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The Nature of Science: A Perspective from the Philosophy of Science

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Unfortunately, as we all know, the philosophy of science is a very difficult subject of byzantine complexity and unplumbed depth. (Ziman, 1994, p. 27)

In a recent article in this journal, Brian Alters (1997) argued that, given the many ways in which the nature of science (NOS) is described and poor student responses to NOS instruments such as Nature of Scientific Knowledge Scale (NSKS), Nature of Science Scale (NOSS), Test on Understanding Science (TOUS), and others, it is time for science educators to reconsider the standard lists of tenets for the NOS. Alters suggested that philosophers of science are authorities on the NOS and that consequently, it would be wise to investigate their views of current NOS tenets. To that end, he conducted a survey of members of the Philosophy of Science Association, and, via various statistical techniques, made claims about the nature and extent of variation among philosophers of science regarding basic beliefs about the NOS.

As three philosophers of science, we laud Alters' attempt to understand philosophers of science' view on the NOS. We believe, however, that his techniques for investigating this question are inappropriate and that consequently, several of his conclusions are unwarranted. In this comment, we will substantiate these criticisms. In addition, we will address some of the important questions that motivate Alters' research and attempt to unravel the "byzantine complexity" of philosophical views about the NOS. We begin with our concerns regarding Alters' research. We then provide a taxonomy of philosophic issues; and finally, we suggest some roles for philosophy of science in science teaching and the education of science teachers.

Concerns with Alters' Research

Essentialism and Family Resemblance

The concept of the NOS seems to presuppose: (a) that there is a nature of science to be discovered and taught to students; (b) that a list of tenets can describe the nature of science; and (c) that for a discipline to count as a science, each of the tenets must be true of that discipline. In philosophical parlance, this is an essentialist view of science, for there is believed to be one essence of nature or set of criteria that describes all and only the activities and inquiries that count as science. Most philosophers of science and science educators who have considered this question have concluded that this essentialist view cannot be maintained. Instead, they treat “science” as what Ludwig Wittgenstein called a *family resemblance* concept. “Science” is not a sharply circumscribed concept, but denotes rather a series of paradigmatic examples and—importantly—a rider such as “and other closely similar activities.” Any science uses methods and has values belonging to this series. However, no science need exhibit all of them.

Pedagogically, essentialism about the NOS may be appropriate. That is, a de cision that must be made based on the developmental level of the students in question. Nonetheless, the presupposition is problematic as it appears in Alters’ study, for it leads to many philosophic controversies. For the purposes of our discussion, we will continue to use the standard science education label of “the nature of science,” recognizing that it stands for a cluster of values, methods, and activities. On this basis, we will now proceed to our assessment of Alters’ study.

Contrary to Alters, we think that the lists of tenets he cites show important areas of consensus among science educators. We will first consider four areas of consensus among science educators and then specify two areas of dissensus that are related closely to debates in philosophy of science. Our generalizations below refer to writings on the NOS by Kimball (1967) and also those cited by Alters: Giddings, Lederman, Cleminson, and Ryan and Aikenhead. Our intention is not to provide an exhaustive reading of the actual views on the NOS held by the authors Alters cites. We simply wish to show that many of the tenet lists Alters uses overlap considerably in content.

Areas of Consensus about the NOS

The Main Purpose of Science Is to Acquire Knowledge of the Physical World. Kimball’s (1967) first tenet is: “The fundamental driving force in science is curiosity concerning the physical universe. It has no connection with outcomes, applications, or uses aside from the generation of new knowledge” (p. 111). Many adopt this tenet, and Alters chose part of it to be the first survey question.

There Is an Underlying Order in the World Which Science Seeks to Describe in a Maximally Simple and Comprehensive Manner. This belief encompasses several popular tenets: first, that the world is orderly; and second, that science seeks to construct theories which describe this order. Other tenets stress that theories should be comprehensive and use mathematical tools for precision and simplicity.

Science is Dynamic, Changing, and Tentative. Science educators appear also to agree that science does not consist in a static collection of facts. Indeed, it is an ongoing process, sometimes punctuated by striking changes in beliefs and methods. As a result, we cannot take current scientific knowledge to be complete and final.

