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Reconsidering the 'nature of science' as a curriculum component

JOHN L. RUDOLPH

Although the nature of science has long been seen as an important, indeed central, component of science education during this century, efforts to integrate an authentic view of the nature of science into the curriculum have often met with little success. Work in the field of science studies since the 1960s has compounded this difficulty by presenting educators with various competing, often conflicting, views of the essence of scientific inquiry. I discuss previous attempts to come to grips with this fundamental issue of how to deal with the competing views of science and suggest an alternative approach for integrating nature of science issues into the school science curriculum. What is needed is for educators to accept that no single nature of science exists and to develop curricula that help students understand instead the diverse, local practices that are found within and across scientific disciplines.

Since the beginning of the science studies renaissance in the early 1960s, the nature of science has gradually assumed a more prominent place on the academic agenda of the science education community. One consequence of the growing attention to the history and philosophy of science as a means to enhance student understanding has been the establishment of the 'nature of science' as a central component of the secondary school curriculum (Hodson 1988, Lederman 1992, Jenkins 1996, Soloman *et al.* 1996, Matthews 1998). Nearly every key science education policy document in the USA, from the American Association for the Advancement of Science's *Project 2061: Science for All Americans* (1989) to the National Academy of Science's *National Science Education Standards* (National Research Council 1996), has highlighted the importance of this topic in science education. Calling for greater attention to the nature of science in the vague language characteristic of these broad policy documents is a relatively easy task. More problematic, however, is implementing such abstract prescriptions in the classroom.

The very success of the aggregate field of science studies these past few decades, which has done so much to draw critical attention to questions concerning the generation and use of scientific knowledge across society, has itself contributed to the paralysis of practical action with respect to

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science education. Since the 1960s, the relatively uniform view of science articulated by historians and philosophers has shattered into a heterogeneous array of competing perspectives—from diehard realism to radical constructivism, with a variety of views in between (Rouse 1996, Loving 1997). The critical examination of science within disciplines such as sociology, philosophy, history, anthropology and women's studies has, as disciplinary frameworks tend to do, further contributed to the hardening of these distinct views of science (Hess 1997). The simple existence of these various interpretations poses a nearly intractable problem for the science educator seeking to abide by the prescriptions to include some substantive treatment of the nature of science in the school curriculum. The inevitable question is which nature of science does one use?

Jenkins (1996) has provided a comprehensive examination of this curricular dilemma. Scholars generally agree that current working notions of science in the classroom are clearly inadequate; they are for the most part convenient fictions—no more than myths according to some (Bauer 1992). These range from the traditional five-step scientific method to the less algorithmic, yet still oversimplified, inductivist methods of generating new scientific knowledge. Despite the widespread recognition of this undesirable state of affairs, however, as Jenkins (1996: 139) states, 'replacing the conceptualization of the nature of science traditionally associated with school science with an understanding which reflects more accurately contemporary scholarly insights into the scientific enterprise is a far from straightforward task'. In framing the difficulties confronting those wishing to incorporate a more accurate 'nature of science' into the science curriculum, Jenkins's essay provides the jumping-off point for my discussion of one possible solution to this problem.

It seems that much of the difficulty many see in incorporating the nature of science into the school curriculum resides in the particular manner in which the practice of science has been historically described. Such accounts have been concerned primarily with establishing some universal characterization of science into which the work of any given scientist in any discipline, past or present, might easily fit. This work has been motivated largely by the desire of scholars to provide a philosophical, metascientific justification for the privileged place in society that science currently enjoys (Rouse 1996)—a goal that, in many ways, overreaches the more circumscribed goals of science education. As I will argue, building an understanding of the nature of science from the divergent daily practices of science instead, provides not only a more authentic portrayal of those practices that make up 'science', but also allows for a more natural integration of nature of science concerns with the traditional school science curriculum. This curricular approach, however, requires the perhaps difficult step of abandoning any notions of a universal 'nature of science' and embracing the diversity of the particulars.

