Essay Review: *Isaac Newton's Scientific Method*

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William Harper, ***Isaac Newton's Scientific Method: Turning Data into Evidence about Gravity and Cosmology***. Oxford: Oxford University Press (2012), 360 pp., $75.00 (cloth).

Perhaps no argument in the history of science has been scrutinized as much as that of Newton in Book 3 of the *Principia*. One might find it astonishing, then, that philosophers still have fundamental disagreements about how, exactly, the argument of Book 3 is supposed to work and what it establishes. What's the problem? If William Harper is right in his new book, *Isaac Newton's Scientific Method: Turning Data into Evidence about Gravity and Cosmology*, the problem is that we have been trying to fit the argument in Book 3 to extant views of scientific inference, but none of these views capture essential aspects of Newton's methods. Over the last couple of decades, an important body of work on Newtonian methodology has developed, spearheaded by Harper and George Smith (the phrase "turning theory into evidence" in the subtitle of this book is a tribute to Smith, who coined the phrase), but this work is largely unknown outside history and philosophy of science circles. A common theme in the work of both Harper and Smith is the inadequacy of predominant views of scientific methodology, especially the hypothetico-deductive (H-D) model, for understanding Newton's methods in the *Principia*. In light of the continuing influence of the H-D model in philosophy of science and other areas of philosophy, one of the clear aims of this book is to bring this work on Newton, and its associated view of scientific methodology, to a wider philosophical audience. Although, as I shall explain, there are some problems with the way in which

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Harper presents this view, the book is a formidable challenge to the H-D view, and any philosophers interested in scientific methodology would benefit greatly from reading it.

Many readers will, of course, be reading this book not so much for this view of scientific methodology but simply as a detailed guide to the argument of the *Principia*. For such readers, especially those who are philosophers, I can think of no better book. It differs from recent work on Newton by philosophers such as DiSalle (2006) or Janiak (2008) in focusing less on metaphysical or conceptual issues and more on methodological ones—the kinds of questions that Harper mainly deals with have to do with how the argument in Book 3 is supposed to work, what evidence was available to Newton at the time, and exactly what that evidence established. There are, to be sure, some excellent books that examine the argument and the methods of the *Principia* in detail, such as Densmore (2003), but this book stands out in having been written by a philosopher, with a philosopher's interests explicitly in mind.

As the title indicates, the main aim of the book is to try to understand Newton's scientific method—how it works, and what advantages it offers over other methods. Harper believes that Newton's method is not best thought of as being H-D and, further, that Newton's program largely owes its success to the ways in which Newton's method goes beyond the H-D method. So perhaps the most important task in this book is to lay out exactly how Newton's method goes beyond the H-D method (Harper claims that the method is not Glymour-style bootstrapping either, but the main target is the H-D method) and exactly what advantages it confers—how is it an improvement over the H-D method? Through an extremely detailed examination of Newton's methods, Harper convincingly shows that the H-D model seems to miss very important aspects of Newton's methods. Unfortunately, I think Harper's diagnosis of the reason for the inadequacy of the H-D model misses the mark. For Harper, the problem with the H-D model ultimately lies in its having the wrong criteria for empirical success. I think, on the contrary, that the problem is a more general one. Because of an overemphasis on confirmation, philosophers have not recognized the importance of certain aspects of scientific theorizing in Newton, particularly the use of theory for what I call *exploration*. I will explain what I mean in the rest of this review.

According to Harper, Newton's method is characterized by three main features that distinguish it from the basic H-D method (375): first, it involves a "richer ideal of empirical success"; second, it makes use of "theory-mediated measurements"; and third, it involves the acceptance of theoretical propositions as "provisional guides to research." Further, these three features all come together "in a method of successive approximations that informs applications of universal gravity to motions of solar system bodies."

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Harper states what the richer ideal of empirical success is in somewhat different ways throughout the book. If we put the pieces together, we can say that this ideal involves "systematic dependencies" (25), "accurate measurement of parameters by the phenomena they explain" (2), and "convergent measurement" (160). The ideal goes beyond the H-D method because, Harper says, it involves more than mere prediction (30).

