ABSTRACT: Two seemingly complementary trends stand out currently in school science education in the United States: one is the increased emphasis on inquiry activities in classrooms, and the other is the high level of attention given to student understanding of the nature of science. This essay looks at the range of activities that fall within the first trend, noting, in particular, the growing popularity of inquiry activities that engage students in engineering-type tasks. The potential for public disengagement from science and technology issues is described as a result of the continued juxtaposition of these sorts of inquiry activities with our current, idealized portrayals of the nature of science—the emphasis of the second trend. Drawing on Dewey’s instrumental theory of knowledge, an alternative way of thinking about science is offered that would not only provide for a more authentic understanding of science, but also invite much needed public participation in the broad governance of science in modern-day democratic societies.

INTRODUCTION

Few things in science education are as popular these days as inquiry. Although the current era’s focus on inquiry was born with the curriculum reform movement of the 1950s and 60s—particularly through the seminal writings of Joseph Schwab (1958, 1962)—the present resurgence, at least in the United States, can be traced to the standards-setting publications Science for All Americans (American Association for the Advancement of Science [AAAS], 1990) and the National Science Education Standards (National Research Council...
[NRC, 1996]. Publications since these have given inquiry even greater exposure (Minstrell & Van Zee, 2000; NRC, 2000), and the introduction of computer-based instructional technologies have generated additional excitement among researchers looking to harness these resources to develop more effective and authentic learning environments in which inquiry can be realized (see, for example, Linn, Clark, & Slotta, 2003; Shaffer & Resnick, 1999; Songer, Lee, & Kam, 2002). This emphasis on inquiry has coincided, not surprisingly, with a parallel emphasis on the nature of science in the curriculum, which encompasses both an appreciation of scientific process at the microlevel (what happens at the laboratory bench for instance), as well as an understanding of science as a widespread social and intellectual enterprise (the organization of knowledge production in society) (AAAS, 1990; NRC, 1996). The intersection of these two things in the classroom—inquiry as an instructional method and the nature of science as a learning goal—and the consequences of that intersection for the public understanding of science is the subject of this essay.

I was prompted to write about this topic after having run across a description of yet another hands-on, scientific-inquiry activity in which students were expected to build cranes to lift things or construct containers to protect fragile objects. It seemed to me that these kinds of activities, which are an increasingly common part of the school experience, were fundamentally different from the kinds of things scientists do—science being more about constructing ideas than things. To pass off such activities as “science,” I felt, was to misrepresent science, and that to do so deliberately would, therefore, compromise student understanding of what science was all about. It was this initial concern that got me thinking about the larger issues related to inquiry, the nature of science, and the goals and aims of science education as they are currently understood among scientists and educators.

This paper is organized along the same lines—as these issues might unfold in the natural progression of thought. It opens with a look at classroom inquiry activities and then moves on to treat larger issues related to science and the public. Specifically, I provide a brief survey and analysis of the types of activities that fall under the rubric of inquiry, paying close attention to the distinction between things and ideas that initially led me to this project. I then examine current portrayals of the nature of science and discuss the implications of their juxtaposition with certain kinds of inquiry experiences. My concern here is to point out the potential that exists for discouraging public participation in science- and technology-related issues. I go on to offer an alternative way of thinking about science grounded in an instrumental theory of knowledge that would invite more public involvement in science, and end with some suggestions for how inquiry activities might be resituated in the curriculum to accomplish this goal.

Two distinct critiques make up the heart of this work. The first concerns the unreflective use of inquiry activities in the context of the dominant portrayal of the nature of science in school classrooms at all levels. The second and more substantive critique picks up where the first leaves off. It focuses specifically on the larger issues related to the persistent portrayal of science as distinct from more applied and practical forms of knowledge, as driven by an internally referenced search for truth in isolation from societal concerns. This view of science, which has a strong presence in current textbooks and policy documents, I argue, needs to be radically reconsidered in the interest of greater authenticity and in order to secure a more symmetrical relationship between the institutions of science and the public they serve.

THE CURRENT TREND

It goes without saying that the recent rush to inquiry in science teaching (where it has been faithfully implemented) has resulted in a number of positive trends in classroom instruction. The activities most frequently discussed in textbooks and research journals almost
invariably involve students in “hands-on” manipulation of apparatus or natural objects, the development of representations of their ideas and observations, and collaborative discussion and problem solving. In many cases these projects are student directed or even initiated, which provides a valuable sense of ownership over the learning that occurs (Barron et al., 1998; Lehrer & Schauble, 2002; Roth, 2001; Schneider et al., 2002; White & Frederikson, 1998). Student involvement in manipulation, representation, discussion, and so on, many have argued, is the path to meaningful learning in any subject area (Bransford, Brown, & Cocking, 1999; Carpenter & Lehrer, 1999). Not to be overlooked is the fact that inquiry activities are simply more engaging for students than typical teacher-centered instruction, and when the current emphasis on the nature and process of science is folded into the mix—learning goals for which these activities seem to be, and often are, tailor made—it would seem almost impossible to mount any substantive criticism of this approach. On the surface this may be the case. However, when one begins to look more carefully at classroom inquiry teaching and examines how its associated activities are situated within the broader science curriculum, particularly with respect to the nature of science, problems begin to emerge.

A quick survey of activities that fall into the class of things commonly referred to as inquiry reveals a surprising variety. They include everything from the pedestrian observation exercises and single-variable experiments common to commercial science curricula to the much more sophisticated and scientifically authentic inquiry activities developed by some educational researchers. Chinn and Malhotra (2002) have recently completed a comprehensive analysis of inquiry activities from these various sources and have arrayed them along what they define as a simple to complex (or simple to authentic) continuum. They make a number of compelling points related to degrees of authenticity in this mapping. As useful as their framework is, there are other ways to look at these activities, and I would argue that examining them, at least initially, along another axis—what might be traditionally thought of as a pure-applied continuum—opens up space for some different and rather interesting conclusions.

