trade-off, for instance, by welcoming Wylie's (2019) suggestion as to how preparators can record their work (in specimen records but not in publications) or by helping to describe the range of ways in which a lack of workflow metadata about fossil preparation techniques constrains or limits the evidential value of fossil data.

Furthermore, the emphasis Wylie places on the preparators' autonomy—perhaps over and above the possible epistemic gains of imposing metadata reporting requirements on preparators—calls attention to one of the broader themes of *Preparing Dinosaurs* overall, namely, that science is not only conducted by and for scientists but incorporates the labor and expertise of a wide range of workers with different backgrounds, incentives, skills, and prestige. Wylie's account of knowledge preparation thus serves as a needed reminder to practice-oriented philosophers of science that oftentimes the scientific practices that do *not* make it into scientific publications, or cannot even be learned about by talking to trained scientists, can have serious implications for the structure and scope of scientific research.

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Review of Slobodan Perović's *From Data to Quanta – Niels Bohr's Vision of Physics*

Slobodan Perović, *From Data to Quanta – Niels Bohr's Vision of Physics*. Chicago, IL: The University of Chicago Press (2021), 280 pp., $45 (cloth).

Of late, there has emerged a promising strand in the historical and philosophical literature on Bohr that focuses on the central importance assigned in his view to the details of the experimental context under which observations of the systems

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described by quantum theory are made. Perović's book, which I summarize in the first part of this review, belongs to this tradition. The book is not without its shortcomings, which I summarize in the second part of this review, but overall it is a plausible, accessible, and illuminating presentation of Bohr's views that should be of interest to both historians and philosophers of science.

Perović presents Bohr's contributions to physics, and his vision of physics as a whole, as having a decidedly methodological character. According to Perović, Bohr's particular conception of methodology arises out of an experimentalist strand of thought in physics that can be traced to Sir Francis Bacon (8, 13). It is, according to Perović, unlike the metaphysically motivated approach, traceable to Ludwig Boltzmann, that motivated Erwin Schrödinger's development of wave mechanics—an approach that requires a physical theory to yield explanations of phenomena in the form of clear, intuitive pictures, and to be committed to a principle of continuity (119–22). Bohr's approach is also, according to Perović, unlike the more abstract approach Werner Heisenberg took to the development of matrix mechanics, which privileges spatiotemporal localizability (115–19).

For Bohr, according to Perović, the fact that physics is an experimental science is largely responsible for its success. This does not mean, however, merely that a physical theory's predictions must be testable, but also that empirical data must be made use of in the very construction of the mathematical expressions that a theory employs to describe phenomena (30).[1] For Bohr, on Perović's reconstruction of his approach, we are to understand by this that physical inquiry proceeds in multiple inductive stages, associated with different layers of hypotheses of varying levels of generality; from (in the first stage) concrete hypotheses relating to specific experimental setups to (in the second stage) the more abstract intermediate and "master-level" hypotheses that unify and systematize our understanding of a given experimental domain (2). Note that Perović's conception of an "hypothesis" is quite broad:

> I use the notion of the hypothesis, or of postulations broadly understood, as a general working term to cover the entire inductive process, from these basic accounts of experimental particulars observed and recorded in laboratories (lower hypotheses) to theoretical models of phenomena, the notion of theoretical principles or axioms, and finally the notion of theory as a comprehensive and substantially mathematized structure grasping relevant phenomena. (44)

On Perović's reconstruction of Bohr's approach, the first stage of the inductive process, in which experimental particulars are observed and recorded, is characterized by the use of everyday language (that a spot was registered on this rather than that part of a screen, for instance), made further precise using the mathematical tools of classical physics (34). This results in an experimental account whereby we describe how we have set up a particular experiment ("what we have done"), and what information it yields ("what we have learned") about an object that

[1] Compare Smeenk and Ellis's (2017, section 2) discussion of what they call "a more demanding conception of empirical success."

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we assume is able to interact with our experimental apparatus in a particular way in accordance with some lower-level hypothesis relating to the setup (44). Such an account is itself a kind of hypothesis; and it is selective in the sense that such accounts typically restrict their attention only to some particular features of the experimental data and not others (44–5).

In the second stage, our aim is to unify the various experimental accounts that have been produced in the first stage. Unlike the first, neither everyday language nor the classical-mechanical constructions that refine it need directly constrain the second stage (39–41, 62). But they nevertheless indirectly constrain it insofar as the ultimate aim of the second stage is to obtain a comprehensive grasp—a so-called "master hypothesis"—relating the overall experimental domain of an area of inquiry, and thereby explain how the various lower-level hypotheses quantitatively relate to one another (50–51). At least this is true until new experiments are performed (60). For despite the fact that an accepted master hypothesis will be implicit in any account of a given set of data, the first stage of the inductive process can in principle continue to operate effectively independently of the second stage (15) if the novel theoretical relations that are formulated in the second stage do not directly manifest themselves via controllable parameters in the lower-level experimental accounts. Further, given this, it generally becomes a bad methodological move to formulate a candidate master hypothesis by positing entities motivated only by one set of lower-level hypotheses, because in doing so we ignore the theoretical questions prompted by positing the entities associated with other sets of lower-level hypotheses suggesting further experiments that one might perform (67, 72, 106, 139, 144).

