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ESSAY REVIEW

New Textbooks for Teaching Philosophy of Science

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Barker, Gillian, and Philip Kitcher, *Philosophy of Science: A New Introduction*. New York: Oxford University Press (2014), 192 pp., $29.99 (paper).

Potochnik, Angela, Matteo Colombo, and Cory Wright, *Recipes for Science: An Introduction to Scientific Methods and Reasoning*. New York: Routledge (2018), 348 pp., $52.95 (paper).

Staley, Kent W., *An Introduction to the Philosophy of Science*. Cambridge: Cambridge University Press (2014), 298 pp., $32.99 (paper).

1. Introduction

The recent publication of three new introductions to the philosophy of science offers a good opportunity to examine them comparatively and to use them as a springboard for discussing the goals and objectives for teaching philosophy of science, and for designing textbooks for this purpose.

I will review *Recipes for Science: An Introduction to Scientific Methods and Reasoning*, by Angela Potochnik, Matteo Colombo, and Cory Wright (PCW hereafter); Kent W. Staley's *Introduction to Philosophy of Science* (KS henceforth); and Gillian Barker and Philip Kitcher's *Philosophy of Science: A New Introduction* (BK hereafter). The perspectives on teaching philosophy of science, the concepts for an undergraduate textbook for teaching it, the level of difficulty given their intended audience and learning goals are all different among the three books. Following a summary of the books, I assess them with respect to some key issues, and end with a suggestion for a future textbook.

2. Summary

2.1. Potochnik and colleagues' introduction

The title *Recipes for Science* is meant to evoke two ideas about science inspired by comparisons with cooking. Science comes in a variety of scientific activities and there is no special list of features that guarantees good science; however, generalizations can be made about how good science is done. The subtitle, *An Introduction to Scientific Methods and Reasoning*, discloses that it intends "to facilitate a clear understanding of the key elements of science and why those elements are significant" (3). PCW present them from a philosophical perspective and include brief explanations of some philosophical problems that the elements pose. The authors do "not dwell on philosophers' debates about science" (ibid.). In this respect it is similar to Giere et al.'s (2006). Primary texts should complement it if used in an upper-level philosophy of science course.

Recipes covers three large themes: the nature of science and its key methods (Chapters 1–3), scientific reasoning (Chapters 4–7), and the goal of science and its relationship to society (Chapter 8). Each chapter has three sections. The "Introduction" and each chapter begin with an accessible description of a case from science that illustrates a notion or problem discussed in that part of the book. Chapter 1 opens with a brief history of research on climate change and its dire consequences to illustrate the importance of science. This poses the problem of defining science in contrast to pseudoscience. A possible list of defining characteristics is complemented with characterizations of science based on its history, subject matter, and methods. Furthermore, PCW add to that list individual and social norms that protect against bias and flaws in reasoning, given that science is a collective enterprise. PCW argue against the received view that there is a set scientific method, and explain three steps common to the many recipes of doing science: formulating hypotheses, developing expectations based on them, and testing expectations against observations. Laboratory and field experiments, their organization, roles, strengths, and shortcomings, as well as varieties of observational studies, are presented thoroughly in Chapter 2. It ends with short notes on computer simulations and thought experiments, and briefly examines two philosophical problems—underdetermination and crucial experiments. Chapter 3 uses the story of building the San Francisco Bay model to explain the role of models in science, how they are constructed, their relationship to targets, and their subsequent analysis. It then introduces, with adequate exemplification, models of data and different models of phenomena, and details their different roles in scientific reasoning. The chapter ends with a more philosophical examination of how one learns from models, presents their role in testing hypotheses as analogous to that of experiments, and outlines the features common to all models and the inevitable trade-offs among them.

