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Creating the Conditions for Scientific Literacy: A Re-Examination

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This article explores the way in which scientific literacy has been defined, justified, and operationalized in current proposals for science education reform. We argue that, although the vision of scientific literacy reflected in reform proposals is broad, progressive, and inclusive, it is being implemented in narrow and conventional ways. As a consequence, we are not optimistic that current proposals will lead to a significant increase in the scientific literacy of the U. S. population. In the article, we discuss limitations in the current direction of science education reform and examine some alternate

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ways of thinking about it.

In Pursuit of Scientific Literacy

> Far too many [young Americans] emerge from the nation's elementary and secondary schools with an inadequate grounding in mathematics, science and technology. As a result, they lack sufficient knowledge to acquire the training, skills and understanding that are needed today and will be even more critical in the 21st century. (Educational Testing Service, 1988, p. 4)

United States schools are today being asked to overcome four problems thought to stand in the way of adequate preparation in science for the next century. The first problem is the apparently low level of scientific knowledge among members of the population. Miller (1991) has reported that only about 6% of American adults are knowledgeable about science facts and theories and, according to the International Association for Evaluation of Educational Achievement (1988), U. S. students' test results compare unfavorably with those of students from other countries. Second, science is said to be poorly taught in schools: Many teachers are underprepared, science activities are poorly designed, and standards for performance are too low (Aldridge, 1992). Third, the percentages of women and minorities in many science fields remain disproportionately low (American Association of University Women, 1992). Fourth, too few citizens are prepared to *use* scientific knowledge to make decisions that affect their lives (Aldridge, 1992; Berliner, 1992; Rutherford & Ahlgren, 1990). Taken together, these problems are said to diminish the country's ability to compete effectively in the global economy and to address serious social and environmental issues.

The increasing sense of alarm generated by discussion of these problems has led to the development of three national-level proposals for science education reform, including the American Association for the Advancement of Science's [AAAS] Project 2061 (AAAS, 1993; Rutherford & Ahlgren, 1990); the National Science Teachers Association's [NSTA] Project on Scope, Sequence, and Coordination of Secondary School Science (Aldridge, 1992; NSTA, 1992, 1995); and the National Research Council's [NRC] National Science Education Standards (1994).[1]

All three proposals view "scientific literacy" for all Americans as the educational solution to these problems and urge the nation to make it the overarching goal of science education reform. Although the specifics of the proposals vary somewhat, there is remarkable agreement that scientific literacy is a broad and inclusive vision, requiring considerably more than familiarity with a set of scientific facts.

AAAS's Project 2061

Initiated by AAAS in 1985 when Haley's comet most recently passed close to earth, Project 2061 was named for the year of the next return of the comet. The project's name marks the realization "that children who would live to

see the return of the Comet in 2061 would soon be starting their school years" (AAAS, 1992, p. 5) and that the reform envisioned is substantial and long-term. Project 2061 grew out of the work and recommendations of five panels, composed primarily of scientists and charged with developing recommendations for educational reform in five areas: biological and health sciences; mathematics; physical and information sciences and engineering; social and behavioral sciences; and technology. In the first phase of Project 2061, the panel reports were synthesized in the publication, *Science for All Americans* [SFAA] (Rutherford & Ahlgren, 1990), a 246-page monograph that defines scientific literacy and describes the content and processes necessary to achieve it.

SFAA defines scientific literacy as having and using knowledge of science, mathematics, and technology to make important personal and social decisions. In SFAA, Rutherford and Ahlgren write:

> Scientific literacy—which encompasses mathematics and technology as well as the natural and social sciences—has many facets. These include being familiar with the natural world and respecting its unity; being aware of some of the important ways in which mathematics, technology, and the sciences depend upon one another; understanding some of the key concepts and principles of science; having a capacity for scientific ways of thinking; knowing that science, mathematics, and technology are human enterprises; and knowing what that implies about their strengths and limitations; and being able to use scientific knowledge and ways of thinking for personal and social purposes. (1990, p. x)

While giving some attention to the contribution of scientific literacy to global competitiveness, the value of scientific literacy for humanistic and democratic purposes figures most prominently in SFAA's vision of the future:

> Science education should help students to develop the understandings and habits of mind they need to become compassionate human beings able to think for themselves and to face life head on. It should equip them also to participate thoughtfully with fellow citizens in building and protecting a society that is open, decent, and vital. (Rutherford & Ahlgren, 1990, p. v)

SFAA's commitment to scientific literacy for a more socially compassionate and responsible democracy is firmly established in the six principles it sets forth for Project 2061:

- Science can provide humanity with knowledge of the natural and social world that it needs to solve global and local problems.
- Science fosters intelligent respect of nature which will inform our decisions on the uses of technology; without that respect, we are in danger of recklessly destroying our life-support system.
- Scientific habits of mind can help people in every walk of life to deal sensibly with problems that often involve evidence, quantitative consider-

ations, logical arguments, and uncertainty.

•Technological principles give people a sound basis for assessing the use of new technologies and their implications for the environment and culture; without an understanding of those principles, people are unlikely to move beyond consideration of their own self-interest.

•Although many pressing global and local problems have technological origins, technology provides the tools for dealing with such problems and the instruments for generating, through science, crucial new knowledge; without the continuous development and creative use of new technologies, society will limit its capacity for survival and for working toward a world in which the human species is at peace with itself and its environment.

•The life-enhancing potential of science and technology cannot be realized unless the public in general comes to understand science, mathematics, and technology and to acquire scientific habits of mind; without a scientifically literate population, the outlook for a better world is not promising (Rutherford & Ahlgren, 1990, pp. vi–vii).

Ahlgren and Rutherford (1993) also provide an example of how they think a scientifically literate person might act. They anticipate that, if a scientifically literate person reads an article about the logging of a tree species, he or she would think first about how the tree species relates to other parts of the forest ecosystem and then consider possible consequences to other organisms. The authors continue with this scenario by suggesting that their literate reader, on hearing that an environmental impact assessment was being prepared, would question whether the methods used to analyze the data were appropriate and whether the interpretations might be "biased by political or economic self-interest." Finally, the literate reader would utilize "critical response skills" to judge whether the data were represented accurately and whether sound reasoning was used to draw conclusions (Ahlgren & Rutherford, 1993, p. 21).

NSTA endorsed the SFAA vision of scientific literacy. Further, NSTA's Sequence, Scope, and Coordination Project built on the foundation established by SFAA to suggest how the essential content required for scientific literacy should be taught in schools.

NSTA's Project on Scope, Sequence, and Coordination

The Project on Scope, Sequence, and Coordination of Secondary School Science (SS&C) was initiated in 1988, largely through the work of Bill Aldridge, Executive Director of NSTA. Reflecting the interests of NSTA's membership—science teachers, science education faculty, and educational administrators, rather than scientists—the purpose of SS&C was to increase levels of scientific literacy by reforming the way science is taught and science education is organized. Although SS&C does not provide its own definition of scientific literacy, the authors write that the project was designed to be "particularly compatible with the direction, tenets, and themes of ... Project

2061" (NSTA, 1992, p. 9). And like SFAA, SS&C is explicitly committed to a broad vision of scientific literacy that is valuable and useful "for all Americans." Aldridge writes:

> In this country, we teach science only to the elite, and we somehow assume that others cannot learn science....But science is needed by everyone and everyone is capable of learning and enjoying science. [All students] should stay in science until they have had several years of a good learning experience in each of well-coordinated science subjects. (1992, pp. 13–14)

As might be expected, SS&C takes more account of recent developments in learning theory and science education research than does SFAA. In fact, NSTA commissioned a 10-chapter volume of works from some of the most influential thinkers in science education (Pearsall, 1992) to serve as a philosophical and research base for SS&C. At its heart, SS&C advocates "a reform project that spaces learning over several years and moves from concrete experiences to abstraction. Using a spiral approach, the same concepts, principles, laws, and theories are studied at successively higher levels of abstraction, thus helping students to construct their own knowledge" (Aldridge, 1992, p.17).