Before proceeding any further, some clarification is necessary regarding what is meant by the term 'science' as I use it here. If, as I will suggest, educators are unable to avail themselves of any universal characterizations of science, then it would seem impossible to determine what exactly 'science' is and whether any practice is indeed scientific at all. This problem of demarcation between science and non-science has a long history in the philosophical literature. However, as Laudan (1996: 222) observes, it is a question that is ultimately 'both uninteresting and, judging by its checkered past, intractable'. Fortunately, for the science educator, it is a question that need not be addressed at all. Clearly, the educator's fundamental task is to *communicate* established knowledge/practice, not to *adjudicate* which knowledge/practice is or is not to be admitted to the class of things 'scientific'—a task that even the philosophers have found daunting. What is or should be part of the 'science' curriculum is a matter of local negotiation; it is not my intent here to engage in that debate. Suffice it to say that there is a great deal of intellectual activity extant in present-day society that is deemed valuable, represents a socially and intellectually significant aspect of human culture, and toward which a significant amount of the world's resources are directed. Much of this activity can unambiguously be called 'scientific' and such activity (primarily located within the self-regulating, academic disciplines of science) is the target on which science educators should primarily fix their aim.

Universals and the science curriculum

One of the key difficulties educators face in attempting to integrate nature of science concerns into the curriculum stems from the very manner in which the issue has been discursively framed. The phrase 'nature of science' and its treatment by the science education community as a discrete entity have privileged both universal and historically transcendent interpretations of the enterprise called science. Of course, such treatment follows naturally from how science has been traditionally characterized in the history and philosophy of science (Harding 1998). This conceptualization, however, has been reinforced in educational contexts by the desire to simplify the workings of science even further for the purposes of instruction. Thus, although competing views of the nature of science exist (the dilemma that Jenkins outlines) there is the hope within the education community that one view might be settled on—one that is found to be more authentic or one that might be reasonably abstracted from the various interpretations—so that the business of incorporating it into the curriculum might proceed. This approach, in light of the growing understanding of science, seems increasingly unworkable.

The problem of sorting through the competing, sometimes conflicting, views of the nature of science is real enough. The difficulty of integrating the nature of science into the school science curriculum would not, however, melt away with the arrival of some consensus view of what that nature might be. Whatever view is settled upon would retain as *the* nature of science a whole range of universal implications. Those developing curricula would still be faced with the task of instantiating that conception of science within the various disciplines, daily lessons and laboratory activities that make up the school science programme. This fundamental problem would be present using any of the competing views but most have been built upon only a handful of historical or contemporary cases. Thus, the ability of any view so constructed to apply across all scientific disciplines, and even to specific instances within a discipline, is open to serious question. A classic example of this difficulty was found with the syntactic, or axiomatic–deductive view of science that was derived from the well-established theories of Newtonian physics. The attempt to extend this philosophical system to some of the key theories in the biological sciences used to explain the historically contingent, largely indeterminate phenomena of living systems failed miserably (Thompson 1989, Rudolph and Stewart 1998). Further mismatch becomes apparent when one realizes that many of the various accounts of science have been grounded in an attempt to explain large-scale shifts in the practice or theoretical content of science over extended periods of time (Kuhn 1970, Lakatos 1970, Laudan 1977, 1984). The fruitfulness of using such macroevolutionary frameworks of scientific change as a guide to the nature of science in schools in the absence of a similar long-term historical analysis of content knowledge (rarely found in the existing curriculum) seems questionable as well.

The most common tactic employed to circumvent this difficulty, as previously mentioned, has been to abstract from the various views of science some more general, lower-level core set of statements about science around which a consensus among educators can be built (Matthews 1994, Smith *et al.* 1997, McComas *et al.* 1998). This approach would seem to facilitate a relatively unproblematic treatment of the nature of science across a variety of topics throughout the curriculum. The level of meaningful contact between any one topic and this abstracted 'nature of science', however, is likely to be small because of the very generality of its formulation. Statements such as 'scientific knowledge is subject to modification as new information challenges prevailing theories' (American Association for the Advancement of Science 1993: 7) are typical. Although true, they are often only trivially so. They shed little light on the specifics of what scientists do and in many cases are not even unique to science. And in the absence of complete integration into the curriculum, this simplified nature of science is often presented instead as a topic unto itself, thus allowing for its full articulation first and thereby clearing the way for student engagement with the subject matter—the more traditional concern of the science educator. In this way, there is little need to worry about the extent to which the subsequent subject matter may or may not conform to the view of science initially presented. Indeed, in many US key policy documents that is just how the nature of science is presented—as simply another 'topic' to be covered (National Research Council 1996).