Empirical evidence becomes scientific knowledge through various ways of reasoning—the theme of Chapters 4 through 7. Starting with the basics of arguments, their conditional varieties, and the similarly looking fallacies, Chapter 4 explains how to evaluate inferences and identify bad arguments, including the unacceptable grounds for rejecting inferences. It introduces the H-D method, illustrated by the work of Semmelweis; explains confirmation as an invalid argument; contrasts it with refutation; and shows how it leads to the Duhem–Quine problem. The case of Flint's water crisis introduces inductive reasoning and the problem of induction. Philosophical contributions to the latter are limited to brief notes on Hume and Reichenbach. Wegener's theory of continental drift, the sub-Saharan, and pan-Africa hypotheses help the reader learn about abductive reasoning and that its goodness comes in degrees. Chapters 5 and 6 offer an accessible crash course

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in the importance of statistical thinking, the basic notions of descriptive statistics, the rules of probability theory, how to calculate conditional probabilities, correlation, generalizing from descriptive statistics, testing hypotheses with statistics, and the Bayesian alternative.

The question of whether fracking causes earthquakes motivates examination of causation and causal reasoning in Chapter 7. Explanation of the general features of causal reasoning are followed by the skeptical response to causation, which is answered with two guides to causation: spatiotemporal contiguity and correlation. PCW also describe difference-making and physical processes as possible responses to the nature of causation, necessary and sufficient causes, the link between the causal background, and the probabilistic nature of causation. The examination of causal reasoning continues with testing causal hypotheses using experiments and Mill's methods, and causal modeling to search for causal relationships and to test causal hypotheses with causal Bayes nets.

Explaining, theorizing, and values, which are usually examined separately, are the themes of the last chapter of *Recipes*. The section on explaining justifies the topic and describes the error of illusion of explanatory depth, to which even scientists could fall prey. This error and the centrality of explanation in science require the clarification of its nature. PCW describe four attempts and mention some of their weaknesses: Hempel's nomological and the unification conceptions, the causal perspective, and its mechanistic variety. Describing science in terms of hypotheses, expectations, and observations does not capture one of its key components: theories. So, PCW turn to this, with Darwin's and Einstein's theories as prime examples, and the chemical revolution illustrating theory change as envisioned by Kuhn, followed by a consideration of scientific change through integration of new ideas, methods, and joining of theories, and scientific progress. The section on values examines first those influences of sociohistorical contexts on science that limit participation in science, bias research, and use it to advance objectionable social goals and immoral research. PCW then make the case for a positive influence of the sociohistorical. They list several diversity features and explain some ways in which diversity contributes to scientific success. The focus on hypotheses–expectations–observations suggests that science is value free. To dispel this view, *Recipes* explains the acceptable and unacceptable roles of values in science. The book ends with an examination of the harmful effects of publication and funding biases, data dredging, and institutional constraints on science's capacity for self-correction to ensure its objectivity and public trust.

2.2. Barker and Kitcher's New Introduction

Unlike *Recipes*, the works by BK and KS "dwell on philosophers' debates about science" (Potochnik et al. 2018, 3). Philosophical views about various aspects of science take center stage and examples of scientific research are used to illustrate those views, rather than serving as chapter openings that motivate philosophical ideas. They use history of philosophy of science as an instrument to introduce key concepts and questions that traditional philosophy of science poses, and add a range of supplementary topics to that basis.

BK view their book of six chapters as a departure from the practice of updating Hempel's 1966 classic. Their goal is to expand the agenda and to examine issues that

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Hempel and his followers have not discussed. Consequently, they relegate traditionally key topics in the field—demarcation, confirmation, theories, explanations—to just one chapter, and criticize science so as to propose a well-ordered science that serves all, producing a book with a goal and a subtitle: *A New Introduction*.

The Preface and Chapter 1 justify philosophy of science. It is important because science cannot answer philosophical questions pertaining to and arising in research, such as the "nature, autonomy, and ownership of scientific knowledge," or inferences from incomplete evidence, or divisions into races. A "whirlwind sketch" of the history of natural sciences from their origins in ancient Greece helps draw lessons examined later in the book about the scientific revolution. Chapter 1 then outlines the book. It will scrutinize three *celebratory* images of science, which view it as a "wonderful thing, perhaps the best activity in which people have ever engaged, the highest expression of humanity" (9) and assume it to be value free. Those images are replaced with one that is value laden, that considers science's shortcomings and social influences, but that maintains confidence in science. Accordingly, Chapter 2 examines how the problems with the celebratory images emerge in the attempts of analytical philosophy of science to offer general criteria for science demarcation; articulation of general theories of confirmation; and analysis of theories, theoretical language, and explanation. The analytic project did not succeed, yet it left tools that are useful for focused work on more particular topics related to various sciences and their piecemeal improvement. It also wrongly assumed that science is a value-free zone.