Relying on this approach to science teaching and learning, SS&C suggests that scientific literacy as envisioned by SFAA can be achieved by everyone. Through several years of well-articulated science instruction in school, all students should be able to learn and make use of science.

NRC's National Science Education Standards

With both AAAS and NSTA at work on science education reforms, some members of the scientific community began to worry that no single voice spoke for the community as a whole (Culotta, 1994). In 1991, NSTA hosted a meeting where it was first suggested that the National Academy of Sciences and its research arm, the National Research Council, might pen a consensus set of "national standards" for science education. Because of its reputation for impartiality, NRC was seen as the organization that could garner the respect of key players in both the science and science education communities and avoid fracturing the national reform effort.

In 1994, NRC published a draft of its National Science Education Standards [NSES]. Acknowledging its debt to SFAA on its first page, NRC adopted a very similar view of scientific literacy:

> The goal of the National Science Education Standards is to create a vision for the scientifically literate person and standards for science education that, when established, would allow the vision to become a reality. The standards, founded in exemplary practice and contemporary views of learning, science, society, and schooling, will serve to guide the science education system toward its goal of a scientifically literate citizenry in productive and socially responsible ways. (NRC, 1994, p. I-1)

The authors of the NRC document also make clear their commitment to scientific literacy for all. The first principle underlying NSES reads:

> All students, regardless of gender, cultural or ethnic background, physical or learning disabilities, aspiration, or interest and motivation in science, should have the opportunity to attain higher levels of scientific literacy than they currently do. This is a principle of equity....This principle...has implications for program design and the education system, especially the allocation of resources to ensure that the standards do not exacerbate the differences...that currently exist between advantaged and disadvantaged students. (1994, pp. I-6-7)

Building on this vision of scientific literacy, NRC then makes its special contribution: the provision of *standards*. That is:

> criteria by which to judge quality of what students know and are able to do, of the science programs that provide the opportunity for students to learn science, of science teaching, of the system that supports science teachers and programs, and of assessment practices and policies....As criteria and vision, [these] science education standards [taken together] provide a concrete expression of national goals and a banner around which reformers rally. (NRC, 1994, p. I-3)

We applaud this vision of a scientifically literate citizenry in which many and diverse people act in socially compassionate and democratically responsible ways. However, we are concerned that the means being used to promote this vision are too narrowly focused. Where the vision of scientific literacy assumes a spacious view of science applications, current implementation guidelines focus narrowly on key content: specifying what facts, concepts, and forms of inquiry should be learned and how they should be taught and evaluated. While the proposals envision democratic, socially responsible uses of science (hereafter: *socially responsible science*) and participation by many and diverse people, the existing guidelines do not address obstacles known to interfere with socially responsible applications or widespread interest and access. These limitations of the current implementation plans will, we think, make achievement of "science for all Americans" difficult.[2]

Leading With Key Concepts and Practicing Science

Although all three proposals are guided by a broad vision of scientific literacy, the means set forth for achieving literacy in school are narrow. Students' knowledge of key scientific concepts is established as the most important outcome of science education reform, and opportunities to engage in the practices of "real scientists" are considered the means to that end.

A closer look at the proposals reveals that they all consist largely of discussions of the key concepts and methods that students should know.

Almost all of SFAA is devoted to descriptions of the "essential content" that students should understand and to ways of thinking about the nature of science, mathematics, and technology. The key content includes the physical setting (aspects of both physics and earth science), the living environment (life sciences/biology), the human organism (biology), the human society (social sciences), the designed world (engineering and technology), and the mathematical world. Within each category, the "big ideas" and the skills thought to have the greatest scientific significance— for example, natural selection, relativity, and plate tectonics— are stressed, and cross-cutting or unifying themes are suggested.

With the publication of *Benchmarks for Scientific Literacy* (AAAS, 1993), AAAS moved into the forefront of national science education reform efforts. Based on SFAA, the benchmarks set "threshold guidelines" for science content by grade level (i.e., standards that define the minimum content that all students should know at specific grade levels). *Benchmarks* has become a popular and widely distributed document. It is already being used by many states as a guide for their own science standards (Culotta, 1994).