From this perspective, you would find at one end inquiry activities focusing on cognitive goals similar to those in the established scientific disciplines—the development of explanations or models that account for some particular phenomena, for example. I have in mind here the types of activities associated with the BGuILE project, where students explore the microevolution of finches on the Galapagos Islands (Reiser et al., 2001) or Project MUSE, which among its curriculum units, has students develop models of celestial motion to account for observed patterns of day/night, moon rise and set, etc. (Barton, 2001; Stewart, Cartier, & Passmore, 2005). Classroom activities such as these provide opportunities for students to grapple with questions shaped by disciplinary frameworks. The targets of understanding are fundamental natural processes and events, and, in this way, they are reminiscent of the inquiry activities common to the National Science Foundation (NSF)-funded curriculum reform projects of the 1960s (Rudolph, 2002).

At the other end of this inquiry continuum are more technologically oriented projects and activities. These include everything from bridge-design and crane-building tasks to the ever-popular egg drop to which I alluded at the outset—activities where students develop and test solutions to more real world-type problems. One might call this the engineering end of the continuum (Cajas, 2001; Kolodner et al., 2003; Krajcik et al., 1998; Roth, 2001; Sadler, Coyle, & Schwartz, 2001). These activities often involve the manipulation of structures or the fabrication of artifacts to accomplish some preset goal—goals that are primarily material rather than intellectual (Schauble et al., 1995). (By this I mean the goals of the task itself, not the learning outcomes that may result from the completion of the task, which often include the understanding of abstract scientific concepts.) The recent emergence of the learning sciences as an area of research with its focus on theories of mediated understanding and
distributed cognition has contributed to an increased emphasis of late on design tasks of this sort (Kolodner, 2003).

It is easy to see why these more practical inquiry activities have carved out an enduring place in the schools. For one, they purport to illustrate the methods and applications of science in real-world contexts that students can readily appreciate. They make science relevant in ways that abstract disciplinary inquiry often can not. Moreover, their inherent appeal—the ability to generate student interest and engagement that comes from the well-defined, often competitive, task-driven character of these activities—would be hard to overstate. Both teachers and students have little trouble understanding the criteria for success: the boat floats the greatest number of weights, or the egg survives its fall from the top of the bleachers intact. The clear focus undoubtedly contributes to more effective classroom management through student engagement, as well as to the greater likelihood that teachers less secure with their own level of science content knowledge will venture to implement such activities in their classrooms (at least as compared to the more discipline-focused inquiry activities that are situated in a much less familiar intellectual world).

The increased emphasis on engineering inquiry activities, though, poses some problems with respect to the broader goals of science education. Let me preface my comments here by saying that these activities, in and of themselves, are hardly troubling. Time and again, they have been shown to be an effective means of helping students see empirical relationships, test hypotheses, understand important conceptual principles, work collaboratively, and communicate ideas to others (Barron et al., 1998; Bransford et al., 1999; Roth, 2001; Schneider et al., 2002). The problem arises when these task-oriented projects are placed in a classroom context where they come to be seen, either implicitly or explicitly, as “science”—especially the way science as an enterprise is commonly taught and generally understood by the lay public (see, for example, Driver et al., 1996; Toumey, 1996; Windschitl, 2004). For some, the concern is that the close association with science might wash out what is unique to engineering and design epistemologies (Cajas, 2001). But the problem with which I am primarily concerned is more fundamental than this, and it derives from the sociocultural position science holds in the common understanding. It is the conflation of engineering activities with science in this sense, I argue, that is of greatest concern.

The situation can be laid out as follows. The recent, standards-based push for increased public understanding of the nature of science has, as might be expected, led to its greater prominence in the school curriculum (AAAS, 1990; NRC, 1996). Often the discussion of what science is as an intellectual activity is presented as a topic unto itself, isolated from subsequent science content. In these treatments, science is commonly described in universalist terms, as an enterprise that has the ability to produce reliable, objective knowledge about the natural world through the rigorous application of its methods (see, for example, Holt Science and Technology, 2001; Spaulding & Namowitz, 2003; and Wysession, Frank, & Yancopoulos, 2004). This view of science as the search for durable knowledge is consistent with the characterizations of science offered in the recent standards documents, and conforms as well to the descriptions offered by some in the science education research community (Bell et al., 2003; Cobern & Loving, 2001; Smith & Scharmann, 1999; Southerland, 2000). Recent research from the field of science studies, however, has shown that objective truths about the world are not as easily obtained as these descriptions suggest. From this perspective, science is more completely embedded in society (and society in science) than is commonly thought (Barnes, Bloor, & Henry, 1996; Collins & Pinch, 1998; Pickering, 1995).

My concern, though, is not that students are not exposed to the nuances of the complex social and epistemic negotiations that go into the creation and stabilization of knowledge claims in a given discipline. (Fully understanding this is probably beyond the intellectual
capacity of the majority of secondary school students.) Neither is my intent to question the legitimacy of the knowledge science has produced. Although certain readings of nature are undoubtedly influenced by sociological factors, science without question has enhanced our ability to understand and manipulate the world in which we live. What concerns me, rather, is that with these typical descriptions of the nature of science—that is of pure science at its very essence—comes a view of its intellectual work as restricted to an elite group of experts and as happening in isolation from the needs and concerns of society.¹ One measure of the isolationist nature of science is the extent to which science is routinely and explicitly set off from technology. In the National Science Education Standards, for example, the authors state that it is important for students to understand that “science and technology are pursued for different purposes.” Science is described as an activity “driven by the desire to understand the natural world” with the direction of inquiry guided by the curiosity of the scientific mind and only rarely influenced by societal concerns. Technology, in contrast, is explicitly linked to societal concerns, being cast as an enterprise defined by the “need to solve human problems” (NRC, 1996, p. 192). Nearly identical descriptions can be found in Science for All Americans.

