceeds when it is *not* aiming for the testing of theories has continued to elude scholars. Philosophers are perhaps especially challenged in this regard: whereas historians of science and scholars of science and technology studies have been able to fill this lacuna with insightful case studies that demonstrate the richness of science beyond the pursuit of theory, philosophers of science have remained perhaps too wedded to binary distinctions such as the contrast between justification and discovery.

Perhaps the most prominent site where scientific activity comes into contact with the world is the *experiment*, and so it is not surprising that the practice turn within history and philosophy of science also led to the recognition of the significance and autonomy of *scientific experimentation*. Karl Popper's

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dictum that "the theoretician puts certain definite questions to the experimenter, and the latter, by his experiments, tries to elicit a decisive answer to these questions" (Popper 2002, p. 89) suggests a degree of division of labor and separability of tasks that is rarely, if ever, realized in practice. Is it even desirable? Proponents of the notion of "exploratory experimentation" have taken issue with the epistemic hierarchy that is implicit in this traditional picture. Experimentation is not the handmaiden of scientific theorizing; rather, experimentation often proceeds in the absence of fully-formed scientific theories, aiming at the stabilization of novel phenomena (Burian 1997) and generating the very concepts and classifications that form the basis of new scientific theories in the first place (Steinle 1997).

From early on, analyses of exploration in relation to scientific experimentation recognized the multiplicity of exploratory functions: Where some theorists of exploratory experimentation (e.g., Burian 1997) noted its character as a piecemeal methodology for getting a grip on a phenomenon with the help of a rich and heterogeneous array of experimental methods and tools, others (e.g., Steinle 1997) emphasized its role in "purifying" phenomena, not least by generating new conceptual frameworks and, by extension, specific new forms of knowledge. (On this distinction, see also Schickore 2015). The same holds true for exploratory models and exploratory modeling in science. When the terms "exploratory models" and "exploratory modeling" were first introduced into the philosophical debate (Gelfert 2016), they were explicitly motivated by analogy with exploratory experimentation; yet, even then it was clear that "extending the [framework of exploratory experimentation] to scientific models is not as simple and straightforward as one might think" (Gelfert 2016, p. 79). Even if the contextual need for exploratory research is due to the same factor—the absence of a well-formed and applicable theory—it quickly becomes clear that the exploratory strategies and specific epistemic functions involved differ between exploratory experimentation and exploratory modeling.

For one, strategies such as the simultaneous variation of a large number of relevant parameters, which constitute interesting cases of exploratory experimentation—not least since they require considerable experimental ingenuity to pull off—may offer less insight in the case of modeling, where varying parameters often "comes cheaply," as is illustrated by the case of curve-fitting a polynomial equation to data points. This is not to say that such cases never make for interesting exploratory models: In a paper that explicitly builds on the framework of exploratory modeling sketched above, Michela Massimi (2019) has recently discussed how theoretical physicists studying supersymmetric particles have devised modeling techniques—the so-called pMSSM-19 approach—which vary 19 parameters (constrained by certain nomological desiderata) in an attempt to identify regions in parameter space that are consistent with the existence of the "superparticles" posited by supersymmetry.

At the same time, the example illustrates a further important difference between experimentation and modeling as regards the goals of exploration: Whereas experimental interventions simultaneously ensure, and are limited to, contact with the causal fabric of the actual world, models can also explore counterfactual possibilities, thereby delineating the scope of what is possible and impossible. This is why the epistemic function of exploratory models would be mischaracterized if one insisted that they "merely serve the heuristic function of stimulating subsequent research"; instead, they often "explicitly aim at identifying how-possibly explanations or otherwise delineate the space of possibilities" (Gelfert 2019, p. 15).

The papers assembled in this special issue are a vivid testimony to the diversity of practices and methods that qualify as exploratory modeling, and they are noteworthy both for the range of historical and philosophical approaches deployed and for the variety of case studies, which are drawn, *inter alia*, from fundamental particle physics, biochemistry, cognitive science, mathematics, economics, and the model-based study of science itself. It is our express hope that readers will not only consider each contribution in its own right, but will also be encouraged to look for similarities, patterns, and recurring epistemic strategies of exploratory modeling across individual scientific debates and disciplines.

This special issue has been long in the making (a first call for papers was circulated all the way back in 2018, and a subsequent workshop was held at Technische Universität Berlin in November 2019), and we would like to take this opportunity to thank all contributors—and the editors of *Perspectives on Science*—for their patience, as well as all external peer reviewers for their thoughtful and constructive input.

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