In *Benchmarks*, specific concepts are organized by Grades 2, 5, 8, and 12, and the content guidelines take very specific form. One, for example, reads: After the fifth grade, students should know that "Unlike human beings, behavior in insects and many other species is determined almost entirely by biological inheritance," and, after the 12th grade, students should recognize that "the similarity of human DNA sequences and the resulting similarity in cell chemistry and anatomy identify human beings as a single species" (AAAS, 1993, p. 130).

The NSTA and NSES guidelines are similar. For example, according to NSTA: After completing physical science in Grades 6 to 8, students should have observed "the properties of different substances...[including]...color change, temperature change, production of gas or precipitate...[and] conductivity, acid/base [properties]...and relative solubility" (NSTA, 1992, pp. 53–57). NSES includes statements such as: "As a result of activity in grades K-4, all students should develop an understanding of: properties of objects and materials..." (NRC, 1994, p. V-22). By Grade 8 students should "develop an understanding of: properties and changes of properties in matter..." (p. V-76), and by Grade 12 "all students should develop an understanding of: The structure of atoms [and the] structure and properties of matter..."(p. V-130).

In addition to specifying the content with which students should be acquainted, these reform documents also include descriptions of pedagogical practices for teachers. Preferred teaching practices are those consistent with the nature of established scientific inquiry and the practices of actual scientists, including: providing opportunities to "answer the questions of science...by allowing [students] to propose and pursue the ideas, concepts and information" (NSTA, 1992, pp. 15–16); exposing students to the kinds of thought and action typical of science disciplines (Rutherford & Ahlgren, 1990, p. 188); and preparing "lessons, with an emphasis on hands-on activities," such as those performed by practicing scientists (NSTA, 1992, p. 15). NSES, which goes considerably farther than the other two documents by defining science teaching (as well as content) standards, also emphasizes an inquiry-based approach on the model of practicing scientists. For example, "Student inquiry in the science classroom ranges from engagement in concrete activities that provide a basis for observation, data collection, reflection, and analysis to inquiry within a realm of abstractions and theories. To promote inquiry, teachers ask divergent questions. Inquiry might focus on laboratory science and experimentation or on observation and analysis of events in nature; it can also include the use of literature or other media" (p. II-10).

However, specific outcome indicators or teaching strategies to develop students who can use science for "personal and social purposes" (Rutherford & Ahlgren, 1990, p. x), who can act in "socially responsible ways" (NRC, 1994, p. I-1), or who can overcome known obstacles that "exacerbate the differences in opportunities to learn that currently exist between advantaged and disadvantaged students" (NRC, 1994, p. I-7) are not included in these reform documents. The authors of these proposals seem to assume that producing citizens who can use science responsibly and including more people in science will naturally *follow from* teaching a clearly defined set of scientific principles and giving students opportunities to experience "real" science. Schools and teachers are to be held accountable for knowledge but not for its situated or future use.

Thus, while these documents suggest improvements to older forms of science education in which students were required to memorize isolated science facts, the suggested changes remain conservative. While the focus of science instruction may be altered from a set of isolated facts to a set of "key concepts," and from simplified exercises with predetermined outcomes to the practices of real scientists, science learning and instruction remain focused on the development of scientific knowledge and on the methods and habits of mind used by research scientists. Thus, the "leading goal"—the endpoint that actually serves to organize and direct plans for school reform—remains virtually unchanged: to produce more people with better knowledge of key concepts and prepared to act like "real" scientists. While the authors of these reform proposals offer slightly different approaches to pursuing this endpoint, they do not challenge the endpoint itself.

What's Wrong With This Picture?

We are not convinced that the broad vision of scientific literacy can or should be pursued in the ways set forth in the AAAS, NSTA, and NRC proposals. We disagree with the implicit assumption in the proposals that teaching students key concepts and scientific methods of inquiry will necessarily lead to socially responsible use or to a larger and more diverse citizenry who participate in discussion and debate of scientific issues.