Students who come away from these explicit lessons on the nature of science then go on to engage in the increasingly common engineering inquiry activities described above, which are often intended as hands-on examples of actually doing science. Ironically, little effort is made to maintain the distinction laid out in the initial lessons on the nature of science with these activities. In one school textbook, the authors open with the typical chapter on what science is and then walk the student through the steps of the re-design of a ship propeller as a paradigm example of the “scientific method.” This is followed by a “hands-on” scientific inquiry activity in which students are asked to figure out how to fold and cut an index card, keeping it in a single piece, in such a way that they can pass their body through it (Holt Science & Technology, 2001, pp. 6–17). Activities like this are hardly unique in my experience with local teachers, many of whom have no qualms about using these kinds of material challenges as proxies for what scientists do. The danger here is that the qualities ascribed to science in the abstract will carry over to the engineering activities in which students later engage. These students—and ultimately the public at large—may accept that the design, construction, and manipulation of material artifacts are acontextual activities devoid of social, political, economic, and cultural consequences, that these activities are merely “technical” in nature and—even though they have been allowed to give it a go—more appropriately carried out by those with the necessary training and expertise.

Technological design and engineering are, of course, not ivory-tower endeavors. They are tightly embedded in all aspects of the world in which we live. Artifacts are designed in response to particular human problems and situations. Their designs are shaped by innumerable constraints—not just the material and simple economic constraints described in the technology standards (AAAS, 1990; Cajas, 2001)—but by deeper social and political constraints as well. More important is the point made so eloquently by the political theorist Langdon Winner that artifacts and technologies have consequences, not only for the immediate problem that prompted action, but also for the social relations with which a given solution intersects. A few examples will suffice. The invention of the automobile and development, years later, of the interstate highway system contributed to massive social

¹ Here I am referring only to treatments of what is commonly referred to as the nature of science as reflected in popular textbooks and prominent science education policy documents as indicated by my citations. In the broader public sphere (various mass media portrayals and the like), science is presented in multiple and sometimes conflicting ways depending on the context and issues in question (see, for example, Gieryn, 1999; LaFollette, 1990; Toumey, 1996).
transformations at multiple levels through the process of suburbanization (Jackson, 1985). Similarly in the area of industrial production, the role of skilled labor was greatly minimized by the introduction of numerically controlled machine tools into factories after World War II (Noble, 1984). Even something as simple as the mechanical tomato harvester developed by University of California researchers in the 1940s, Winner notes, due to the scale of operations required for its efficient utilization, resulted in the elimination of thousands of family farms and the subsequent consolidation of the tomato industry. The design and deployment of new technologies at any level, from that of complex systems to the simplest hand tool, presuppose in their very form particular patterns of human activity and interaction. The result in all these cases, Winner explains, is that “different people are situated differently and possess unequal degrees of power as well as unequal levels of awareness” (1986, pp. 28–29).

The social and political elements of engineering and design do not go unacknowledged in the policy documents of the major scientific organizations. AAAS’s Science for All Americans in places seems to borrow Winner’s very words. The authors of the chapter on the nature of technology open by stating plainly that “the results of changing the world [via technology] are often complicated and unpredictable. They can include unexpected benefits, unexpected costs, and unexpected risks—any of which may fall on different social groups at different times.” “Anticipating the effects of technology,” they insist, “is therefore as important as advancing its capabilities” (p. 25). Unfortunately, this concern with the complex interactions between technology and society rarely extends down to the level of classroom activities and curriculum design. The most that students seem to experience are concepts internal to the particular system/design process in question, such as issues of cost trade-offs, efficiency, etc.—if they are considered at all during the students’ rush to accomplish the particular challenge presented (Cajas, 2001; Schauble et al., 1995). Even researcher-developed activities, though often more sophisticated than typical classroom inquiries, fail to engage students in questions that cross over into the social and political realms, presenting tasks instead as though technical issues circumscribe the whole of the problem being considered (see list in Chinn & Malhotra, 2002, pp. 198–200).

It seems clear, then, that presenting design/engineering-inquiry activities in the ideological trope of pure science has the potential to further disengage what some observers claim is already a politically quiescent citizenry (Feenberg, 1999; Winner, 1995). When complex technical issues of national importance come up for public debate—issues related to transportation policy, energy development, or communications technology—the likelihood is that the public, seeing the problem as primarily “scientific” and possessing all the characteristics of science in the abstract, might be inclined to defer to the experts. The result is that a small, nonrepresentative group of individuals will make decisions that significantly influence how the majority of citizens will live and relate to one another in the world. While it is true that some technological projects have sparked considerable public reaction—nuclear power in this country and genetically modified organisms in Britain come to mind—these instances of public involvement in technology policy have been primarily reactionary rather than deliberate and, more discouraging, the exception rather than the norm (Shaw, 2002; Winner, 1986, 1995). This state of affairs, I would argue, is one that does not bode well for the collective well-being of our increasingly technological society.

WHAT MIGHT BE DONE

It would be too much to say that the present practices of school science teaching are responsible for the public apathy regarding science and technology policy issues in the United States. If such apathy can be traced to the confusion between science and technology,
it should be recognized that the lay public has long conflated the two, and recent educational research shows that students continue to do so (Driver et al., 1996; Rudolph, 2003b). Moreover, perceptions of science as authoritative and removed from the common affairs of society are derived from nonclassroom sources as much as from classroom sources (see, for example, Burnham, 1987; LaFollette, 1990; Toumey, 1996). But granting these obvious facts does not mean that school science might not be better structured to minimize the problems associated with students seeing technology as science. In fact, given the prevalence of these images in society at large, it would seem incumbent upon the schools to provide some sort of corrective action.