There Is No One, Single Scientific Method. The view that there is no one scientific method appears to be widely held and is consistent with the nonessentialist view of science described above. The view is expressed in the following tenet offered by Kimball (1967): “There is no one ‘scientific method’ as often described in school science textbooks. . . .” (p. 111). Kimball and others rejected an overly simplified hypothetico-deductive method that is frequently given as the only example of scientific methodology in the initial chapters of textbooks and assumed in some science education research (e.g., Lawson, 1993; Lawson et al., 1993).

Areas of Dissensus about the NOS

The Generation of Scientific Knowledge Depends on Theoretical Commitments and Social and Historical Factors. Few deny that theoretical commitments and social and historical factors play some roles in science. However, there is considerable disagreement about their nature and strength. Beginning with the issue of theoretical commitments, we find representative remarks by Cleminson: “observation alone cannot give rise to scientific knowledge in a simple inductivist manner” (cited in Alters, 1997, p. 41); and “We view the world through theoretical lenses built up from prior knowledge.” These beliefs are closely associated with the work of Thomas Kuhn, who argued that it is impossible to make a firm distinction between observational and theoretical languages in the way that some logical positivists had hoped (Maxwell, 1962; Kuhn, 1970; Feyerabend, 1993). On the views of Cleminson and Ryan and Aikenhead, standards for the acceptance of scientific beliefs are also strongly subject to social and historical influence. In two tenets, Cleminson relatedly emphasized that science is “a personal and immensely human activity” that is subject to human stubbornness: “Abandoning cherished knowledge that has been falsified usually occurs with reluctance” (cited in Alters, 1997, p. 41).

In contrast, Kimball’s (1967) tenets do not acknowledge the influence of theoretical commitments. In Kimball, and also in Giddings (cited in Alters, 1997, p. 40), we find the claim that “Science has a unique attribute of openness, both openness of mind, allowing for willingness to change opinion in the face of evidence, and openness of the realm of investigation, unlimited by such factors as religion, politics, or geography” (Kimball, 1967, pp. 111–112).

The Truth of Scientific Theories Is Determined by Features of the World Which Exist Independently of the Scientist. This area of dissensus concerns criteria for determining the truth or falsity of scientific theories and claims. Gidding’s claim that “There exists an objective, external world, independent of the existence of an observer” is a version of the ontological theory philosophers call realism (cited in Alters, 1997, p. 40). For realists, whether a theory or hypothesis is true is ultimately a matter of the way the world really is. Nature is the tribunal of scientific truth, not scientists. On the other hand, there are several tenets which, although somewhat ambiguous, suggest contrary views. Cleminson claimed that “Scientists study a world of which they are a part, not a world from which they are apart” (cited in Alters, 1997, p. 41). This tenet may mean that nature is partly or wholly determined by the cognitive, theoretical, or social characteristics of scientists. A second tenet, offered by Ryan and Aikenhead, is more clearly antirealist: “Consensus among self-appointed experts is the basis of scientific knowledge” (cited in Alters, 1997, p. 41). This statement, representative of the movement in science studies known as social constructionism, replaces nature as an arbiter of scientific beliefs with scientists.

Although our discussion of some of the central NOS tenets is rough and incomplete, it shows broad patterns of agreement and disagreement among science educators. Of those four areas about which there is agreement, we believe that nearly all philosophers of science (and also scientists themselves) would express agreement with science educators. On the other hand, the areas in which science educators disagree also represent areas of controversy among philosophers of science.

Testing Philosophers of Science on Their NOS Beliefs

Alters' goal in conducting his survey was to seek assistance in resolving inconsistencies between the "myriad tenets in circulation" in the science education literature. As he put it, "we must call to authority, to those who study purported tenets of the natural sciences—philosophers of science—not only to examine the various basic tenets of the NOS held by science education organizations and researchers, but to provide some insight into establishing more accurate criteria for the NOS" (1997, p. 42). The results of Alters' survey have been criticized by Smith et al. (1997), who showed that Alters overstated the level of disagreement among philosophers and their disagreement with the NOS tenets. We concur with Smith et al. The survey responses do not disambiguate those aspects of a tenet with which different philosophers agree or disagree. We do, however, have several additional concerns not considered by Smith et al.

First, some of the tenets appear to address several different philosophical issues or debates. It is likely, therefore, that important philosophical differences of belief are obscured by different philosophers' interpretations of the tenets. For example, consider Survey Question 11: "Consensus among self-appointed experts is the basis of scientific knowledge" (Alters, p. 49). In the contemporary landscape of philosophy of science, this tenet really involves several controversial questions about which philosophers disagree: Social constructionists may agree that experts are the tribunal of scientific truth, but they may disagree about whether they are really self-appointed. Others may agree that social consensus is important in science, yet deny that consensus is rightly called a basis or deny that there is just one basis undergirding science.

