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Essay Review

Newton and the ideal of exegetical success

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William Harper, *Isaac Newton's Scientific Method: Turning data into Evidence about Gravity and Cosmology.* Oxford University Press, Oxford and New York (2011). pp. xviii + 410, Price US$45.00 paperback, ISBN-13: 978-0198709428

William Harper's excellent, difficult, and provocative book — winner of the 2014 Patrick Suppes Prize for Philosophy of Science — is by far the most detailed available account of Newton's argument for universal gravitation in Book III of the *Principia*. It should be mandatory reading for philosophers interested in the relation of evidence to theory, as well as technically savvy historians of early modern physics. It should also be recommended to novices. Its chapters are mostly self-contained and its step-by-step approach make it a great companion for first time students of Newton's system of the world.

Harper's stated goal is to explicate *Newton's method*; i.e., Newton's use of evidence and inference in the process of theory construction.[1] To this end, Harper examines the *Principia* and the astronomical and experimental data available to Newton with antiquarian glee. But Harper also has a broader goal. By using methods that are sometimes presentist, he aims to show that from a contemporary perspective Newton's reasoning is *proper* reasoning. This is no trivial task. There are no guarantees that contemporary standards of evidence and reasoning can make sufficient sense of historical cases. Harper demonstrates that in Newton's case they do, and thus highlights a historiographical fact often neglected by highly contextualized, local histories of science: that the validity of Newton's argument transcends its context of composition. The book is thus a genuine study in history *and* philosophy of science. It juxtaposes two goals that are often at odds — revealing descriptive and normative truths — and moves frequently between them.[2]

Since Harper focuses on Newton's use of evidence, it seems fitting to focus on Harper's. His account draws on two main sources. Primarily, it is based on a step-by-step analysis of Newton's inferential practice, as embedded in the propositional structure of the *Principia*. Secondarily, it is based on Newton's methodological remarks, as found in the "Rules for the Study of Natural Philosophy" that precede Book III and some scholia and letters.

How do these fit together? Mostly, the book suggests that Newton's practice elucidates his remarks and that his remarks capture his practice. Their fit also establishes authorial intent — that "Newton's method" was actually *Newton's* (p. 128). But intent is also established silently, through an implied question: How could Newton have made the myriad small, highly-technical decisions required to construct the *Principia* — a work that so clearly exemplifies his method — *without* being explicitly aware of it? At times, the question leads Harper to discount the evidential value of methodological remarks. For example, it leads him to ascribe Newton's method to historical actors even when they did not ascribe it to themselves (p. 377). There are also times when the evidential value of methodological remarks is unclear. Harper speaks of certain ideas as "informing" or "backing" both practice and explicit remarks and of practice and remarks as "realizing" or "exemplifying" certain ideas, leaving open whether these are logical/conceptual relations or accounts of actors' own thinking.

That Harper does not pause on these issues is natural — they are not his primary concern. However, his treatment invites us to explore them. It invites us to ask how well Harper's two evidential sources fit together, what is the evidential value of each, and what we can learn from their fit or lack thereof. In one sense, Harper's book offers an extended argument for one set of answers: that Newton's practice aligns with his remarks, that each supports our interpretation of the other, and that their mutual support shows that Newton practiced his method entirely self-consciously.

I'd like to suggest, however, that reconciling Newton's practice with his methodological remarks is more difficult than it seems. I'll demonstrate this with three short vignettes. Each is a variation on the same theme: that the complexity and nuance of "Newton's method" differ sharply from the simplicity of his reflections on it.

To draw the contrast, I must first outline "Newton's method" according to Harper. Readers less interested in the details of Newton's method can skip directly to the vignettes. I must also make one caveat clear: the few disagreements with Harper I raise below are greatly outweighed by unstated agreements.

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[1] References to Harper (2011) will be to page number only. Reference to the *Principia* will be to book number and proposition (e.g., III.3 is Book III, Proposition 3), quotations are from Newton (1999).

[2] Needless to say, there are many ways to understand the relationship between history and philosophy. For essays that almost uniformly belie my facile division, see Laerke, Smith, and Schliesser (2013).

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1. Newton's method

According to Harper, Newton's method is guided by an "ideal of empirical success" [IES] according to which "a theory succeeds by having its theoretical parameters receive convergent accurate measurements from the [diverse] phenomena it purports to explain" (pp. 160, 370). This ideal is "richer" — by which Harper means both more informative (p. 42) and more stringent (p. 140) — than the ideal associated with the Hypothetico-Deductive method [HDM].

According to the HDM, "empirical success is limited to accurate prediction of observable phenomena" (p. 42).[3] It entails that a theory becomes better confirmed when its consequences — predictions — match observations within some observational tolerance (p. *vi*). A mismatch, particularly an ineliminable one, indicates that the theory must be revised. But the mismatch carries no intrinsic information about which parts of the theory to revise or how to revise them. This is because the HDM allows for inferences from theory to predictions, but not from observations back to theory.[4] Harper argues that Newton's method, in contrast, allows for inferences in *both* directions (p. 43). Its richness stems almost entirely from this more complicated inferential structure.

