Chris Pincock
Mathematics and Scientific Representation.
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At the core of a great deal of recent work in the philosophy of mathematics is the metaphysical debate over the existence of mathematical objects. Although this debate is one of the many topics that Pincock's expansive book covers, it is not the focus. This is, frankly, refreshing. At times, the debate over the existence of mathematical objects, which centres on the indispensability argument, can seem myopic in its reluctance to engage broader questions concerning the role of mathematics in scientific theory and practice. Pincock's book is primarily interested in these more general issues and so is immensely valuable. It is also technically demanding. Far from being a problem for the book, however, its technical rigour is a virtue.

One of Pincock's central aims is to catalogue the various contributions that mathematics makes to representations within science, as the title of the book suggests. This not only feeds back into metaphysical debates within the philosophy of mathematics, but into concerns about the role that mathematics plays in science more generally, concerns that are coming to the fore in, for instance, biology and physics (and thus their associated 'philosophies of'). Pincock offers a conceptual framework for thinking about the many contributions that mathematics makes to science, and engages with questions concerning the contents of our physical and mathematical beliefs. A new way of thinking about Inference to the Best Explanation (IBE) is proposed and recent trends in the debate over the indispensability of mathematics to science are tracked and criticised. For those interested in the metaphysics, one of Pincock's more surprising conclusions is that although the strongest form of the indispensability argument fails, there is reason to believe in the existence of mathematical objects *anyway*. This is because the epistemic contributions that mathematics makes to science are so significant that "there's little hope of doing science without already having a reason to believe the mathematics" (220).

The book is divided into fourteen chapters and supplemented by four appendices. The appendices mostly contain mathematical proofs of mathematical claims put to use in other parts of the book. Chapter One is the introduction, and nicely lays out the central claims to be made in subsequent chapters. These are usefully listed at the beginning (21) and again towards the end (279–80). In Chapter Two, Pincock offers an account of the *content* of scientific representations, providing his own take on what it means for mathematics to be part of that content. Along the way he argues that non-empirical justification is required to make sense of the contribution that mathematics makes to scientific confirmation, a theme which recurs through the book and which is ultimately dealt with toward the end, when the status of *a priori* justification is (albeit briefly) considered.

Chapters Three to Seven outline the contributions that mathematics makes to science. They also constitute the most technically demanding part of the book. Chapter Three distinguishes between *causal* scientific representations (representations that, roughly, use mathematics to model the causal structure of a system) and *acausal* representations

(representations that, again roughly, abstract away from the causal detail of a system via their mathematical content) and argues that mathematics plays a distinctive epistemic role in each. Chapter Four introduces and discusses the notion of an *abstract varying representation*: representations which correspond to mathematical variations of other scientific representations. The focus here, ultimately, is the role that mathematics plays in *unifying* various kinds of representations, thereby revealing important connections between the target systems being modelled.

Chapter Five considers the way in which mathematics can connect scientific representations across different scales and offers nine distinct examples that rely on mathematical scaling. This chapter will be particularly interesting to those working in the philosophy of biology on optimality models of foraging behaviour, since some of these models are partly characterised by their reliance on scale invariance (for an overview see, e.g., A. James, M. J. Plank, and A. M. Edwards, "Assessing Lévy Walks as Models of Animal Foraging", *Journal of the Royal Society Interface*, 8.62 [2011]: 1233–47). The scientific representations discussed in Chapters Three to Five are *derivative* representations: representations that depend for their success on the success of more basic representations. Thus, in Chapter Six Pincock shifts gears to discuss the role of mathematics in basic representations, what he calls 'constitutive representations'. Pincock's claim is that mathematics is especially useful for *formulating* representations of this kind, though it is not essential for that purpose.

The work carried out in Chapters Three to Seven is useful in a couple of ways. On the one hand, simply cataloguing the various roles that mathematics plays in science is something that has not, to my knowledge, been done before in this level of detail. On the other hand, in so far as something like it has been done, the focus tends to be on the *positive* contributions that mathematics makes to science. The possibility that mathematics might contribute negatively to science, underpinning scientific failures, is rarely considered. Chapter Seven is thus devoted to identifying cases in which mathematics has led to stunning scientific failures. Pincock revisits the explosion of the Tacoma Narrows Bridge (a case sometimes cited in favour of the view that mathematics is explanatory), arguing that the abstract mathematical representations used by engineers to build the bridge contain certain scaling idealizations, and it is these idealizations that, in large part, lead to the bridge's destruction. Pincock's general position is that mathematical models can contain certain kinds of illusions (such as scaling illusions) and that these illusions can sometimes be blamed for scientific failures.