At this point, there are two possible solutions that might be suggested. The first would be simply to eliminate any classroom inquiry activities that focus on engineering or technical problems on the argument that they are not “science” in the pure sense of the term and increase student involvement in activities from the abstract end of the continuum that more closely model the intellectual activities of research scientists. The second, less radical solution would be to continue to use inquiry activities from both ends of the continuum, but to add instruction that would make more explicit the distinction between the goals and aims of engineering and those of science. This way teachers could retain all the motivational and cognitive benefits associated with the task-specific, design activities while helping students appreciate, in addition, the inherent social and political aspects of technological design, development, and implementation. The need would be to appropriately contextualize what are currently decontextualized instructional activities. Educators, in other words, should attend to the sociopolitical understanding of technology articulated in Science for All Americans.

Although the actions sketched above might be reasonable first steps toward improving science education in the short term (at least in increasing the possibility for greater public involvement in technological issues), accepting these as the only possible corrective measures would require accepting that the source of the problem lies in the inadequate distinction in classrooms between pure science and applied science, or engineering. This conclusion, though, seems to be mistaken. The real problem, I would argue, lies in the belief that there is any basis for seeing these activities as fundamentally different at all. Ultimately, worrying about an apolitical, decontextualized view of technology only addresses one small part of the problem. It leaves untouched the much larger problem of the public acceptance of an apolitical, decontextualized view of science.

One could rightly argue that in certain places where science and society come together, where there are significant issues at stake (things like global warming, stem-cell research, nuclear energy, and so on), interested groups can become highly mobilized and the claims of science extremely politicized. My point is not to diminish or discount such episodic public participation and the manner in which science is cast in these specific instances. My target in this paper is science in the abstract, as it is considered apart from any particular issue or concern. Clearly an important factor in determining the nature of the context-specific negotiations that take place is this generalized image of science, an image that carries with it certain public expectations of credibility and power. It provides the backdrop against which conflicts between expert opinion and local knowledge are considered, weighed, and ultimately settled. Although these images, for the most part, exist in the background of the public consciousness, they are nonetheless the result of deliberate construction, and currently science in schools is cast in fundamental ways as an activity set off from the public, to be received with appreciation. To make real progress in public participation, we need to grapple with this much more ingrained, seemingly common-sense perception of science itself.

The usual distinction made between science and technology in the abstract is related to the primary aims of each endeavor. Science has been described as an enterprise directed toward
understanding how nature works (what some talk about as the search for truth), while applied science/engineering is believed to focus on solving practical human problems. (This is, as noted earlier, the way the national standards frame the issue.) While a qualitative difference like this is easy to specify in the abstract, mapping it onto knowledge-related activities in the real world is more difficult than one might expect. In his careful analysis of this distinction, philosopher of science Philip Kitcher notes that, even when dealing with just the abstract, pure science end of the continuum, “the complex intertwining of the epistemic and the practical and the mixed motivations of actual researchers ... make[s] the application of any simple distinction ... impossible” (2001, p. 90). In fact, a good deal of sociological and historical analysis suggests that the ideal of “pure science” exists more as an ideological construct than as an actual activity. This image has long been advanced by members of the scientific community to insulate their work from external control, and it works by painting the activities of scientists as disconnected from the material and social concerns of society as a whole (Greenberg, 2001; Guston, 2000; Hollinger, 1990). If science were seen as immediately practical, there would be reason to think that the scientific community should, therefore, be responsive to the needs of society, or should even be directed to pursue work that meets social needs broadly determined (democratically by representatives of government, for example). But, if such practical payoffs come only unexpectedly, as a by-product of the ongoing search for fundamental knowledge, or truth, then the best that can be done is to support scientific efforts as fully as possible and hope that as various research programs advance, practical benefits will follow, though they may be intermittent and nondirected.

The latter position has been advocated by members of the scientific research community in the United States since the Second World War (Guston, 2000; Hollinger, 1990; U. S. Office of Scientific Research and Development, 1945), and elements of this insulated-science view can be seen clearly in the recent science education policy documents. In Science for All Americans (AAAS, 1990), to take the example at hand, the authors explain that research priorities are determined by “influences within the culture of science itself, such as prevailing opinion on what questions are most interesting or what methods of investigation are most likely to be fruitful.” The next sentence makes clear who should be setting the agenda: “Elaborate processes involving scientists themselves have been developed to decide which research proposals receive funding, and committees of scientists regularly review progress in various disciplines to recommend general priorities for funding” (p. 8, emphasis added). Though the phrasing is descriptive, the normative message that the direction of scientific research is best determined by those on the inside comes through unmistakably. The only place the public is mentioned is as part of the broader arena in which scientists participate as well, where they “bring information, insights, and analytical skills to bear on matters of public concern” (p. 11). Here engineers and applied scientists might take the basic knowledge already generated by the pure scientists and go to work solving problems of interest to the lay community.

If we really wish to increase levels of public participation, a more productive stance would be to move away from the pure science image pervading current curricular materials and policy documents. Instead of attempting to separate pure science from applied science, we should acknowledge the practical nature of science in all its various forms. A move such as this would not only guarantee greater authenticity, but also provide a way of thinking about science that naturally invites greater democratic accountability.

There are those who would object to any view of science that would sanction nonexpert input into the direction of scientific research. Advocates of this position often argue that there is an internal logic to basic science that can be fully comprehended only by those who are deeply engaged in the work, and that it is these individuals, steeped in the esoteric knowledge and research methods of the particular discipline or subdiscipline, who are
best positioned to determine the path to truth, or, less provocatively, the most fundamental theories about the natural world. The search for these theories, the argument goes, would only be compromised by the introduction of social needs or concerns. The validity of this view and the socioeconomic position of institutional science in the United States that derives from it (maximum public support/funding with minimum public intervention) turns not only on the assumption problematized above, that pure science can be easily distinguished from practical or applied science, but, more important, on the assumption that pure science has as its cognitive goal the pursuit of fundamental understandings that possess some inherent value apart from any practical applications they might have. One might call this the “truth is its own reward” justification.