Chapter 3 considers philosophical work from the 1990s that gave up on articulating a general account of science. That work considered instead the diversity of the sciences and questioned the ideal of a unified science committed to reductionism in favor of analyzing the practices of various sciences along the lines of Cartwright's vision of a "dappled world." BK also examine the impact of scientific research on reexamining traditional philosophical questions about the empirical inaccessibility of causal relations, the elimination of supernatural entities due to the naturalistic attitude and science's compatibility with religious commitments (an important topic, yet typically discarded in philosophy of science), the place of values and goals within a naturalistic worldview, and the use of the methods of science to improve science.

Chapter 4 examines the historical context of science and the social and political relations that are enmeshed in current science. It explains, first, the Kuhnian view on science and juxtaposes it with the *Unkuhn* view that asserts that recent history of science shows rationality and progress and then takes on the bogey of relativism that sprung from Kuhn's work. BK then examine the realist basis of scientific success and defend a version of the "miracle" argument, given the recognition that in the system of scientific beliefs truth is mixed with error, and propose a pragmatic approach to the progress of science as gradual approximation of truth in a "dappled world" (Barker and Kitcher 2014, 61).

Chapter 5 expresses views that are critical of science. It develops three types of criticism of science, usually lumped together: the prevalent image of science, the flaws in the practice of science, and the institution of science that threatens significant goals and values. The feminist critique is directed at science as traditionally done by fairly well-to-do White men and that has contributed to biases in the natural and

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social sciences. The participation of women in science helped identify and correct those biases at various stages of research. The cultural critique of science objects to the usual practice of focusing on the European tradition as the source of science—or it ignores the various scientific and technological contributions of other cultures, including those by Indigenous people—and criticizes the services scientists offered to colonial powers and continue to offer to corporations that behave colonially everywhere. This critique turns into the ecological critique that warns against oversimplifying research problems and overreliance on the analytic method that ignores the importance of a holistic perspective. Antiscience attitudes due to various factors are also considered. Science is a social endeavor and it is contingent on social history within which decisions about which human goals are worth pursuing are taken, leading to different research projects. This also underscores the importance of diversity in science.

Chapter 6 examines first the traditional aims of science and shows that what is explained, predicted, and controlled, or what truths are investigated is not neutral, but is determined by people doing science, or those financing it, and how their value preferences determine the aims of science. All this raises questions about who should make decisions regarding the direction of research. BK finds shortcomings in the proposals based on various forms of autonomy of science and offers instead the ideal of well-ordered science, complemented with forms of local deliberation that bring together scientists and local people to decide what questions ought to be answered and by what means. The chapter ends with an analysis of what the commitment to science involves for democratic decisions about which beliefs to endorse as a basis for public policy, especially given that some of them are controversial. Neither a free debate open to all, including the uninformed, nor the option of letting an elite group of experts decide are acceptable. The solution is to make science more inclusive of diverse viewpoints while maintaining its distinctive authority, free from misconceptions of the value-free ideal, and to increase science communication.

2.4 *Staley's* Introduction

This book inspects the many difficulties of taking evidence to bear upon theories. It has two parts—"Background and Basic Concepts" and "Ongoing Investigations"—comprising twelve chapters of unequal length. The Preface articulates "promissory notes" about the importance of philosophy of science to three types of readers: future or current scientists, those interested in philosophy generally, and the general public.

Making inferences about doughnuts illustrates and motivates, in Chapter 1, the problem of induction and the continuity between ordinary ways of knowing and science, with Newton's experiments on light refraction being the science example KS uses to examine the problem. In Chapter 2, Popper's view helps interpret Newton's experiments with prisms as a falsificationist project, eliminating induction, and then introduces the demarcation criterion and the piles-driven-into-the-swamp-like basis of science. Chapter 3 considers Duhem's thesis on underdetermination and its revision by Quine as a challenge to both inductivism and falsificationism and sketches some experimental strategies as part of an epistemology of experiment that scientists use to solve the problems of underdetermination.