One example of a systematic dependency is an inference that Newton makes in Proposition 1 of Book 3. The satellites of Jupiter move in accordance with Kepler's Area Rule, and from this he infers that there is a force on these satellites that is always directed toward Jupiter. According to the H-D model, the way in which the inference works is that, given that there is a centripetal force toward Jupiter, you would predict motion in accordance with the Area Rule. You observe such motion, and you thereby infer this centripetal force. Harper points out, though, that the theorems that Newton proves in Book 1 allow him to do more than this—a departure from the Area Rule such that the area rate is increasing indicates that the force vector is off center toward the direction of orbital motion, while if the area rate is decreasing, then the force vector is off center in the opposite direction. Harper says that what is going on here is not mere prediction but measurement—in this case, what is being measured is the direction of the force vector governing the motion of the satellite. We see such systematic dependencies in other inferences that Newton makes as well. For example, Harper considers the inference to the inverse-square law to be a measurement, which is carried out in two different ways—by the motion of Jupiter's satellites in accordance with the Harmonic Rule (also known as the 3/2 Power Rule) and the motion (or lack of it) of the aphelia of the planetary orbits. The -2 exponent in the inverse square law, then, becomes a parameter that explains phenomena such as Keplerian motion of the satellites and the motion of the aphelia, while at the same time the value of this -2 exponent is measured by these phenomena—this is an example of what Harper means by "accurate measurement of parameters by the phenomena they explain."

The central example of converging measurement of parameters is the moon test, the famous argument through which Newton identifies the force holding the moon in its orbit with terrestrial gravity. For Harper, the moon test is another measurement of a parameter—the distance that an object would travel in the first second of fall. Harper shows that the values obtained for this parameter from terrestrial experiments involving pendulums agree very well with the moon-test measurement. Four estimates of this parameter from measurements done with seconds pendulums give a mean of 15.097 Paris feet with a standard deviation of 0.0013 Paris feet, while six estimates of this parameter calculated from lunar distances give a mean of 15.041 Paris feet with a standard deviation of 0.37 Paris feet (182). What do we gain from this converging measurement? Harper says that the "agreeing

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cruder moon-test estimates back up the sharper pendulum estimates" (184). The idea is that you get increased resiliency for the measurement—if a new measurement using a pendulum resulted in a value highly divergent from the previous ones, then the results from the moon test would make this new measurement count less toward the calculation of the mean value of this parameter. Here, Harper uses least squares methods that were unavailable to Newton to make this point, which I find puzzling—is Harper saying that Newton's thinking was somehow along these lines, and he would have used these methods if they were available to him? Or is this supposed to be more of a reconstruction of why the method works, rather than what Newton actually intended? This is unclear from what Harper writes.

Going back to the three main features that Harper thinks distinguish Newton's method from the H-D method, perhaps the most important feature for Harper is the acceptance of theoretical propositions as "provisional guides to research." This phrasing is somewhat misleading, because it sounds like the theoretical propositions act as some kind of heuristic. But in Harper's view, the provisional theoretical propositions play a crucial role in enabling measurements to be made. This feature of provisional theory acceptance is connected to Newton's Fourth Rule for Philosophizing. Rule 4 says two things—that we should rule out hypotheses in favor of propositions that are gathered from phenomena and, also, that we should provisionally take such propositions to be either exactly or very nearly true. Harper emphasizes the importance of this second part of Rule 4 for Newton's methodology. This is a view pioneered by George Smith (2002), as Harper acknowledges. The methodology involves taking propositions that are gathered from phenomena to be exactly true, so that deviations between what you would expect the phenomena to be like, given that these propositions are true, and what the phenomena actually are observed to be like can be found. These deviations are then taken to be new phenomena that can potentially be explained through the further measurement of parameters. The provisional theoretical propositions are thus, in a sense, constitutive of phenomena—through which new measurements can then be made.

If we accept Harper and Smith's interpretation of the significance of Rule 4, then there are two important consequences for how we should think about Newtonian methodology. First, the method is forward-looking—one of the motivations for theorizing is the enabling of measurements that might become possible in the future. Second, the method comes apart from confirmation—one might provisionally accept a theoretical proposition that is only weakly confirmed, on the basis of the promise of future empirical payoff (Harper himself has used the term *acceptance* for describing this aspect of theorizing). Now this gives rise to a worry—since we can, in some cases, accept theoretical propositions that are only weakly confirmed, there is a significant possibility that they could turn out to be false. And if so, it

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seems that the new "phenomena" would turn out to be illusory, and any measurements made through such phenomena would be illegitimate or, even worse, misleading (Smith has coined the term "garden path" for research predicated on theory that turns out to be false). Does Newton's scientific method have some mechanism for dealing with this problem? This is an important question that arises in Harper and Smith's framework and on which further research needs to be done.

