Ideal or Real: What is the "Nature of Science?"

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Michael Matthews has devoted his professional life to teaching about the nature of science through studies in the history and philosophy of science. He considers knowledge of the nature of science to be essential for science literacy and the most important legacy of science education. Throughout his career, Matthews has consistently argued that slowing down science lessons to consider the meaning and usage of scientific terms through case studies in the history and philosophy of science develops and deepens student awareness of important epistemological and metaphysical issues. Struggling with questions about what things can be known and how we can know them, and with questions about what things actually exist in the world and possible relations between them, leads students, according to Matthews, to pay close attention to the reasons scientists give to justify scientific claims. Fostering enduring student concern for reasons that justify scientific belief encourages students to reach sensible and informed judgments not only about scientific claims, but also claims made in other fields of inquiry.[1]

In his essay, Matthews continues his exploration of the nature of science through a study of the structured interrelations of data, phenomena, and theory in scientific epistemology. In this response, I briefly summarize the main points the article raises. Then, I criticize Matthews's presentation and treatment of the relations between of data, phenomena, and scientific theory and question his claim that disentangling these terms in the way he suggests leads to a deeper understanding of the nature of science. I argue that the model Matthews offers of the structured interrelations between data, phenomena, and scientific theory does not adequately account for the reasons scientists give for justifying inferences to the existence of unobservable phenomena and presents a misleading view of the nature of science.

Scientific theories are widely believed to predict and explain things that we observe or perceive. Matthews argues, however, that scientific theories typically do not predict and explain things that we observe; the things that scientific theories account for are, for the most part, unobservable. His argument relies on a distinction between data and phenomena that emerges from various science education documents and Newton's statements about phenomena in the *Principia*. Data are observations that are represented in a language. They are raw, discursive representations of real objects, processes, events, or states that do not "mirror" or "copy" or otherwise "correspond" to the real. Data, as evidenced by the representations of the pendulum offered by Leonardo, Galileo, and Huygens, vary with our purposes and, according to Matthews, are therefore clearly theory dependent. Phenomena, on the other hand, are detected through data but are usually not observable. They are stable idealizations that emerge from the triangulation of idiosyncratic data; phenomena are underdetermined by data. Scientific theories predict and explain properties of phenomena, and phenomena serve as evidence for those same theories. Data serve as evidence for the existence of phenomena, but data cannot be predicted or explained by scientific theories. In this view, theories are tested against idealized phenomena, not predictions about observed data.

Galileo's mathematical proofs of the properties of pendulums serve, for Matthews, as a case study for exploration of the interrelations between data, phenomena and scientific theory. Galileo's proofs were greeted with widespread skepticism for the simple reason that they did not correspond with empirical observations — real pendula did not behave according to Galileo's predictions. When the law of parabolic motion was tested against ideal pendula, it was true; but, when the law was tested against the pendula experienced in everyday life, it was false. According to Matthews, this situation was more than slightly unsettling to Galileo's contemporaries. Since Aristotle, the objective of science was to tell people about the world in which they lived and the methodology of science relied on evidence from human sensory perceptions to learn facts about the world. Galileo's theories challenged these basic assumptions about the nature of science.

Matthews represents the interrelations between data, phenomena, and theory that emerge from his case study of Galileo's proofs in a table that differentiates five levels of scientific claims. Level five claims refer to everyday phenomena; level four claims refer to observations of real world events; level three claims refer to representations of observations (data); level two claims refer to scientific phenomena; and, level one claims refer to fundamental scientific laws or theory. He draws these conclusions: level one claims are tested against level two scientific phenomena; level one claims do not predict or explain level three data or level five everyday events; and, level two phenomena do not correspond to level three data.

Matthew's concludes his essay by noting that modem scientists, philosophers of science, and the general public continue to fail to distinguish between data and phenomena thereby maintaining the mistaken idea that scientific theories explain everyday phenomena and the data we observe through our senses. If teachers slow down science lessons and explore the meaning of these terms, then students not only learn more about the nature of science, they team to pay closer attention to empirical and conceptual issues that generalize into other classrooms and subject matters.