Another way out of this predicament offered by Jenkins and others (e.g. Siegel 1993) is to have students themselves engage the competing views of science. The pluralism so rampant in science studies, Jenkins (1996: 146) contends, 'need not be regarded as an insurmountable problem for science education. It can, instead, be seen as an aspect of science which students should be taught and encouraged to explore'. As straightforward as this solution might seem, difficulties remain. The amount of time required to engage fully in such an exploration would radically tip the balance of the curriculum away from the established emphasis on subject-matter content—a change sure to spark objections from those who see technical proficiency as a key goal of science education. Such an approach would entail essentially a shift, to some degree, from teaching science to teaching the history and philosophy of science. Although such a shift would not be undesirable in and of itself, it seems important to acknowledge the qualitative change in the curriculum that would result. More problematic, however, would be bringing students to the level of intellectual sophistication required for them to even begin to consider the complex philosophical, sociological and historical arguments that would make up the subject of such a comparative study. This approach necessarily presupposes some student understanding of the science in question before considering the broader context in which it operates, which begs the question of how that initial understanding might be developed. Such issues are real impediments to this sort of multidisciplinary engagement.

All this is not to say that the understandings of science that these views contribute are not valuable at some level. What I am suggesting here is that such views provide less educative value to the science student seeking to understand the practical operations of scientific work than might be expected. Given the brief survey above, there are essentially two problems that need to be considered with respect to incorporating nature of science issues into the curriculum. The first, and more pragmatic, concerns the match between these universal views of science and the structure of the school science curriculum based as it is, at least in the USA, on traditional disciplinary distinctions. These conceptions of science, either drawn from science studies or simplified for curricular purposes, in their desire for breadth of coverage have sacrificed their ability to inform the specifics of any given disciplinary practice. The second, more fundamental problem that must be addressed is the growing concern over the validity of universal conceptions altogether. Both these issues suggest the need for a reconsideration of how the nature of science might be both conceptualized and integrated into the science curriculum.

Recent work in the field of science studies appears to have forced the issue of universality. Specifically, scholars have begun to question the legitimacy of the various universal, grand theoretical narratives of science that have been developed over the past several decades (Galison and Stump 1996, Harding 1998). The view increasingly gaining favour is that scientific research is best understood as a kind of situated practice, dependent on the intersection of particular experimental systems, communities of researchers, modes of organization, and even historical circumstance, which provide the context for the generation of scientific knowledge (Rouse 1987, 1996, Buchwald 1995, Pickering 1995a, b, Rheinberger 1995, Galison 1997, Knorr-Cetina 1999). Pickering (1995b: 43, 42) notes that this shift in science studies, which has become 'a self-conscious movement during the past decade' is based upon the realization that to 'make sense of science one has to think about both scientific knowledge *and* the practice with which it engages'. Careful examination of scientific practice has revealed not only the use of unique experimental systems or a particular deployment of instrumentation, but also distinct modes of argumentation, standards of objectivity, even shifting conceptions of rationality. In other words, *educators see science more accurately as an array of multiple, heterogeneous* *practices* that are informed very little by the various universalist accounts that float overhead.

Recognizing this highly contextualized local nature of scientific work, however, does not in and of itself resolve the difficulty faced by the science curriculum developer. Setting aside the various global accounts of the nature of science, only to be faced with a decidedly more complex particularist approach to science certainly does not seem to make things any easier. The difficulty lies in the difference between the ever-shifting, open-ended epistemological arena of scientific research and the highly stylized, relatively static representation of that knowledge and research in the school curriculum. Accepting the particularist basis of scientific practice as a whole requires one to come to grips with how to go about capturing the highly contextual nature of this work, given the various constraints imposed by the nature of organized instruction.