Second, serious difficulties attend Alters' "discovery" of 11 philosophical positions about space and time in particular and philosophy of science in general. Alters identified these 11 underlying philosophies using Survey Questions 17 and 18. He asked philosophers to "indicate [their] strength of belief in each of . . . four basic philosophies" as they relate, first, to "the epistemology of theories of the structure of space" and, second, "to the epistemology of scientific theories in general" (Alters, p. 50). The four basic philosophies are apriorism, conventionalism, positivism, and realism. Alters then defined his 11 basic philosophies by identifying clusters of philosophers whose responses to these two questions occupied certain subspaces within the four- dimensional space of possible "strength of belief" assignments. For instance, Position 3 included all philosophers who indicated a strength of belief of 5–23% in conventionalism, 50–100% in realism, and 0% in apriorism and positivism.

There are difficulties with Alters' procedure. First, Alters correctly noted that different philosophers use these terms in different ways, so he offered "clarificatory" definitions of these terms. Still, the resulting definitions are mistaken or confusing. We have room only to assert that these definitions are idiosyncratic and frequently ambiguous. We suspect that this circumstance obscured the responses of individual philosophers to Questions 17 and 18.

Third, the instructions for Questions 17 and 18 present these four philosophies (in some sense) as alternatives to each other. Yet, on our understanding of positivism, a priorism, conventionalism, and realism, these views are not clearly alternatives. The first two are general theories of the sources of knowledge (belonging to epistemology). Conventionalism, however, is a theory of meaning (semantics) and realism is a theory about what really exists in the world (metaphysics). Although positivism and apriorism are often regarded as opposing, alternative epistemological theories, it is not clear how these are individually to be understood as alternatives to both conventionalism and to realism. From our point of view, the questions confuse us in much the same way as one would be confused by instructions to rank (in order of preference) cheesecake, apple pie, mathematics, and tennis. We do not claim that semantics and metaphysics are irrelevant to epistemology, only that philosophers with similar views about semantics or metaphysics may diverge sharply on epistemology.

A fourth difficulty involves Alters' use of the term "strength of belief" in his instructions for Questions 17 and 18. The term "strength of belief" alone suggests that what is intended is what philosophers call subjective (or personal) probability (i.e., a person's estimate of the probability that a given statement is true). However, if philosophers were to interpret the question in this way, most would have believed it necessary to assign 0% to each philosophy, because most would not think that any of the positions expressed were completely true. The fact that Alters instructed that respondents' percentages sum to unity, however, suggests that the probabilities must be interpreted in a different way: namely, as the degree to which philosophers thought each of the positions was correct. Although it is true that philosophers might think that each of these positions is correct to a certain degree, it is hard to see how to assign percentages in this way. One could never, for example, assign a percentage to conventionalism (or any of the other philosophies) by estimating the percentage of the (infinite) class of propositions in the physical sciences involving conventional definitions.

The final set of difficulties that we address involves Alters' use of analysis of variance to infer the significance of the 11 philosophies for respondents' views about NOS tenets. He attributed statistical variance on responses to differing answers on Questions 17 and 18 of his survey. However, statistically significant results would have been obtained from many other partitions of this data set, as well. Alters seemed to be offering a causal explanation of why philosophers answered the survey questions as they did. As has clearly been shown by Lewontin (1974), however, the existence of statistically significant differences revealed by analysis of variance is consistent with a wide variety of different causal structures. Lewontin's criticisms apply even if differences in means are attributable to real differences in individuals in the population, but our discussion shows that the situation is even worse, since the 11 philosophical positions used in

Alters' analysis of variance and multivariate analysis of variance calculations are artifacts of experimental design.

A Taxonomy of Philosophic Issues

Our general conclusion is that Alters' study obscures the substantial areas of consensus among both science educators and philosophers of science and fails to reveal what the contentious philosophic issues are. Our analysis leads us to assert, more broadly, that attempts to chart the philosophical landscape by means of quantitative methods will fail. The philosophical questions involved in the NOS are simply too intricate and interrelated to be reliably encoded by surveys or other quantitative studies.