With all of this in mind, I think there are problems with the way in which Harper describes Newton's method as going beyond the H-D model. An important element that the work of Harper and Smith introduces is that, for Newton at least, methodology comes apart from confirmation. So I thought that what Harper would do is to show that insofar as the H-D model is concerned only with confirmation, it will not capture certain very important aspects of Newton's method. Instead, Harper characterizes the crucial difference between the H-D model and Newton's method as being their respective criteria for empirical success. According to Harper, the H-D model takes successful prediction to be the only criterion of empirical success, whereas Newton has a "richer ideal of empirical success"—and this includes things like convergent measurement and systematic dependencies. But a proponent of the H-D model might be puzzled by what Harper says because the H-D model, at least in its modern-day form, usually admits criteria for theory choice beyond mere successful prediction—such as the so-called empirical virtues, like simplicity or unification. So I imagine that to many H-D theorists, it sure looks like what Harper is proposing can be accommodated by some modifications to the H-D model in which you add virtues such as systematic dependencies or convergent measurement. Because of the sheer generality of the H-D theory, as long as you do not separate out confirmation from methodology, it is very difficult to show that what Newton is doing is not H-D.

What is missing, then, if we think only in terms of confirmation? Well, neither Harper nor Smith have quite put it this way, but I think that if we want to understand what Newton is doing, what is missing is the role of exploration. Consider the problem Newton faced. Both Harper and Smith have emphasized the importance of the Copernican Scholium in the augmented version of *De Motu*, a manuscript that was the precursor to the *Principia*. In this scholium, Newton speculates that the solar system might be complicated, consisting of many parts, and there is the potential that all of these parts are interacting with one another. We did not, at the time of Newton, know whether there could be other parts that we could not see, or whether there could be strong interactions with an invisible ether. It is an extremely complicated system to which we only had limited access, and we needed to figure out what the significant parts of that system are and what effects they had on one another. We can, of course, see many of the significant parts of

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the solar system, such as the sun, the moon, and the planets, but there could potentially have been parts that we cannot see—parts that have a significant effect on the motions of the other parts. If there are such invisible parts, we can come to know of them only through the effects they have on the visible parts. But if the solar system is a massively interacting system, then we need some way of separating out the effects each of the parts have on one another.

One aspect of exploration that we need a better understanding of is the use of theory for exploration. In seismology, for example, scientists are exploring a complicated system to which we have limited access—the interior of the earth. In carrying out this exploration, seismologists make use of the theory of waves in continuous media. In much the same way as you need the theory of waves in continuous media in order to carry out exploration of the interior of the earth, you need the theories of gravity and mechanics in order to carry out exploration of the solar system. But there is a big difference. We are confident that the theory of waves in continuous media will be applicable, more or less, to the material in the deep interior of the earth. But Newton did not know antecedently whether the theories of gravity or mechanics would hold way up there, where the moon and the planets are. So here is what makes Newton's problem such a difficult one: in order to explore this system, you need to use a theory, but you do not know in advance whether the theory is actually applicable. If, like Newton, you are trying to explore a complicated system in which you do not know in advance whether certain theories are applicable, the important questions are going to be, What are the significant parts of this system, and what effects do they have on one another? In which parts of a system, and under what circumstances, is such-and-such a theory applicable?

The inference from the Keplerian motion of Jupiter's satellites to a centripetal force directed toward Jupiter is best thought about with these underlying questions in mind. It is not just a measurement—it is telling us something about this particular system, the solar system. It is telling us that, look, there is a force on this satellite, and there is very good reason to believe that this force is coming from Jupiter. And it is better to think of the moon test, as well, not in terms of confirmation but exploration. Here, I find Harper's analysis of the moon test in terms of resilience rather misleading. It suggests that the significance of the moon test is confirmatory—it increases our confidence in our measurement of the 1-second fall parameter. I think, on the contrary, that the greatest significance of the moon test for Newton is not in its confirmatory power but in its implications for exploration. The moon test tells us that there is reason to believe that the force that holds up there is identical to the force that holds on the earth. And thus that there is reason to believe that we can take the precise measurements of the 1-second fall parameter that we have made on the earth and apply the

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values from those measurements up there, where the moon is. The moon test does not appreciably increase the confidence we have in the measurement of the 1-second fall parameter. Instead, it increases the scope of applicability of the parameter values measured on the earth, which we can then use to explore reaches of the solar system that we could not before.

Newton's *Principia*, and the centuries-spanning research program it led to, is one of the most impressive achievements in the history of science. Harper's book gives us magnificent insight into the fine details of this research program, and how and why it works. Philosophers who are interested in scientific methodology, however, are going to be looking for more general conclusions that can be drawn from Newton's work, and here I think the picture that Harper draws is still rather fuzzy. Nevertheless, I hope that this important book will convince more philosophers that there is indeed something missing from current theories about scientific methodology, and we can continue to try to bring the picture into sharper focus. In particular, instead of merely trying to understand how scientific theories are confirmed, we should work toward a better understanding of the various uses of scientific theory—for example, as a tool for exploration or for "turning theory into evidence."

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