Science as cognitive practice

One approach to integrating a particularist view of science into the curriculum is to build upon the organizational structure that already exists. Even a cursory examination of typical science curricula reveals a particularist bias, at least with respect to subject matter. The course of study at the secondary level is frequently broken down into disciplinary categories, and within these one often finds arranged the key knowledge claims or theories of the discipline. Alongside these knowledge claims can be laid some characterization of the current practices of scientific research. By mapping the important features of these practices to the conceptual structures they both employ and produce, one would effect in essence an epistemological recontextualization of subject-matter knowledge. Subject matter so contextualized would likely take on significantly greater meaning for students, and because each knowledge claim has been generated or itself functions within a particular constellation of scientific practices, students would begin to understand the nature of those activities—not in some universal sense, but rather in the very real, local way those practices work to extend scientific understanding of whatever domain is under investigation.

The slightest pause will allow one to recognize that, in some ways, the argument being made here proposes nothing new. The idea that knowledge claims can be fully understood only in the context of their generation goes back at least to the earlier writings of the US pragmatists. The situated nature of knowledge was a defining feature of John Dewey's writings in both philosophy and education. This theme was developed further by Joseph Schwab in the middle of the century and tied to prescriptions for the development of curricula in science education. Schwab (1958: 375) claimed that scientific knowledge was 'unintelligible or misleading', unless it is understood in 'the context of inquiry which structured and bounded the matters' to which it refers. He even appreciated, at a certain level, the particularist view of science, calling for greater attention to the *plural* nature of scientific inquiry in the curriculum.

It would not be enough, however, merely to return to the curricular prescriptions of the early 1960s. Acknowledging the context-dependency of scientific knowledge as a step toward greater integration of nature of science issues into the curriculum is a sound first step to be sure. One must recognize, however, that understanding of the operations of science has changed dramatically over the past 40 years. Educators need to begin to exploit the vast literature of the science studies community, not to develop some universalist picture of science, the value of which is questionable, but to begin to understand what the various practices of science look like in all their myriad forms, in order to provide some reasonably authentic context in which to situate the scientific knowledge claims of the curriculum.

One key step in this direction (though by no means the only one), that takes advantage of more recent examinations of scientific research, is to recognize the distinct cognitive goals scientists pursue in various disciplines. As a rough characterization, cognitive goals can be thought of as the immediate intellectual ends toward which scientists work. Generally in science, two distinct cognitive goals can be identified to which numerous sub-goals obviously contribute: developing reliable theoretical models and reconstructing past natural events.

The importance of modelling in science as a cognitive activity cannot be overemphasized. Various case studies of scientific practice have identified the construction and extension of models as the central task of scientific research (Rouse 1987, Giere 1988, Pickering 1995a). Such work is, as Pickering (1995a: 55) explains, 'constitutive of scientific practice'. These models, in turn, do most of the heavy-lifting in science through their instrumental use organizing and directing subsequent research (Downes 1992). In outline, they can be thought of as conceptual systems containing specified elements that interact in well-defined ways. Each model describes, in some sense, a particular naturally occurring system and provides a means for its manipulation, the results of which further contribute to an understanding of that system. What is important to note is that, although overarching theories may provide a larger structure for a given discipline or field of research, the immediate goal of nearly all researchers is the extension and refinement of existing scientific models (Giere 1988, Pickering 1995a, Rouse 1996). Previously, the primary goal of science was characterized as seeking a coherent, systematic, unified theoretical understanding of the natural world—a view reinforced by early philosophers of science (Rouse 1987). More recently, however, expectations for what theories might accomplish in terms of systematicity and coverage of phenomena have been revised downward. Theories are increasingly being viewed more practically as 'a loosely connected set of models', whose 'range of application is not fully specified and whose effectiveness and accuracy vary considerably within that range' (Rouse 1987: 83–85, see also Cartwright 1983, Giere 1988). In other words, most scientists occupy themselves trying to understand only how selected, highly circumscribed portions of the world work, not with developing a coherent picture of the world as a whole.

Historical reconstruction as a goal of scientific work differs fundamentally from modelling, in that the final intellectual product is a chronological sequence of past natural occurrences (Sober 1988). Such a chronology, be it a phylogenetic history of various species or a record of climatic changes in the earth's history, is eminently particularist, always consisting of a unique chain of historically contingent events. The immediate goal in this case is not the development of a model, but rather the establishment of a reliable record of what has occurred and when. The work involved in constructing such a chronology certainly depends on some understanding of the myriad processes responsible for the natural changes that have taken place, which are understood only through the models that have been developed to represent them. The key difference is that, although theoretical models may be used instrumentally to help establish parameters to guide the reconstruction of a particular series of events, the immediate intellectual commitment of the local research community is to the chronology of events itself, not to whatever models might be employed incidentally in its development.