How, then, can science educators take advantage of philosophy of science to help resolve pressing issues about teaching the nature of science? We suggest that, rather than appealing to philosophers as authorities, science educators become acquainted with philosophical debates about science, and with the arguments and kinds of evidence adduced in favor of different positions. Just as science educators stress that science is more than a collection of facts, we emphasize that a philosophical position about the nature of science is more than a list of tenets. Some science educators have engaged philosophical literature on the NOS. While the efforts of some have paid off well (e.g., Matthews, 1997, 1994), others have had less success, as our epigraph suggests.

Philosophers of science should do their part by helping to make explicit the connections between philosophical literature and the educators' NOS debate. Although it is beyond the scope of this article to provide a full analysis of these connections, we offer the following brief taxonomy of the main issues in philosophy of science today to help focus interdisciplinary discussion about the NOS. Before we begin, however, we emphasize that philosophy of science is a dynamic, changing field, and also that philosophy of science is increasingly specialized. Philosophers of quantum mechanics, for example, may have concerns that overlap little with philosophers of biology, chemistry, or social science. None of the lively debates endemic to particular philosophies of science are presented here. To the extent that philosophy of science remains a unified field of study, however, the following issues are both important and relevant for understanding the NOS. We present them in no particular order.

Unity of Science versus Disunity of Science. This debate bears directly on the NOS tenets because some philosophers of science believe that different sciences have very little in common. Some advocates of the disunity of science believe that there simply is no "nature" of science; some believe that there is nonetheless a family resemblance. There are a variety of reasons available (metaphysical, epistemological, and scientific) for holding these views which we have not discussed, most of which bear on the NOS issues (e.g., Nagel, 1961; Hacking, 1996; Dupré, 1993; Rosenberg, 1994).

Demarcation. The task of demarcating science from other forms of inquiry was an important component of philosophy of science of the 1930s and 1940s (that is, of logical positivism or logical empiricism). In the wake of its decline, most philosophers believe that it is impossible to formulate criteria that demarcate science and nonscience. This question is closely related to that of the unity and disunity of science. Some believe that theories and practices can be identified as more or less scientific, while a few—particularly those inspired by developments in literary theory (and all things French)—would maintain that there is no distinction at all between science and nonscience. The view that there is no genuine distinction tends also to be championed by some sociologists of science, particularly social constructionists. On the other hand, philosophers active in debates about creationism and a constitutional (as opposed to philosophical) separation of science and religion argue that some ways to demarcate science from nonscience, such as Popperian demarcation, remain workable and important (e.g., Ruse, 1996; Holton, 1993).

Realism versus Instrumentalism. Debate about realism was mentioned above and takes different forms in different branches of philosophy of science. Usually, it concerns the metaphysical question of whether theoretically posited entities (such as quarks in physics, or economies in social science, or species in biology) actually exist objectively and behave according to the theories or laws that describe them. A realist in one of these domains believes such entities do exist, often on the grounds that theories about them would otherwise not be successful. Instrumentalists, or antirealists, believe instead either that such entities do not exist or that the success of theories does not reliably prove that they exist. They regard theories and theoretical entities as tools or instruments that nonetheless help us to understand and manipulate the world. Some philosophers are realists about one scientific domain, but antirealists about others. Furthermore, some philosophers classify themselves neither as realists or antirealists, but argue in- stead that the realism debate is sterile, or even meaningless (see, e.g., Boyd, 1983; van Fraassen, 1980; Fine, 1986; Pickering, 1984).

Rationalism versus Historicism. Largely in response to Thomas Kuhn's influential work (1974, 1970), in which the history of science is portrayed as a sequence of sometimes mutually contradictory paradigms or worldviews, the issue known as "theory choice" came to dominate philosophy of science. Viewed one way, the central question is whether scientists rationally and deliberately choose which theories they believe are best (rationalism) or whether, as Kuhn seemed to imply, their allegiances are determined by historical and social forces manifest in their training and in intellectual fashions (historicism). Kuhn even likened changes of scientific belief to religious "conversion experiences" (Kuhn, 1970, pp. 151 and 204) and thereby challenged critics to specify precisely in what scientific rationality consists. Most who took up the challenge (Lakatos, 1978; Laudan, 1984, 1977) agreed with Kuhn that scientific change was sometimes radical and revolutionary, but aimed to show that the process was still either rational or progressive in certain ways. Others attempted to apply Bayes' theorem of rational choice to theory choice in science. This debate, however, has largely fallen from philosophical interest in recent years. Almost all philosophers (but not all historians or sociologists) now eschew radical historicism.