Impediments to Socially Responsible Science Use

One reason for our concern is that no clear conceptual connections, strategies to achieve, or empirical support are offered to suggest how knowledge of science content and methods might lead to its use in socially responsible ways; the link is merely assumed. In fact, recent research based in activity theory suggests that no such automatic link should be expected. Studies of speech practices inside and outside of schools indicate that the practices of learning to talk, act, and think in terms of academic science may discourage socially helpful and responsible uses of science beyond the classroom walls.

Norris Minick, for example, suggests that a fundamental feature of Western schooling is the inculcation of speech practices that privilege existing forms of scientific rationality (1993). He argues that such speech practices serve to divorce everyday, situational concerns and commitments from successful school science.

James Wertsch (1991) provides a good illustration of how the tradition of school science discourse differs from the less literal, more situationally sensitive discourse of kindergartners. Wertsch presents the example of a little boy, Danny, who has brought a piece of lava to share at his class's show and tell (T = teacher, C1 = Danny, C2, C3, etc. = other students).

> T: Danny, please come up here with what you have. (C1, with a piece of lava in his hand, approaches T)....
> C3: (Addressed to C1:) Where did you get it?
> C1: From my mom. My mom went to the volcano and got it.
> T: And you know what? You were with her.
> C1: No I wasn't.
> T: Yes. You may have forgotten. I think you were just a little guy and you were sleeping. [Your] Mommy just told the story in the office that you were sleeping the day you went to Mount Vesuvius to get this lava rock....Is there anything you want to tell about it?...
> C1: I've always been...taking care of it.
> T: Uh hum.
> C1: It's never fallen down and broken.
> T: Uh hum. Okay. Is it rough or smooth?
> C1: Real rough...and it's sharp....
> T: Is it heavy or light?
> C1: It's heavy.

Wertsch's point is that there is a difference between the way that Danny and the teacher describe the rock. Danny describes it:

> from the perspective of how the piece of lava is related to his individual life history...and the personal characteristics of being careful and responsible....in Bourdieu's terminology,... [Danny's description: "It's never fallen down and broken"] is in the "practical schemes of classification, which are always...linked to practical contexts."

The teacher describes it from her perspective ["rough or smooth?" "heavy or light?"], which is grounded in what Bourdieu identifies as "explicit, standardized taxonomies..." (p. 115). Wertsch goes on to explain that the way this teacher and others organize their classrooms is grounded in practices that privilege one speech genre, in this case a scientific one, for describing objects and events (p. 116). Although the teacher seems sensitive to the importance of students' personal experiences ("And you know what? You were with her...."), her attempts to bring student talk and thinking into accord with established practice lead her to *write over* students' situated discourse with the discourse of scientific rationality. In order to perform the task correctly (describing the piece of lava), the students must suspend their personal experiences of the object and adopt a form of scientific discourse that ignores their knowledge of situational factors, social conventions, human interests, and others' motives (see also Minick, 1993, p. 350).

Valerie Walkerdine, in her study of the development of mathematical concepts by kindergartners (1988), further demonstrates that success in school work depends on children's ability to suspend their knowledge of reality outside of school. In Walkerdine's examples, we see the emerging differentiation of one speech genre for school from another for the home.

The difference in speech genres inside and outside of school is illustrated when the young students were asked to manipulate quantities in a school exercise—going shopping—that is intended to be familiar to them (Chapter 7). In this case, the amounts of money the children are asked to work with were much smaller than what they knew to be the actual cost of the items they were asked to buy in the exercise. Thus, to behave appropriately in this school task, the children had to suspend what they knew about money and shopping outside of the school.

The long-term outcome of this kind of separation is strikingly demonstrated in a study by Roger Säljö and Jan Wyndhamn of two groups of 15- and 16-year old Swedish students who were asked to determine how much it would cost to mail a letter which weighed between two amounts on a published postage rate table (1993). One group were students in a mathematics class; the second were students in a social studies class. Säljö and Wyndhamn found that, when the problem was presented in mathematics, students tended to solve it using a linear mathematical relationship and thus produced an answer in an amount between those listed on the rate table. When the problem was presented in social studies, students solved it by selecting the amount listed for the next highest weight. The authors write:

> But the conclusions drawn are not simply about the power of context ...a more accurate account of what the actions imply is that they do not merely reflect contextual definitions of appropriate modes of handling the problem. Rather, the participants construe wider contexts in terms of which their solutions...appear rational. (p. 336)

The students' written comments on the problems indicated that what they considered "rational" or "fair" differed by reference to two wider contexts.