Chapters Eight to Thirteen focus on issues that Pincock considers to be ancillary to the central focus of the book (Pincock uses the name 'other considerations' for this group of chapters). Chapter Eight revisits the unreasonable effectiveness of mathematics in science. Drawing on his previous overview of the epistemic contributions that mathematics makes to science, Pincock argues that, actually, there is nothing particularly mysterious about the role that mathematics plays in scientific discovery and progress. Indeed, it is something that we should expect given the substantial work that mathematics can be made to do within scientific representation.

Chapter Nine focuses on the indispensability argument. What's particularly nice about this chapter is the way that Pincock pulls apart two different forms of the indispensability argument: a version that concludes in favour of realism about the truth-value of mathematical statements, and a version that concludes in favour of the existence of mathematical objects. This is a distinction that is often considered unproblematic and yet Pincock does a good job of showing that it matters. In the end, Pincock's view is that the best version of the argument is the truth-value realism version. Chapter Ten extends this discussion of the indispensability argument by considering the recent explanatory turn in the debate over its cogency. Pincock parts ways here from a number of philosophers working in this area (and on both sides of the debate) by using the explanatory power of mathematics *against* the indispensability argument, contending that mathematics must already be confirmed before it can be thought to play an explanatory role in science. Hence, there is a sense in which, for Pincock at least, the indispensability argument is question-begging.

Chapter Eleven is an extended discussion of Batterman's asymptotic (i.e. limit operation) explanation of the rainbow, along with the role that mathematics plays in this explanation. One interesting issue that this chapter raises relates back to the indispensability argument: Pincock does not raise it here, though it comes up in a forthcoming work ("Mathematical Models of Biological Patterns: Lessons from Hamilton's Selfish Herd", *Biology and Philosophy*, DOI: 10.1007/s10539–012–9320–8). Batterman's cases highlight *inter alia* a problem for the indispensability argument that Pincock favours. The problem, roughly, is this: asymptotic explanations appeal indispensably to idealizations, and so the proponent of the explanatory version of the indispensability argument may be forced to accept the unattractive conclusion that some idealizations are true. What the proponent of that argument really requires, then, is a way of differentiating between the explanatory involvement of idealizations in science and the explanatory involvement of mathematics (see, e.g., P. Maddy, "Indispensablity and Practice", *The Journal of Philosophy* 89.6 [1992]: 275–89). One option, which would support Pincock's case against the indispensability argument, is that mathematics must be justified prior to its role in science, but idealizations are justified in other ways (if, indeed, they are justified at all).

Chapter Twelve engages with standard fictionalist approaches to mathematics and argues that such approaches cannot fully account for the epistemic contributions that mathematics makes to science. Although the point is, perhaps, a familiar one, Pincock's approach is novel. His argument proceeds by consideration of recent work on fiction and truth-in-fiction and uses lessons learned from this wider debate to inform the discussion surrounding mathematical ontology. Chapter Thirteen targets non-standard versions of mathematical fictionalism. The thesis of this chapter is that some fictionalist approaches to mathematics have difficulty accounting for change in our mathematical concepts, which is a new complaint against fictionalism.

Chapter Fourteen is the conclusion, but it also speaks to one issue that, for Pincock at least, remains outstanding. As noted, Pincock argues that the justification for mathematics must be prior to its role in science, and thus non-empirical. Pincock's position here is that the justification for mathematics is *a priori*. As Pincock is aware, this is difficult to square with the epistemology of mathematics. How can we know that mathematical statements are true through purely *a priori* means? Pincock gestures toward some answers to this question, but is understandably tentative at this late stage of the book. Discussion of this issue would no doubt make for a good sequel, which I, for one, hope he intends to write.

Sam Baron
University of Sydney