Kitcher, in his recent work on science and democracy, provides a cogent analysis that calls this assumption into question. The resources of science, he explains, have always been selectively directed toward securing what he calls “significant” truths, the most powerful form of significance in the ideology of science being epistemic significance, which is defined as knowledge deemed “intrinsically valuable” (2001, p. 65). It is this particular kind of significance that has been invoked to insulate science from external control; it undergirds the argument that only scientists know the route to fundamental knowledge. Much here depends, though, on just what makes something intrinsically valuable. The most commonly offered accounts of value focus on the desire to arrive at some all-encompassing understanding of the fundamental processes of nature. Using examples from scientific practice, Kitcher illustrates, however, that there is no logically defensible position that would hold that there is any single, overarching explanatory framework (a grand unified theory) science aims to achieve. After considerable analysis, he concludes, in fact, that there is no context-independent measure of scientific significance at all. The pursuit of any research, rather, is determined by a complex network of concerns related to both practical aims and simple human curiosity, both of which evolve and change in historically contingent ways.

THINKING INSTRUMENTALLY

Kitcher is not alone in questioning the intrinsic-value-of-knowledge argument typically put forth by the scientific community. John Dewey would no doubt feel right at home with Kitcher’s treatment of scientific significance. The idea that scientific questions are dependent upon a particular social historical context harmonizes well with Dewey’s writings on the situated nature of inquiry in the last century (Dewey, 1903, 1938). In attempting to reframe science as a practical activity, I draw on Dewey’s philosophy of pragmatism, specifically his idea of instrumentalism, which posits that science, indeed all knowledge, should be thought of as a means for meeting human needs (Godfrey-Smith, 2002; Westbrook, 1991). While Kitcher’s later philosophical writings might be drawn upon in a similar way, Dewey’s work promises to be more useful not only because of his historical association with education, but also, more importantly, because of the power of the metaphor he uses: science as a tool for progress.

This perspective on knowledge assumed a prominent place in school subjects in the early decades of the 20th century as part of the wave of reform known as “progressive education” (Kliebard, 2004; Rudolph, 2005). During this period, science educators used Dewey’s ideas to leverage radical changes in science education with the goal of having students see the power science had to remake the world. The most widely adopted instructional manifestation of this was the project method of instruction, which entailed having students explore and grapple with the real problems of their home and community (Rudolph, 2003b). Common projects included things such as building a humidifier for the home during the dry winter months or assessing electricity use by local industries in the community, activities that, with
a little updating, look very similar to the engineering-inquiry and project-based science activities currently in vogue. Proponents of the latter approach have, in fact, explicitly tied their work to this earlier tradition (Barron et al., 1998). However, the error of these early reformers, I would suggest, was to cast everyday engineering and design projects as all science was, nothing more. The abstract disciplinary practices, viewed as too specialized to be of real use to the large numbers of noncollege bound students streaming into the classrooms of this period, were pushed to the margins or out of the curriculum entirely. The result was an incomplete implementation of an instrumentalist science curriculum—a curriculum truncated for ease of use.

It is, of course, easy to appreciate the instrumentalism of an efficient bridge design, for example. One can see how its physical structure solves a problem of getting things or people from here to there. What has gone unacknowledged is the instrumentalism of the content and research practices of the basic disciplines. It is these elements of institutional scientific research—of pure science—that need to be understood in an instrumental sense, as tools designed and deployed to meet human needs. This is not to say that there should be more applied science in the curriculum or that greater effort be directed toward drawing out the practical applications (either potential or actual) of abstract disciplinary knowledge. The philosophical point is to recognize that all knowledge, even the most esoteric theoretical concepts from the most uncommon fields of research, has meaning only to the extent that it provides a means to some end. As Dewey explained in his 1903 Studies in Logical Theory, “the test of validity of [an] idea is its functional or instrumental use in effecting the transition from a relatively conflicting experience to a relatively integrated one” (p. 75).

To put it more plainly, ideas provide a means for resolving unsettled situations. Successful inquiry entails the development of ideas such as new concepts and theories that resolve these situations and, in addition, provide new intellectual tools for the conduct of further inquiry. “Atoms, molecules, chemical formulae,” for example, “have primarily an intellectual value and only indirectly an empirical value,” according to Dewey. “They represent instruments for the carrying on of science” (1916, p. 222). Such intellectual constructs derive their meaning not from a direct correspondence with nature in some static, descriptive sense, but rather from the manner in which they establish relations between other constructs as part of what Dewey calls a “cognitive system” (p. 222). Knowing comes from understanding the functional role of ideas in this system and how they are designed to further our understanding of the workings of nature, of the “relations, connections, potentialities, and interactions” of the world (Godfrey-Smith, 2002, p. 32). The increased scope of human understanding that results from the development of these intellectual constructs and their relations, though perhaps not immediately applicable in the sense that a bridge is, allows us to operate more intelligently in the world—to see better the consequences of our actions.

Dewey’s instrumental view of knowledge within the relatively narrow confines of disciplinary practice was continuous with his view of science as a social and cultural activity, and this continuity was central to his broader social and philosophical agenda. The pursuit of inquiry, at all levels, was to be instrumental to human purposes, what he described as the “control of nature in the interests of mankind” (1916, p. 224). The goal of education, particularly science education, he went on to explain, was therefore to “create an intelligence pregnant with belief in the possibility of the direction of human affairs by itself” (p. 225). Science, in other words, was to serve societal needs rather than its own (Jewett, 2003; Mirowski, 2004; Rudolph, 2003a).