The proper consideration of cognitive goals has important implications for developing a school science curriculum that more accurately reflects the various facets of scientific practice. Clearly, instructional emphasis on formal theory or the importance of scientific laws (a feature of science that largely died out at the close of the 19th century), to say nothing of the mythical hypothesis–theory–fact progression, presents students with a distorted view of the tasks scientists set out to accomplish and the forms of the conceptual knowledge they use to those ends. A curriculum built upon the modelling activities of the scientific research community, where appropriate, would bring students closer to the everyday workings of science. Focusing on cognitive goals as one part of a structure around which to build school curricula, in addition, forces one to consider as legitimate ends of science goals that fall outside more traditional characterizations. As I have outlined above, the goals of the chemical and physical sciences may be largely subsumed within a modelling perspective, yet that same perspective would provide only an incomplete picture of scientific practice in the biological and earth sciences, where historical reconstruction remains an integral part of research.

Intimately associated with the cognitive goals researchers pursue are the various methods of justification, or argumentation they use in establishing their knowledge claims. For example, scientists developing models of phenomena that are easily observable, or at least manipulable, often rely on demonstrative arguments, whereas scientists working in disciplines that focus on historical reconstructions primarily warrant their knowledge claims via non-demonstrative reasoning.[1]

The difference between the two types of justification is an important one. At the macroscopic level, notions of demonstration in science are relatively unproblematic. One might verify a particular model of pendular motion, for example, simply by comparing the expectations of the model with an experimental pendulum, taking into consideration the differences one would expect to see between an ideal and real system. Providing demonstrable warrants for knowledge claims about processes or entities only postulated to exist (i.e. not directly observable), however, is less straightforward.

Galison (1997) has identified two kinds of epistemological strategies in the field of microphysics that have been used to generate representations of unobservable processes for the purposes of testing the adequacy of theoretical models. The first relies on the ability of the experimenter to produce some macroscopic image that maps directly onto the microscopic process in question, which can then be analysed for correspondence to the model being tested. Arguments for the existence of subatomic particles based on images from cloud or bubble chambers use this type of demonstration, which Galison refers to as *homomorphic*.

The second type of demonstration uses 'masses of data to make statistical arguments for the existence of a particle or effect' (Galison 1997: 19). Here, demonstration is achieved through a match between the statistical expectations of a model and the observable outcome patterns of the experimental system. The underlying processes remain unobservable in this case, but the fidelity of the model can often be assessed through the active manipulation of the system variables with subsequent tracking of the observable consequences. Because demonstration of this sort relies on chains of logical relations, Galison has termed it *homologous*. These types of warrants are characteristic of physics research that uses electronic counting devices such as the Geiger-Müller counter to record natural phenomena. A similar type of demonstration is used in transmission genetics, where aggregate data from multiple generations within a species provide the necessary justification for a given underlying genetic model.

In contrast, non-demonstrative inference is used when the phenomena in question cannot be represented in ways that easily map on to the corresponding knowledge claims. This avenue of argumentation is the only one available in the development of historical reconstructions, which obviously are claims about past events well beyond the reach of human observation. The evidence in such instances consists of artifactual traces of past processes—a classic example being the remnant background radiation supporting the big-bang origin of the universe. The strength of such arguments often depends on the number of artifacts and how the knowledge claim in question groups and explains what had previously seemed rather disparate phenomena.

Such reasoning, however, is not limited to cases of historical reconstruction. Certain phenomenological circumstances require that claims be based on non-demonstrative inferences, even when the cognitive goal might be the articulation of a theoretical model. The most significant example of this, perhaps, is found in the justification of the model of evolution by natural selection. Although biologists believe evolution is an ongoing phenomenon, the process in any single macroevolutionary speciation event takes place over spans of time that render it effectively unobservable. There is typically no way for scientists to visually track speciation in real time, eliminating the possibility of homomorphic demonstration, and, similarly, the consequences of any experimental manipulation are impossible to recover, making any sort of homologous demonstrations impossible as well. Thus, apart from analogical arguments from microevolutionary events, models of macroevolutionary change must rely largely on arguments of a non-demonstrative sort—assembling a case based on evidence from the fossil record, biogeographical distribution of organisms, comparative anatomy and embryology, and the like. Similar reasoning can be found supporting geological models of plate tectonics or astrophysical models of stellar formation.