In mathematics (when the problem was construed in the world of mathematics), a "rational" response was to find it "unfair" that letters of different amounts would cost the same to send—hence, the motivation to calculate a reduced rate based on a linear algorithm. In contrast, in social studies (when the problem was construed in the context of everyday life), the arbitrariness of the postage rate system was taken for granted, and "fairness" was not an issue. In this example, the potentially counterhegemonic principle of equality, learned in the course of school mathematics—and by which the students might legitimately have objected to the postal service convention and tried to change it—is not viewed by most of them as relevant to the world of their everyday practices.

Finally, in a study of engineering education at a large research university, Gary Downey and his colleagues suggest how students concerned about societal needs are either weeded out or changed by the program (Downey, Hegg, & Lucena, 1993). The authors write:

> For students who stay, interacting with the [engineering] curriculum...disciplines all to ask not "What kinds of new designs does society need?" but 'What kinds of technical problems do I want to solve?" In accepting engineering problem solving as the pathway to good design, while accumulating stories of others who "couldn't hack it and were weeded out," engineering students also learn to take problems for granted and to confine their attentions to finding solutions. (Downey et al., 1993, p. 8)

From the perspective of this body of research, attempts to make knowledge of key concepts or opportunities to practice "real science" the first priority for school science are not likely (alone) to increase the chances that students will want or be able to use academic science in their lives beyond the school. Pressures to conform to established practice—be it the discourse of science or the conventions of school—work against a simple translation from knowledge of content to social or personal use. This body of research discredits the assumption—seemingly pervasive in current reform proposals intended to increase scientific literacy—that socially responsible uses of science will follow from knowledge of key concepts and the practice of scientists as presented in schools.

Barriers to Access and Participation

Another limitation of the current reform proposals is that relatively little notice is given to the social or cultural constituents of school success that are known to block or discourage participation by more and different people in science. While some have addressed the treatment of girls and minorities in classrooms (e. g., Sadker & Sadker, 1994) and the development of "culturally relevant" curriculum units (e. g., Addison-Wesley, 1993; Bonta, 1991; Sertima, 1990), we begin with a more fundamental problem that few have taken seriously: students' lack of interest in the academic aspects of school (see also Lave, 1990).

Although teachers may accept the authority and legitimacy of what is conventionally taught in school, students often do not (Eckert, 1989; Fordham, 1993; Holland & Eisenhart, 1990; Lave, 1990; Willis, 1977). For reasons that range from boredom to opposition to hopelessness, many students do not find compelling what is defined as knowledge in school. Bored by school work, students turn to their peer groups for interesting topics and challenges.

Although the research on student peer systems does not single out science for special attention, this body of work does make clear that given the categories that matter in the informal student activity system, the social cost of participating in school learning can be high and the perceived pay-off low for many students. For the "lads" in Willis' study, the smart Black students in Fordham's study, and the disaffected "burnouts" in Eckert's, the price of doing well in school is low status in the peer group. Teaching key concepts better does not alter the social cost to students of doing well in school. If we want more young people actively engaged in school subjects, including science, we must find ways to lower the social costs and make the social benefits more meaningful to students (see also Lave, 1990).

This need seems especially acute for science education reform because science is an academic area known to discourage girls, women, and minorities. Despite 2 decades of federal programs and funding to increase the representation of women and minorities in science, there have been few changes in the percentages of underrepresented groups in science. During the past decade, the gap between girls and boys' achievement in science has increased (AAUW, 1992), and efforts to raise the numbers of minority scientists show no appreciable gains ("Gender and the Culture of Science," 1993).