Although Perović's book is an important contribution to the literature on Bohr, it is not without its shortcomings. The first of these concerns the book's overall framing. Changing the prevailing attitude towards Bohr among philosophers of science is one of the aims of the book. In his introduction, Perović relates how this attitude has for the most part been negative (3–5). As for Perović, although he does not wholeheartedly endorse every aspect of Bohr's vision of physics, he writes that "[t]he strengths and limitations of [Bohr's] approach made him a thoroughly distinctive kind of physicist who ought to be investigated in a cross-disciplinary manner" (1). And indeed, on the picture that Perović then proceeds to give us of Bohr, Bohr's strengths, at least to this reviewer, far outweigh his weaknesses. But although Perović's goal is an admirable one, and though he is correct that Bohr's view has been much maligned over the years, Perović exaggerates the extent to which it has been rejected by philosophers of physics. This has been especially true over the last couple of decades. Consider, for instance, Jeffrey Bub, whose 1974 monograph is cited by Perović as an example of the low esteem in which Bohr has been regarded by the philosophical community (3). Perović does not mention, however, that Bub (initially with Itamar Pitowsky), in more recent years, has come to self-consciously defend an essentially (neo-)Bohrian interpretation of quantum mechanics, something Bub has been quite explicit about in his recent publications on the subject.[2] Other philosophers of quantum mechanics who have recently published monographs explicitly defending (neo-)Bohrian interpretations include William Demopoulos, Klaas

[2] See, for instance, Bub (2017). Bub now uses the label "(neo-)Bohrian" when describing his view informally (personal communication).

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Landsman, as well as myself (with Michael Janas and Michel Janssen). Outside of philosophy departments, Bohrian, or at least Bohrian-inspired, approaches to the foundations of quantum mechanics remain popular. The theoretical physicists Časlav Brukner and Anton Zeilinger, for instance, have for many years self-consciously defended a (neo-)Bohrian interpretation of quantum mechanics. And although certain interpretations such as the relational interpretation and QBism, for instance, diverge from Bohr, they are likewise explicit about the significant ways in which their views are indebted to his (Fuchs 2017, section 1; Rovelli 2020, 139). There has lately even been an upsurge of interest in Bohr in the general philosophy of science community (see, e.g., Evans 2020). Indeed, Perović's book is a very welcome addition to the growing literature related to so-called "orthodox" interpretations of quantum mechanics. But it is far from being a lone voice crying in the wilderness, and it is regrettable that Perović has (likely unintentionally) framed the book in such a misleading way.

My second criticism is more substantial. What is especially valuable about this book is, as I have already mentioned, the emphasis it correctly places on the experimental context as central to Bohr's vision of physics; the emphasis it places on the methodology central to that vision; and finally Perović's detailed historical accounts (especially in Part 2) of the actual experiments that informed Bohr as he developed his atomic model. But this reviewer is less convinced of the value of the particular details of Perović's Baconian (13, 36, 69, 139–40) reconstruction of Bohr's approach to physics. My worry is not so much that this analysis—in terms of different layers of physical inquiry characterized by lower-, intermediate-, and master-level hypotheses—is wrong but that it is too vague. Consider, for instance, the way that Perović uses the term hypothesis. On the common understanding of what a hypothesis is, hypotheses describe matters of fact; some particular arrangement of matter, for instance, or that some regularity holds in a given domain. Perović's clearest statement of what the word hypothesis means is in the passage already quoted above from page 44. This statement seems consistent with the common understanding just described. Yet if we consider Perović's characterization of the correspondence and complementarity principles—the key principles informing Bohr's contributions to the old quantum theory and to quantum mechanics, respectively—we find that they have a decidedly methodological character. The correspondence principle, an intermediate hypothesis (88), is a "central heuristic hypothesis, not a metaphysically or otherwise driven pursuit of models" (90), and similarly for the complementarity principle (172). It seems, then, that methodological principles are to be included in the notion of an hypothesis on Perović's reconstruction. My only objection to this is that it seems clear, to me at any rate, that methodological principles have their own distinctive role to play in the progress of science. And that by conflating them, as Perović does, with existential and nomological claims, it becomes far more difficult to give an account of how they all work together to yield scientific knowledge.

It is ironic that Perović's reconstruction self-consciously ignores those approaches to Bohr's thought that focus on, for instance, its neo-Kantian or pragmatist aspects (5–7). The motivation for this seems to be that an analysis of scientific methodology should be done independently of philosophical considerations (7). I do not have the space to debate the broader point. I will only point out that it is questions like these, concerning the status of various kinds of scientific statements and the ways in which they work together, that occupy the neo-Kantian and pragmatist approaches to scientific knowledge. Perović is, of course, correct that it would be a mistake to "focus on the search for an exact metaphysical or epistemological account to which [one] think[s] Bohr may have subscribed and which, in turn, may have shaped his major contributions to physics" (5). But it is also a mistake to characterize these approaches to Bohr's thought in this way; for the goal, at least in the better examples of this literature, is not to subsume Bohr's view under some "ism," but to emphasize that the questions that Bohr was concerned with, concerning the methodology of physics and *its* epistemological underpinnings, are the same kinds of questions that arise naturally within these thinkers' philosophical frameworks as well. Just as it was for them, "[w]hat was at stake for Bohr was exactly how, not whether, physical reality could be ascribed to individual states" (118). Bohr is neither Immanuel Kant, nor C. I. Lewis, nor Grete Hermann, nor Harald Høffding, his onetime teacher and mentor. Nor is Bohr even Sir Francis Bacon. But the point of at least the better examples of the literature comparing him to these thinkers is that his thought is best understood if one considers it as being (in some cases quite literally) engaged in conversation with theirs (and somewhat less engaged with the concerns of present-day analytic metaphysics, for instance), and that the questions all of them grappled with, of scientific methodology and its epistemological underpinnings, are ones that should be central to any serious philosophy of science.

Although it has its shortcomings, Perović's book is a welcome and important contribution both to the historical scholarship on Bohr and to the philosophical study of scientific method. Anyone with a serious interest in either topic will profit, as I have, from reading this book.

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