Though one cannot reasonably expect to generate a science curriculum that captures all the diversity and nuances of reasoning and justification that no doubt exist, some workable approximation might be developed (be it similar to what I have outlined here or altogether new) that would contribute to student understanding of the broad range of intellectual practices in science. It appears well documented in the science education literature that students often possess naïve realist perceptions of the nature of science—perceptions that privilege demonstration and experimentation over other forms of reasoning (Larochelle and Desautels 1991, Ryan and Aikenhead 1992). A good deal of science depends on justification by other means. These, I contend, should be represented in the school science curriculum as well.

The question of just how such epistemological and cognitive concerns might make their way into the classroom is a real concern. To this, I can only provide some suggestions along with some examples of work with which I am familiar. As I noted in the introduction to this section, it would seem expedient to begin with the existing structure of the science curricula—that is, school subjects such as biology, chemistry and physics. After all, instruction in science has traditionally focused on the existing conceptual frameworks of these various disciplines. The next step would be to break down these subject areas into the primary practices of which they are comprised—to generate a map of each discipline so to speak—and develop curricular materials that capture and convey those practices to students as faithfully as possible. These materials might include historical readings, data-rich simulations of laboratory or field problems, or even well-crafted lecture/discussion materials. The goal of the overall course of study in science, according to these prescriptions, would be to communicate to students some understanding of a representative sample of the divergent practices that are found in each disciplinary field.

One example of this approach, although only sketched here, can be found in the high school genetics course described by Cartier and Stewart (in press) and Eisenhart and Finkel (1998). Drawing on the practices of geneticists, these researchers have constructed a curriculum designed to help students appreciate the model-based nature of inquiry in the field of transmission genetics. Early on in the course, students are introduced to various inheritance phenomena as well as Mendel's model of simple dominance as a means to explain some subset of that phenomena. Students are then provided with a computer simulation that enables them to pursue research questions on the genetics of fruit flies. In the course of their work, they inevitably encounter anomalous data, which, in turn, requires them to revise the initial model of simple dominance with which they began. The class is organized so that student research groups present and defend the models they have developed before their peers, using cross-data to support their ideas. During these presentations, students come to appreciate the work involved in constructing and justifying arguments in the practice of genetics. More generally, this course helps illustrate for students the homologous demonstration of knowledge claims along with the cognitive goal of modelling. Other research practices in biology might be illustrated in similar ways. Much work remains to be done, however, particularly in resolving the broad disciplinary categories that structure the school science curriculum into their component working practices. It is these practices, as I have indicated, that should serve as the focus for building the science curriculum.

Refocusing the debate

Absent from this discussion of the nature of science and the science curriculum to this point—perhaps noticeably, perhaps not—is an explicit articulation of the relationship between science and some notion of its *ultimate* aims, particularly that of attaining truth, or coming to know some mind-independent natural world. Currently, in the field of science education, this concern over the precise claims one can make regarding the capabilities of science to generate an accurate, or true, representation of the world has occupied the attention of numerous scholars. This attention, I suggest, has come at the expense of productive work toward integrating an understanding of scientific practice into the school curriculum. What needs to be considered more carefully is the relationship between this concern for the ultimate aims of science and the more immediate goals of science education.

Much of this preoccupation with the ultimate goals of science can be traced to Kuhn's influential work, *The Structure of Scientific Revolutions* (1970), which heralded the rise of science studies and ushered in the growing emphasis on the nature of science in science education. Prior to Kuhn, the reigning philosophy of science was that propounded by the logical positivists, whose work centred on finding some systematic, foundational means to ensure, if not certainty, at least empirical reliability with respect to scientific claims (Joergenson 1970, Galison 1990). They cast their lot with the seemingly objective nature of sensory experience; from raw observation, they believed, one could construct indubitable knowledge given the rules of logic and a well-defined observational language. The antipositivist movement of the 1960s which Kuhn so indelibly marked, as Galison (1990) points out, essentially inverted the positivist relationship between observation and theory. Where, previously, observation had provided the transcendent constraints that shaped theory, now it was theory that conditioned not just what might count as evidence, but even what scientists had the ability to 'see', given their conceptual commitments.