The recovery of Dewey’s theory of knowledge as a framework for thinking about science education opens up the potential for greater democratic participation in the areas of public life influenced by science and technology. Helping students understand science as the process “by which past experiences are purified and rendered into tools for discovery and
advance,” (1916, p. 225) in Dewey’s words, would place in the forefront of the public mind the overriding question regarding what these tools are for. It would enable the public to begin thinking about the social ends to which scientific research is directed. From this perspective, scientific questions would no longer be perceived to have only technical parameters, to be decided by those with the appropriate training and expertise, but would be considered against a broad background of social and political factors. The questions scientists ask would necessarily emerge from the questions we ask ourselves, and those would need to address Winner’s concern about how we want to exist as a society. A consequence of this instrumental view of knowledge would be, as one might expect, the breaking down of the myth of scientific self-determination—the central component of the pure science ideology that has come to infuse representations of science in science education policy documents and curriculum materials.

THE NEED FOR PUBLIC ENGAGEMENT

By now it should be clear that the argument I am making regarding the public understanding of science differs from those typically encountered in public discourse about scientific literacy. The focus in various forums has traditionally been on, among other things: the ability of science to inform decision making about societal issues related to the environment, health, energy policy, and the like; the value of scientific thinking for individuals in their daily lives, to make them intelligent consumers; or how a general understanding of science enhances our appreciation of the natural world (AAAS, 1990; DeBoer, 2000; NRC, 1996). The majority of inquiry activities developed in both commercial curricula (even those with an explicit science/society emphasis such as ChemCom and SEPUP) and by education researchers contribute to just these sorts of outcomes. In every instance, though, the influence flows outward—usually downward—from science to the public. In this model of the science/society relationship, little if anything moves upstream. While I would not deny the valuable contributions science can make in these traditional conceptions of scientific literacy (and even to some nontraditional ones [see Roth & Barton, 2004]), there remains a need to open a channel of influence back the other way, and this means coming to terms with the political economy of institutional research in the United States.

Perhaps the most obvious argument for greater public input into the scientific enterprise arises from the fact that the citizens are the ones footing the bill for the research taking place. In 2001, the last fiscal year for which there are firm numbers, the federal government allocated $3.3 billion to the National Science Foundation for research and development. As much as that may seem, it represents only a small fraction of total federal outlays for R&D in any given year in the United States. The budget of the National Institutes of Health (NIH), the agency responsible for research in the biomedical fields, is approximately six times that of NSF, and when all agencies are combined (including research conducted in the Department of Defense, NASA, the Department of Agriculture, etc.), the total swells to $79.7 billion—a level of funding that represents the culmination of years of steady increases over the last half century (Greenberg, 2001; National Science Foundation, 2004). Yet, despite this huge investment in scientific research, public input into how these funds are distributed along various lines of inquiry is essentially nonexistent. Funds at the leading research-sponsoring agencies such as NSF and NIH are allocated internally through the time-honored process of peer review (Jasanoff, 1990), and Congressional oversight of the research enterprise as a whole has been far from vigorous. As science policy analyst Daniel Greenberg recently noted, “the politics of science is governed by an autonomic acceptance of the value of science, by Democrats and Republicans alike.” The result, he goes on, has been “a bipartisan abdication of responsibility accorded to no other activity, not even
defense” (2001, p. 9). This uncritical acceptance of science extends equally to the public at large where surveys consistently show that citizens maintain a high level of esteem for and deference to basic research despite little understanding of both scientific concepts and processes (Miller, 2004). Only infrequently—in cases of true funding excess, as in the case of the superconducting supercollider, or where there is suspicion of fraud—has the public stepped in to curtail the scientific community’s political autonomy (see, for example, Greenberg, 2001; Kevles, 1997).

For the sake of comparison, one might look at the debates surrounding the recent reauthorization of the Elementary and Secondary Education Act of 2001—more commonly known as No Child Left Behind (NCLB). Though unrelated to scientific research, NCLB represents an area of public policy for which the federal government has, by definition, a highly limited role. Funding for NCLB in fiscal year 2001 was $14.2 billion and set to rise not much higher than mid-$20 billion per annum in subsequent years (Congressional Budget Office, 2001). Yet, despite the circumscribed role of the federal government in education and budget allocations that run at one fourth those for scientific R&D, public debate over the wisdom of this legislation has been vigorous and sustained as evidenced by the hundreds of pages of Congressional-hearing transcripts and countless op-ed pieces in daily newspapers across the country (see, for example, Hoff, 2004). Unfortunately, there seems to be little correlation between public expenditures and public debate related to those expenditures. It could be argued that, given the potential impact of NCLB on our systems of education and our children, it is only natural that its provisions be thoroughly examined in a range of public venues. Such a justification, though, would suggest that when it comes to science, since there is so little discussion, citizens must have few expectations that this work will have any significant influence on their day-to-day lives, despite spending $80 billion on research in any given year—a troubling conclusion to say the least, and an indication of the extent to which the public has failed for whatever reason to become invested in the oversight of scientific research and development.

My use of “the public” as a general term throughout this paper I want to be sure to note is not unproblematic. There is, of course, no single public in any society, nor any carefully cloistered group of researchers that exists in opposition to a collective public. It should be readily acknowledged that society is made up of multiple, overlapping social and political groups and constituencies the members of which span the science/society divide (see Einsiedel, 2000; Yearly, 2000). But even given this ever present fragmentation, “the public” as a conceptual category remains useful. My notion of it centers on the idea of the collective good, or commonwealth. In this sense, the public represents the whole of society over and above the specific interests of any single group. It includes those individuals who are not immediate stakeholders on a given issue, those without organized lobbies to represent them, and especially those who are least advantaged in society. The lack of input in science and technology policy issues from individuals who represent this public interest is, according to policy analyst David Guston, a “continuing problem” (1999, p. 451; see also Kitcher, 2001).