I submit several criticisms of Matthews's presentation and treatment of the structured interrelations of data, phenomena and scientific theory and question his claim that disentangling these terms in the way he suggests leads to a deeper understanding of the nature of science. First, the triplet "data, phenomena, theory" or DPT does not straightforwardly appear from the excerpts in the science education documents and the *Principia* that Matthews quotes. The word "phenomena" is clearly used in two different senses in both sets of excerpts, yet only one sense — the "scientific" sense — is represented in the DPT triplet. The second sense — the "everyday" sense — appears late in the paper when Matthews differentiates between five levels of scientific claims. The failure to note immediately the role everyday phenomena plays in the practice of science and to distinguish it more clearly in the first part of the paper from scientific phenomena not only contributes to reader confusion; it, more importantly, obscures the sometimes crucial A role everyday phenomena play in initiating scientific inquiry.

Second, Matthews's treatment of data is inadequate in two respects. He claims that because our representations of real events (data) can vary according to our purposes and interests, they are "clearly" theory dependent. The fact that data are "theory-laden," however, appears to be of peripheral relevance when assessing the reliability of data and the grounds for justifying an inference to scientific phenomena. The central analytic issues involve procedures for handling observational and measurement error and for handling problems associated with data analysis and statistical inference, not theory-ladenness. Bogen and Woodward point out "We are justified in believing claims about phenomena...[only when] data are available which constitute reliable evidence for such claims," and establishing reliability involves tolerating and managing data that are associated with high levels of complexity and idiosyncrasy.[2] Matthews's lack of attention to the analytically important roles of data analysis and statistical inference has two consequences: it results in an inadequate analysis of the role of data in establishing the stability of phenomena; and it results in an inadequate account of the reasons scientists give for justifying inferences to the existence of unobservable phenomena. Scientists cannot justifiably infer the existence of phenomena without procedures for the systematic handling of experimental error, and for data analysis and statistical inference.

Finally, and most important, Matthews fails to note that the table he constructs to represent the structured interrelations between everyday phenomena, observation, data, scientific phenomena, and scientific theory is itself an idealized "phenomenon" or view of scientific practice. The model clarifies the elemental referents that constitute scientific claims, but it incorrectly implies that the referents are always clearly defined and that scientists move smoothly and straightforwardly from level five objects or events to level one explanations. Matthews's idealized model of the structured interrelations between scientific referents does not exist in the real world any more than Galileo's ideal pendulum exists in the real world. Real world science includes complex, ambiguous, and often contradictory claims and practices that do not correspond to his model. His model, consequently, distorts the nature of science. Just as Galileo's laws of pendulum motion present a misleading view of the nature of the real world, Matthews's model of the structured interrelations of data, phenomena, and theory presents a misleading view of the nature of science.

Matthews's career project to explore the nature of science through case studies in the history and philosophy of science for the purpose of encouraging students to pay attention to the reasons scientists and others give to justify belief is laudable. I hope the criticisms I have offered of this particular case study are helpful to him as he pursues his wider project.

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1. For a representative sampling of Matthews's work, see Michael R. Matthews, *Science Teaching: The Role of History and Philosophy of Science* (New York: Routledge, 1994); Michael R. Matthews, "In Defense of Modest Goals for Teaching About the Nature of Science," *Journal of Research in Science Teaching* 35, no. 2 (1998), 161-74; Michael R. Matthews, "Learning About Scientific Methodology and the 'Big Picture' of Science: The Contribution of Pendulum Motion Studies," in *Philosophy of Education 2001*, ed. Suzanne Rice (Urbana, Ill.: Philosophy of Education Society, 2002), 204-13.

2. James Bogen and James Woodward, "Saving the Phenomena," *The Philosophical Review* 97, no. 3 (1988): 351.