The epistemological relativism that many read into Kuhn's work prompted extended efforts to locate the rational core that many believed existed at the heart of science and eventually gave rise to the competing views of science discussed above. Some developed grand narratives of progress that eschewed realism but retained an underlying rationalism (Laudan 1977). Others committed themselves to conceptualizations of science that embraced some form of realism as the only explanation for science's success (for examples see Fine 1986). The more radical turn came from the new sociologists of science who sought to demonstrate the power of social interests in shaping knowledge and, thereby, undermine the notion of a rational epistemic core. Rouse (1996) makes a compelling argument that the primary purpose of all this scholarship over the past three decades has been either to develop some intellectual justification for the central place of science in contemporary culture (a task undertaken for the most part by the philosophers) or to demonstrate that no intellectual justification is tenable and, thus, delegitimize the cultural authority science has enjoyed to this point (the work of the sociologists). In other words, the debate has centred not so much on the accuracy of the picture of science presented, but rather the adequacy of the various metascientific narratives to support the privileged place of science in society—a debate constitutive of what Rouse terms the 'legitimation project'.

The science studies preoccupation with this legitimation project has clearly spilled over into the broader science education community, that composed of both science education researchers and scientists proper. This has been more than evident in the flare-ups that have been tagged battles in the 'science wars' (Holton 1996, Ross 1996). Within the science education research community a significant amount of space in the leading journals has been devoted to various discussions of just this issue (Matthews 1994, 1998, Stanley and Brickhouse 1994, 1995, Brickhouse and Stanley 1995, Good 1995, Lederman 1995, Loving 1995, 1997, Suchting 1995, 1996, Osborne 1996, Nola 1997, Staver 1998). These discussions nearly always tend to settle on the conflict between the apparent relativism of constructivist accounts of science on one hand and the rationalist/realist views of science on the other. This extended and often pointed discourse surely provides ample evidence that much is at stake with respect to the fundamental philosophical perception of science and the school science curriculum. Or perhaps this issue requires further examination.

Some, no doubt, would argue that an essential part of science education is the demonstration of the legitimacy of the 'scientific method' (as traditionally conceived), to prove philosophically the power of scientific inquiry as a means of arriving at some sort of truth about the world. Others might claim that the rational analysis of science in light of its ultimate goals is necessary for complete student understanding of the dramatic instrumental success of science as a way of knowing. But, one might ask how important such legitimation really is. It cannot fail to escape the attention of those concerned that, despite the apparent attacks on the epistemological authority of science, the USA is at the same time in the throes of distress over the comparatively low achievement of its students in science and mathematics (National Science Board 1998). Clearly, science has not achieved its stature in the school curriculum, owing solely to philosophical arguments regarding its privileged purchase on truth. The industrial nations of the world—especially since the Second World War—have largely placed their trust in science because of its perceived utility for generating economic development, military superiority, medical advancement and so on. These are the warrants, right or wrong, for its present inclusion and emphasis in the school curriculum.

When one begins to look for the specific contributions that participants on either side of the legitimation project might make to science education, what is striking is the lack of natural intersection. The difficulties inherent in universals aside, these grand theoretical views of science, focusing as they do on questions of ultimate goals, have little to say about the day-to-day work of practising scientists. Regarding the ultimate questions, Rouse (1996: 4) rhetorically asks, 'Should we believe that well-established scientific theories are (likely to be) true? Should we eschew belief and accept those same theories as empirically adequate at best? Or should we endorse the pursuit of those theories without committing ourselves to attitudes of acceptance or belief?'. Tellingly, he suggests that 'scientists themselves might quite understandably be indifferent toward these interpretive disputes ... since *these positions place no constraints on and offer no advice for scientific practice*' [emphasis added]. This point, it seems, is significant and goes some way toward answering the question regarding the value of the legitimation project for science education. The situation Jenkins (1996) relates with respect to these competing notions of science is problematic precisely because it deals with deep-seated and unresolved philosophical and sociological issues about the very nature of knowledge—issues that are more properly considered within the broader domains of philosophy. In the traditional school science curriculum there is no ready place for such extended discussions. They add nothing to student understanding of how science works.