If the worst that resulted from this lack of public engagement were that scientists were left alone to pursue curiosities and interests of their own choosing, perhaps there need not be much cause for alarm. We might, of course, lament a missed opportunity to better manage our scientific capacity in the public interest. But, as we have seen from the instrumental perspective outlined earlier, science is a tool, a means to some end, and though the public has not yet fully appreciated the implications of this, other interest groups unfortunately have. Their willingness to exploit the publicly funded science research enterprise for their own purposes provides an even more compelling argument for greater democratic participation in science and technology policy.
One of the more well-documented examples of the scientific enterprise being bent to outside purposes took place during the post-World War II period from about 1945 through the early 1970s. During this time, the federal government invested heavily in scientific research. Convinced that the cutting-edge scientific advances that helped bring about the Allied victory in the war needed to be maintained into the new Cold War with the Soviet Union, federal agencies such as the Department of Defense and later NSF poured millions of dollars into basic as well as more programmatic research. The result of this national-security-based influx of money, according to leading historians of the era, was to reorient the questions and practices of science toward concerns related to the manipulation and control of complex systems that would contribute to the development of new and more effective surveillance and weapons technology. Although some scientists were well aware of the direction this government patronage was taking them, others were able to maintain an illusion of intellectual autonomy—they believed that they were simply engaged in interesting disciplinary questions of their own choosing (Forman, 1987; Leslie, 1993). The changes in the nature of scientific practice were so pervasive that they formed the basis even for the reform-based high school science materials that flowed into the nation’s schools on the heels of Sputnik in the 1960s (Rudolph, 2002, 2003a).

Closer to home, recent scholarship from the field of science studies has suggested that with the demise of the Cold War a different constellation of interests led by multinational corporations rather than the military has begun to exert its influence on the nature of knowledge production in the sciences. In the seminal book, The New Production of Knowledge, Gibbons and others describe a new mode of knowledge production that has emerged toward the end of the 20th century. This new mode is defined by, among other things, an increased emphasis on knowledge produced in the context of application. This, the authors note, has been facilitated by “the expansion of the market for knowledge and the increased marketability of science,” the driving force of which “lies in the intensification of international competition in business and industry” (Gibbons et al., 1994, p. 46; see also, Nowotny, Scott, & Gibbons, 2001). Although the specifics of their characterization as well as the totality of the historical transition they describe have been debated (see Jasanoff, 2003; Pestre, 2003), there seems to be general agreement among scholars that science has indeed become more closely wedded to industrial needs and commercial interests over the past few decades (Hagendijk, 2004; Kleinman, 2003).

This growing fusion of science and industry, which has resulted in a new hybrid some refer to as “technoscience,” has not taken place completely under the radar. In addition to its recognition by the science studies community, there have been efforts by members of the science policy community and various federal agencies to create structures to help ensure, as one policy analyst puts it, “the integrity and productivity of research” (Guston, 2000; see also Fuller, 2000; Jasanoff, 2003). These efforts represent, unfortunately, only the smallest of steps toward greater accountability, and the belief in anything more than minimal accountability is likely to be swamped by the persistent images of pure science advanced by idealistic members of the scientific elite and, in turn, the science education research community. Ultimately, the continued advocacy of the “pure science” model with its demand for political autonomy provides an open field for special interests—be they military or commercial—to bend publicly funded research to their own needs.

RECONTEXTUALIZING INQUIRY IN THE CURRICULUM

As compelling as the argument for greater public participation in science may be, reaching that goal is by no means something easily accomplished via the schools. However one looks at it, a rather formidable challenge remains, and that challenge is twofold. The first part
concerns the way inquiry activities in the science classroom might be reconceptualized and/or resituated so as to bring about student understanding of the instrumental nature of knowledge in the Deweyan sense. The second part of the challenge involves the work of putting the new curricular ideas into practice in meaningful ways. In this last section, I offer only a glimpse of the reconceptualization part of the challenge, leaving the question of implementation with its own suite of obstacles for another time and other researchers.

In a perfect world, the educational experience of students would reveal to them the fully integrated nature of all our fields of knowledge with the social and political world in which we live. Knowledge would come to be seen as part of a recursive process where human needs provide the context for the development of intellectual tools that not only meet the needs for which they were created, but also lead to understandings of the world that open up new possibilities for reflective action. An appreciation of science from this perspective would require the incorporation of significant amounts of historical, philosophical, and sociological material into the curriculum, all coordinated with the content and processes of the natural sciences. This would be accomplished ideally through interdisciplinary collaboration among the various subject-matter teachers, primarily those in the social studies and sciences—the result being an integrated curriculum in the fullest sense. A model such as this, perhaps, is too much to expect realistically—it would require teacher expertise in multiple disciplinary fields as well as a degree of institutional flexibility (for extensive curriculum revision and collaborative instruction) that seems unfeasible, if not impossible, given the present state of the schools. There are certain steps that could be taken, however, that are well within reach of the science teacher working in a typical science classroom, and I offer these as a way to begin a dialogue about how inquiry might be used to help move the public toward a greater sense of control over the direction of scientific research.

The first step takes us back to where this essay began, with the engineering tasks that have captured the lion’s share of classroom attention. I would suggest that there be continued emphasis on these sorts of inquiries in the classroom, at least in the earlier grades. As research has shown, these activities provide an important starting point for students. Their concreteness and task orientation provide the key motivational context for delving into questions about the natural world, and the material aspect, in particular, offers a natural scaffolding that enables students to see the criteria for and experience success in the inquiry process. Helping students appreciate the instrumental nature of their designs and the resulting material artifacts would need to be an explicit goal of instruction, one that, given the nature of the activities, should be easily accomplished. A crucial additional goal of instruction, however, would be to set these activities in a broader social and political context. Teachers would need to help students see not only the narrow technical aspects of the design process, but the more far-reaching social and political implications of such projects as well—teachers would need to take seriously, in other words, the cautionary language of Science for All Americans that “the results of changing the world are often complicated and unpredictable” (AAAS, 1990, p. 25) and fully explore such issues in the classroom.