Chapter 4 analyzes the efforts of the logical empiricists to articulate a criterion of meaning based on verification and continues with a short section on the syntactic and semantic views on theories. It ends with an appendix that introduces the basics of semantics that lead to a definition of a structure as model of a theory.

The next three chapters review the challenges to logical empiricism by Kuhn, Lakatos, and Feyerabend. In just fifteen pages, Chapter 5 describes the context of philosophical ideas in which Kuhn's *Structure* was created, explains the main notions used to describe the transition between paradigms and the differences between the resulting sciences, and presents problems with Kuhn's view. The Old Quantum Theory and the New Quantum Theory illustrate the transition, while morphologically based phylogenetics and molecular phylogenetics are used to show that applying Kuhnian ideas to a specific scientific field is not straightforward. Chapters 6 and 7 are dedicated to the different perspectives of Lakatos and Feyerabend on the rationality of science. A tale of the discovery of Neptune and the failure to discover Vulcan illustrate the methodology of research programs. KS explains the twofold argument for epistemological anarchism: the argument from progress and Feyerabend's discussion of Galileo's reasoning for Copernicanism, followed by the argument from happiness rooted in the Millian defense of liberty.

The second part of the book leads with two generous chapters—Chapters 8 and 9 (sixty-one pages in total)—on scientific reasoning with probability for hypothesis confirmation and testing—the Bayesian and frequentist perspectives respectively. Both chapters begin with introductions to the conceptual underpinnings of each approach to probability, the dominant approaches to the central notions (the logical and pragmatic approaches to Bayesianism, and Fisherian significance testing and Neyman-Pearson testing), challenges from philosophical dissenters, and examples for illustration—an artificial, yet historically accurate example of determining fossil origins with Bayesian reasoning, the discovery of the Higgs boson, and a study on the carcinogenicity of formaldehyde.

Chapter 10 inspects the realist and antirealist views on the success of science. Dirac's theory of holes motivates the introduction to realism. Objections to realism formulated by Laudan based on the history of science and from van Fraassen's empiricism follow the introduction. The chapter then explains several subsequent attempts to reinforce realism, including the experimental and structural versions, all illustrated with cases from physics, plus notes on observation and underdetermination.

Chapter 11 on explanation begins with the usual suspect—the covering law model—while the Hodgkin and Huxley model of action potential illustrates it and shows that the satisfaction of its conditions is not sufficient to explain some phenomena. Deficiencies of the covering law model motivate the causal and mechanistic conceptions of explanation, represented by Woodward's manipulationist account and the mechanistic view by Machamer, Darden, and Craver. Achinstein's focus on the explaining act and Kitcher's emphasis of unifications represent the pragmatic and the unificationist perspectives, respectively. This explanatory diversity shows that there is no single account of what constitutes an acceptable explanation, each of them highlighting aspects of scientific explanation.

The last chapter examines the roles of values in science. Against the backdrop of Lacey's version of a value-free science, KS eloquently reviews some key recent contributions to the research on values in science that converge to show that the value-free ideal is neither achievable nor desirable. Science is not autonomous because the nonepistemic value commitments of various stakeholders constrain it. The indirect role of nonepistemic values in making inferences from data and in dealing with inductive risk shows that science is not impartial (KS reuses here the formaldehyde example from Chapter 9, making an educationally important connection between two topics that are usually separated: testing and values), and feminist standpoint epistemology demonstrates that science is not neutral. Nevertheless, following the arguments of Longino and others, Staley shows that the substantive roles that values play in scientific reasoning can be reconciled with its objectivity.

3. Critical engagement

3.1. Learning goals and objectives

The three textbooks are based on overarching learning goals. Although not explicit, the goals could be inferred abductively from the statements on the importance of philosophy of science and given how the various contents of the books are justified (PCW, pp. 2–3; BK, pp. 8–10; KS, pp. xi–xiv). Despite their differences, all three books have epistemic goals of understanding various aspects of scientific research and reasoning, and normative goals of ensuring science is a trustworthy route to knowledge and is useful to society.