Practice and Experiment versus Theory. This debate involves the question: Is science a body of knowledge or is it something more inclusive, such as a way of life or a body of practical techniques? Several philosophers and historians in the 1980s argued that to fully understand the NOS, one must take into account the way scientists do experiments, the ways they organize and structure their laboratories, and the ways they operate in political, economic, and cultural networks. Most philosophers would agree that these are important for understanding science. One important area of disagreement, however, is whether scientific knowledge is merely contained within scientific practice or scientific culture on the one hand, or whether it is inextricably formed and maintained by it (e.g., Galison, 1987; Pickering, 1984; Latour and Woolgar, 1986).

Feminist Philosophy of Science. Historically, women have been excluded from science. How has this shaped scientific theory or scientific practice? Feminist authors ask: Whose knowledge is this? Whose experiences provide the evidence? Who decides what the scientific goals are? Feminists approach the goals of science as multilayered and context dependent, frequently claiming that there is no unconditioned subject position. Rather, knowledge results from social interactions among members of a community and between them and the purported objects of knowledge. Some feminists claim that male-centered science results in bias or problematic and unquestioned presuppositions. Other questions include: Are there distinct feminist research methods? If so, are they appropriate for the natural sciences? What would a feminist science look like? Most feminists claim that taking these concerns into account will result in better science. Some claim, more strongly, a different science will result (see, e.g., Harding, 1996, 1989; Keller, 1983; Keller & Longino, 1996; Lederman, 1993; Longino, 1990; Rosser, 1992).

Recommendations for Science Education

As philosophers of science, we are not experts on science pedagogy. However, we are quite familiar with problems that arise in teaching our students about the nature of science. Although our judgments are based upon our experiences in teaching to undergraduates, we think they may be relevant to teaching students at other levels. Thus, we would like to conclude with a few remarks about which philosophical issues can be fruitfully discussed with both secondary school students, and with their teachers in science education courses, and which are better avoided.

First, we suggest that educators avoid discussing the failings of logical positivism. From the sources we have seen, it appears that the position science educators call logical positivism is a straw man position held by at most a few philosophers, and only for a short period of time 70 years ago. Instead, educators should discuss the idea of empiricism more generally. This would include discussion of the many and different ways that experience and the use of experiments informs scientific beliefs, and also the important fact that scientists often argue about how to understand and interpret the results of measurements and experiments. The history of science is a rich source of examples and should be used for illustration.

Second, we suggest that philosophical debates about realism should be avoided, and that a naively realist view is most appropriate for science education. A naively realist view accepts the existence of the entities scientist study and avoids nuanced and controversial philosophical debate about realism. These debates are often Byzantine and confusing even to those of us who work in them. Our experience is that many students on first exposure misunderstand antirealism and instrumentalism.

Third, it is valuable to introduce students at an elementary level to some of the ideas developed by Kuhn. In particular, we find that students benefit by considering the idea that different paradigms compete with each other, and that they can easily understand some of the ways in which theoretical commitments and social issues can influence the development of science. On the other hand, students should be made aware that some interpretations of Kuhn's views are extreme and not persuasive (such as the popular claim of radical incommensurability between paradigms). The middle of the road approach we offer here seems to be suggested by some of the NOS tenets given in the American Association for the Advancement of Science reports.

Fourth, we believe that strong social constructivism should be avoided. We believe that Matthews (1994, 1993) correctly diagnosed the problem with the constructivist position advocated by some science educators. These educators begin with valuable psychological, historical, and epistemological insights about the role of the mind and of society in shaping perception and inference. However, they proceed often to infer unwarranted metaphysical views. Some philosophers and educators may disagree with this diagnosis, but we think it indisputable that the relations between these psychological, epistemological, and metaphysical issues are subtle. We believe that discussion of them is likely to create more confusion than insight.

Finally, although we have described significant areas of philosophical disagreement about the nature of science, we do not advocate developing multiple sets of views about the NOS as Alters envisioned (1997, p. 42). Such an approach easily leads to an overly simplistic pluralism in which all philosophical positions are seen as equally viable. Instead, we recommend illustrating the rich complexity of science with its practice and its history. Such study will offer students a better picture of the complex family resemblances between all the activities we call science.

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