Establishing a solid foundation of engineering-based inquiry experiences is important not only for accomplishing the specific learning outcomes for which they are so well suited, but also for setting clearly in the student’s mind the key connection between means and ends. The next step would be to begin the transition to abstract, disciplinary inquiries. But, rather than attempting to set these off somehow from the more concrete activities, the aim would be to draw out the instrumental commonalities between them—to use the engineering activities as an explicit model for the “pure science” inquiries. That is, students would be brought to see how questions in the disciplines emerge from human needs and social conditions in much the same way new technologies do, and not from just idle curiosity. An examination of motivations and influences, past and present, would assume a more prominent place in
the curriculum as students see and develop scientific concepts, explanations, and models as **solutions** to abstract problems. In every sense the effort would be made to frame the processes and products of inquiry as the development of intellectual tools grounded in real-world problems. It would require only small modifications in some of the more well-developed disciplinary inquiry activities described in the literature (see, for example, Cartier & Stewart, 2000; Passmore & Stewart, 2002; Sandoval & Reiser, 2004) to provide this additional contextual material and to make the necessary conceptual linkages to the more common engineering-inquiry tasks.

A final recommendation concerns the often overlooked range of methods and approaches that make up the diverse practices of science. As I have described at greater length elsewhere (Rudolph, 2000), there is hardly a uniform method by which researchers in the sciences pursue answers to their many questions. The methods, standards of evidence, norms of argumentation, technologies, even the questions themselves, vary across disciplines as well as within the range of subdisciplines in any given field (see Cartwright, 1999; Galison & Stump, 1996; Longino, 2002). The manner in which knowledge is developed in solid-state physics, for example, is vastly different from the manner in which it is developed in paleontology, and different still from the field of epidemiology. *And this would be expected from an instrumental perspective*—as the kinds of questions vary across domains so too do the means for answering them. Different intellectual tools—be they methods, theories, or what have you—are required for the different sorts of tasks that arise in dealing with the continuous range of human concerns and social needs. This plain fact suggests that students be exposed to the variety of inquiry approaches and be made aware that these approaches vary depending on the context in question and evolve over time as their efficacy is tested in practice.

A necessary casualty of this approach, though one we need not mourn, is the monolithic portrayal of science. No longer should the nature of science be compressed into the opening chapters of the book or distilled into a small set of general descriptive statements that purport to capture the essence of science in its entirety. As well meaning as such efforts have been, in their perpetuation of the pure science ideal—deliberately or not—they have done more harm than good when it comes to creating an image of science that welcomes public input into its operations. What is needed, I would argue, is for students to see and experience the methods of inquiry in all their richness and diversity as practiced in the world. As students come to appreciate the context dependency of inquiry, they will be better positioned to realize the instrumental nature of science and understand the importance of public input into the question of how the tools of science ought to be used.

**CONCLUSION**

Many questions, of course, remain. The most pressing in my mind is the question of feasibility. Can we reasonably expect the public to develop a sophisticated, instrumental view of knowledge as described by Dewey? Perhaps not. But it would not be unreasonable to think that, in drawing out the metaphor of knowledge as a tool, we can begin to help the public develop a perception of science as the means of accomplishing collective goals—goals that ought to be decided by means of deliberative democratic processes, imperfect as they are. It is not unreasonable at all to think that we can, if we choose, bring science down from its lofty perch so that it might do the work we decide needs doing.

The question of how the public participates in making those decisions is an important one. Ideally, public input would flow through elected officials who, in representative democracies, are charged with overseeing the funding and other programmatic aspects of the research agencies under their control. This approach, however, has not proven to be all that effective, at least not in the United States. The immediate problem seems to be a
structural one. In the absence of any specific institutional mechanisms for soliciting public input, it seems clear that special-interest politics prevails. In contrast to the situation in the sciences, there has been some movement to create channels through which public interests might be expressed when it comes to the implementation of new technologies or in the development of regulatory standards for certain types of industrial operations. Mechanisms that have been used include the use of public hearings, referenda, negotiated rule making, and public advisory committees in the United States, as well as focus groups and citizen’s juries, which have been tried in the United Kingdom and Germany among other places (Fiorino, 1990; Rowe & Frewer, 2000). The most promising of these various mechanisms at the moment seems to be the consensus conference, which has been institutionalized in Denmark and is beginning to make its way to other countries (Allspaw, 2004; Einsiedel, Jelsøe, & Breck, 2001). In the setting of scientific research priorities, the primary task may very well be establishing these sorts of structural mechanisms through which the interests of the lay public could be communicated. But a necessary precondition to such action is the belief that the public rightly has a voice in these matters, and this is where a broad understanding of the instrumental nature of science is key. Such an understanding would create a fundamental expectation that our governmental representatives be actively involved in setting science policy and in advocating for the development of structural mechanisms for public input. Education along these lines, thus, is the necessary first step.

In outlining the recommendations above I make no claim to providing any detailed roadmap for achieving higher levels of public participation in science policy via the schools. My goal has been, instead, to raise an important issue that has emerged from some current trends in science teaching—in this case, the increasing acceptance and utilization of engineering-inquiry tasks and the focus on the nature of science—and to point out the potential social and political consequences that might result from their confluence as they are currently constituted in the school science classroom. What I hope I have been able to do over the course of the preceding pages is to draw attention to a missing component of the relationship between institutional science and the public that supports it—the importance of public input into the direction of scientific research—and to offer a way of thinking about science that might help fill that void. Since the earliest days of mass schooling in the United States, to take the example with which I am most familiar, the contributions of science to daily life and society at large have been repeatedly emphasized (DeBoer, 1991; Montgomery, 1994); it is time we realize that the relationship is properly reciprocal and work toward making it so in practice.

REFERENCES