A novelty introduced by *Recipes* is that each chapter section begins with three to five learning objectives that the particular section has to achieve, and between six and twelve exercises whose completion should help students accomplish the objectives along three dimensions: (1) to know the content from the chapter; (2) to solve problems related to that content; and (3) to form an attitude toward science given that content. BK and KS do not articulate their objectives.

3.2. Why philosophy of science?

A philosophy of science textbook should explain to students why philosophy of science is worth studying because many students might assume a Feynman-style rejection of philosophy of science. All three books could strengthen the case for philosophy of science. They could show that philosophical questions and fundamental assumptions involved in scientific research could be answered differently, which then impacts how one *understands* and *does* science. Additionally, they could use prophilosophy claims by scientists, especially the prominent ones, who might appear to students more persuasive than philosophers. For recent examples, see Rovelli (2018) and Gholipour 2019).

3.4. Diversity

Unlike previous introductions to philosophy of science, the three books consider diversity. PCW emphasize in two places the benefits of diversity for science (p. 38 and p. 299, which is more complete). References to non-Western cases of science and protoscience vary from several in PCW, to a few in BK, to none in KS. Students would also benefit greatly from learning how antidemocratic regimes, which refuse to disappear, such as those from USSR/Russian Federation and the People's Republic of China, foster some freedom of research, while suppressing many other freedoms.

The three books do not extend their appreciation for diversity in the sciences to philosophy of science, citing only Anglophone philosophers, except for some translations from Duhem, Latour, and Stegmüller.

3.5. Other aspects

Recipes uses various graphical means to communicate ideas, emphasize key notions, illustrate experiments, and show the faces of some scientists. The book has a companion website containing sample syllabi, slides with some of the visual means used in the book, exercises and descriptions of two extended projects, and suggestions for further reading not included in each chapter. BK and KS do not offer a companion website, slides, or exercises. Their use of visuals is limited to a few figures apiece and italics for identifying key terms. BK employs textboxes for descriptions of science examples and for some philosophical ideas, but its use of the smallest font and format of the three makes reading harder. BK, but not KS, suggest further readings.

Because the books appear designed to be used within a standard term and their publishers impose limitations, they do not cover many topics. One recommendation is that they cover more topics to give teachers more flexibility in assigning mandatory and recommended readings, to offer a more complete overview of the field, and to give additional learning opportunities to exceptionally curious students. Publishers should support such an expansion.

4. Toward a future textbook

A very small number of students taking philosophy of science continue with this field into graduate studies and beyond. The rest pursue various majors and take the course arguably because of general education requirements, yet some have a genuine interest. A typical class contains students of different majors and with varying exposure to science. Given the nature of this audience, it is appropriate to ask what the suitable learning goals and the best methods for achieving them are. Some textbooks, including those by BK and KS, include a historical component that invariably contains assessments about the failures of various philosophical views and how they were further explored, yet without a successful solution. This strategy is important for the education of future philosophers of science, but students who do not wish such a career might wonder why they should learn about the many failures of philosophers and their contributions, especially because in their science courses they do not learn the many failed scientific endeavors.[1] BK, and others, view Hempel's textbook as a classic. Yet Hempel did not employ history of philosophy of science as an instrument to introduce notions, questions, and debates from philosophy of science but instead used a synchronic approach, focusing on issues and giving clear answers. PCW take this approach, but their book often contains less philosophy and more science, admirably presented. Other synchronic introductions seem better suited for students dedicated to graduate work in philosophy. Given this situation, it seems there is still a

[1] I agree with Kent Staley's observation from his feedback on this review that "science education might benefit from spending more time on 'failed scientific endeavors.'"

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need for a textbook that will contain accessible presentations of scientific facts to forge a common ground for students of various majors, as PCW do, and introduce them to details of philosophical views and some of the debates, as BK and KS do, so as to help them gain an understanding of science that they do not get in their science courses, usually limited to a brief exposition of the scientific method, and to help them become better scientists.

Aspirants to the Philosophy of Science Association offices often promise closer cooperation with the sciences. Philosophy of science textbooks are a central avenue for reaching science majors and future working scientists, but how to make philosophy of science relevant to them has received less attention than deserved. PSA could start discussing the learning goals and the appropriate ways of implementing them.

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