Let's start with informativeness. Because of its bi-directional structure, Newton's method allows phenomena to *measure* — i.e., provide information about— theoretical parameters. Consider an example (pp. 28, 119ff). In proposition I.45, Newton showed that the apsides of a body in near-circular orbit (the points of nearest and farthest approach to the central body) do not precess *iff* that body moves under the influence of a single centripetal force that is as $1/r^x$ from the force center, where $x = 2$. He also showed that forward precession corresponds to $x > 2$, while backward precession corresponds $x < 2$; both as a function of the precession angle, so that apsides that *approximately* do not precess correspond to an x that is *approximately* 2. This *systematic dependency* allows the precession angle to *measure* the distance exponent of the force law.[5] It was exploited in proposition III.2. Newton noted there that the lack of noticeable precession in the orbits of Mercury, Venus, Mars, Jupiter, and Saturn shows "with the greatest exactness" that the force holding those planets in their orbits is as $1/r^2$ (Newton, 1999, p. 802). Newton's procedure was *not* to hypothesize a certain value for the parameter (e.g., $x = 2$ in $1/r^x$) and then check whether the observed phenomena bear it out, as the HDM recommends. Rather, it was to set up a sufficiently sophisticated inferential structure so that *even if the phenomena did not bear out the consequences of an inverse-square law*, useful information could be extracted from them. Newton could thus turn *any* data about precession into "far more informative evidence than can be achieved by hypothetico-deductive confirmation alone." Dependencies of this sort were exploited throughout the *Principia*, in what Harper calls *theory-mediated measurements*.

Importantly, to the extent that a theoretical parameter can be involved in multiple dependencies, it can be measured by diverse phenomena. Agreement between such measurements indicates that the information extracted from them is consistent; that is, that they are truly informative about the parameter they measure. Harper notes that accruing agreement also entails that the extracted information is *resilient*; that is, less open to revision by new measurements. He demonstrates this by means of statistical analyses. We will return to this issue below.

Of course, for a systematic dependency to measure a theoretical parameter, it must be expressed using a theory. More precisely, it must be expressed using a theoretical "background framework" that is both general enough to leave some parameters unspecified (i.e., it must involve weak background assumptions) and powerful enough to entail a sufficient number of systematic dependencies that can be exploited in measurement (p. 22). In the *Principia*, the framework is constituted by the laws of motion and the account of space, time, and force on which they depend. It is drawn out in books I and II, and then used with real-world data in book III to measure the direction and strength of forces and the (relative) masses of solar system bodies.[6] Theory-mediated measurement may not seem remarkable to contemporary readers — after all, we are used to inferring boson masses from patterns of luminescence in scintillator arrays — but it was relatively new in the seventeenth-century (p. 196). More to the point, it was used by Newton in a remarkably controlled way; namely, to tie together a *single* feature of the available data and a *single* theoretical parameter, so that one can fully determine the other. This enabled Newton to "turn theoretical questions into ones which can be empirically answered by measurement from phenomena" (p. 2).

This brings us to the stringency of Newton's method. Apart from the constraints on theoretical parameter values imposed by the IES, Newton's method involved a commitment to the *provisional acceptance* of claims established by means of theory-mediated measurement. Harper argues that Newton eschewed thinking of empirical support in terms of probabilities (pp. 36, 48). Instead, he took claims established by means of theory-mediated measurements to be provisionally true (or provisionally approximately true), where provisional truth (or provisional approximate truth) is understood as a commitment to using the established claims for the purpose of furthering the IES; i.e., using them in order to generate additional, better theory-mediated measurements (pp. 36, 260ff). Newton also took rejection or revision of previously accepted claims to be mandated *only* when those claims proved no longer useful for furthering the IES or less useful than available alternatives (p. 260).

These criteria entail that even if two theories have identical observational consequences, the one that better promotes the IES is preferable. Newton's method thus allows for theory-choice between empirically equivalent theories, ones between which the HDM cannot discriminate (p. 45). Almost trivially, the method also prohibits "mere contrary hypotheses" — i.e., claims that are logically compatible with the data but do not replicate *any* IES successes — from undercutting claims that are IES-backed. For example, it prohibits the possibility of a Cartesian-style vortex theory from casting doubt on universal gravitation, unless a vortex theory can be produced that bests universal gravitation *according to the IES*. Likewise, they prohibit broad inductive skepticism from undercutting generalizations from measurements established in

[3] For the most part, Harper considers a rather spare version of the HDM inspired by Christiaan Huygens. When he considers more sophisticated versions (say, Bayesian formulations), it is to show that they still cannot "recover the features that we have seen to make Newton's method so successful in physics and cosmology" (374).

[4] In certain cases, a mismatch might carry information even on the HDM. For example, if a theory hypothesizes a linear relationship between two variables, the data might straightforwardly suggest another factor. However, the informational content of the data in such a case is not a feature of the HDM, but a feature of the particular theory and mismatch under consideration. The HDM itself cannot guarantee that such information would be available.

[5] Smith (2002) details how Newton builds sensitivity to approximations into Books I and II by means of *quam proxime* propositions, propositions whose antecedents are approximately true *iff* their consequents are also approximately true. This idea is folded into Harper's notion of a systematic dependency. For an additional, mutually illuminating account of Newtonian methodology, see also Ducheyne (2012).

[6] Determining solar systems masses is a thorny issue. Harper's chapters 9 and 10 are essential reading. See also Smith (2013, 224ff).