To bracket these philosophical issues when considering the development of curriculum is not to suggest that the nature of science be eliminated from school study. Indeed, I maintain that some well-defined space should and can be profitably provided in the school curriculum for just such broad philosophical, historical and sociological examinations of past and present scientific inquiry. To think, however, that such issues can be meaningfully and seamlessly integrated into existing science instruction is to strain reason. What is suggested here is that the focus on the nature of science as a curriculum component in existing instruction, presently constructed with some universal intent, be recast from the universal to the particular and from a concern with the ultimate goals of science to the proximate goals of practice.

A particularly useful philosophical disposition for understanding science in this way has been laid out by Arthur Fine (1986). He calls his approach to understanding science the Natural Ontological Attitude (NOA). I would suggest that movement toward just such a disposition by the science education community would contribute a great deal to a necessary refocusing of our approach to the treatment of the nature of science in schools. Fine (1996a, b) describes, as Rouse (1996) after him, the persistent search by various philosophical schools (realist, instrumentalist, constructivist) for some general, essentialistic account of science, all of which he claims are inherently flawed. In place of such universal accounts, he offers NOA, which, as he states, counsels people 'to try to take science on its own terms, and try not to read things into science'. 'If one adopts this attitude', Fine (1996b: 149) explains, 'then the global interpretations, the "isms" of scientific philosophies, appear as idle overlays to science: not necessary, not warranted, and in the end, probably not even intelligible'. The question of ultimate aims ('Does science aim at truth, or does science merely aim at empirical adequacy?') is neatly sidestepped, not because such questions are difficult or unresolved, but rather for the more important reason that, as Fine (1986: 173–174) states, 'nothing seems to accrue to our understanding of science if we go looking for general aims or goals'. According to NOA, the meaningful goals of science, the day-to-day ends toward which scientists work, are to be found and understood in the local context of practice. As for truth, that too is found in the context of practice—defined by the local standards of the community of researchers. It is the nature of this practice, varied as it is from discipline to discipline and even from one research question to the next, that the curriculum should seek to capture in some form and offer to students.

Conclusion

The move from universal conceptions of the nature of science to an appreciation of particularities of its practice for the purposes of curriculum development in science education is desirable on several fronts. Such a move—even at the level outlined here—would allow students the opportunity to experience and begin to understand the rich diversity of scientific endeavour. Of all the academic subjects that comprise the school curriculum, few are subject to the persistent and gross oversimplifications with respect to methodology that science is. The unfortunate state of science education in this regard is something that no 'nature of science' cut from whole cloth, no matter how qualified or sophisticated, has the power to remedy. A particularist understanding of science derived from the analysis of existing practice provides the necessary opening through which subject-matter knowledge in science can be properly contextualized as the product of inquiry. Thus, the goals and methods of microphysics can be presented as distinct from those of cosmology, the nature of evidence used to support claims in evolutionary biology as different from evidence for models of cellular respiration. Students would begin to see that what counts as knowledge depends not on some universal calculus of rationality or algorithmic operation of method, but rather on the specifics of the phenomenon and research methods in question. They would hopefully develop some metaunderstanding of the particular norms of the local research community and their potential for change over time. Such an approach to the nature of science, built from the particulars of practice, would clearly complement the existing structure of the science curriculum in ways that not only would help students see the many processes of science, but also would enhance the meaning of the subject matter itself.

One of the enduring goals of science education is the development in students of some understanding of the nature of science. That understanding, as I suggest in this paper, can only be found in the practice of science itself. As valuable as the varied grand philosophical, historical and sociological narratives might be, in the end, just as there is no non-empirical access to the 'real' world, there is no referent outside science itself that can provide a more authoritative picture of what science is in all its rich diversity. It seems it is there that understanding should be grounded, with each inquiry, case, or research programme providing the bounds for what science is about in that particular instance, and with each instance building toward a greater understanding of not what science *is*, but rather what science *includes*.

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Note

1. Although the terms 'demonstrative' and 'non-demonstrative' have well-defined meanings within the formal language of the philosophy of science, they are used here in their more everyday sense and are to be read as referring to phenomena that can be loosely identified as 'observable' and 'unobservable'.

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