The processes thought to contribute to the underrepresentation of girls, women, and minorities in science are many and varied. They include: the mass media's stereotyped portrayals of scientists as nerdy, male, and White (e.g., Nelkin, 1987); the "chilly climate" of science classrooms and degree programs (e.g., Hall & Sandler, 1982; Sadker & Sadker, 1994; Seymour & Hewitt, 1994; Tobias, 1990); the ways women and minorities are culturally produced as statistical categories of "people who leave" science and engineering programs (Downey et al., 1993); the known manipulation of scientific findings for corporate or political gain (e.g., Greider, 1992; Nelkin, 1987); and the systematic exclusion of non-Western, nonmale interests and perspectives from science disciplines (e.g., Harding, 1991; Keller, 1985).

Yet, the current reform proposals suggest that changes in the scope and depth of science content and classroom instruction can overcome these barriers. The following excerpt from SFAA is illustrative:

> The recommendations in this book apply to all students....In particular, the recommendations pertain to those who in the past have largely been bypassed in science and mathematics education: ethnic and language minorities and girls....We are convinced that—given clear goals, the right resources, and good teaching throughout 13 years of school—essentially all students...will be able to reach all of the recommended learning goals by the time they graduate from high school. (Rutherford & Ahlgren, 1990, p. x–xi)

In essence, the reform proposals suggest that better teaching, higher standards, and sensitivity to student differences can overcome long-standing obstacles to participation. The proposals take no account of feminist or minority critiques of science.

Over a decade ago, Evelyn Fox Keller (1982) argued that feminist and minority critiques of science could be arranged on a 4-point continuum from liberal to radical. The liberal critique suggests that women and minorities are underrepresented in science because they have not been treated in the same encouraging way as have men. The liberal solution is to find ways for girls, women, and minorities to gain equal access to the range and depth of positive science experiences already available to boys and men.

This is the approach taken by AAAS, NSTA, and NRC. An excerpt from NSES provides a case in point. The second underlying principle of NSES (after the principle of equity) states: "All students will learn all science in the content standards" (p. I-7). Later in the document, NRC explains what teachers should do to meet this principle:

> Teachers of science orchestrate their classes so that all have equal opportunities to participate in learning activities. Students with physical disabilities might require modified equipment; students with limited English ability might need to be encouraged to use their own language as well as English...; students with learning disabilities might need more time to complete science activities. (p. II-13)

Yet, in Keller's scheme, the liberal approach is the most conservative one.

A second, more radical, level of critique suggests that the predominance of men in the sciences has led to a bias in the choice and definition of the problems scientists have addressed. For example, in the health sciences, contraception, until very recently, has received little attention, and the focus of the work (generally by male researchers) has been on contraceptive techniques and devices to be used by women. From this perspective, science discourages women and minorities because it does not seem interested in or relevant to the topics that concern them.

The third and fourth levels of critique question the fundamental processes and foundations of science. The third level suggests the possibility of bias in the design and interpretation of research. The study of primatology provides a good example (e.g., Haraway, 1989). When White males were the only primate researchers, they viewed the primate troop, composed of a single adult male with several females and young, as a harem and interpreted their data from the assumption that the male was the troop leader. Years of field observation studies by female researchers (e.g., Jane Goodall and Diane Fossey) have convinced primatologists that the social organization of some primate troops is better explained by matriarchy: Males are used by females as a resource for sperm, protection, and companionship. The possibility of this type of bias suggests that science discourages women and minorities because its theoretical stances tend to privilege White male standpoints.

The most radical level of the critique of science offered by Keller is a challenge to the truth and warrant of the conclusions of natural science on the grounds that they reflect a preference for objectivist, rationalistic, and detached justifications more often associated with men than women. In contrast, some social scientists and a few natural scientists, notably Barbara McClintock in her research on corn plants, base the warrant of their conclusions on long-term, sympathetic identification or participation with the subjects of the research (see also Heshusius, 1994; Keller, 1985). The authority of long-term, sympathetic participation is more often associated with women than men. From this perspective, women are discouraged from pursuing science because the standards of warrant women prefer are so often disparaged or ignored.

The means of lowering barriers for women and minorities suggested by AAAS, NSTA, and NRC address the type of bias identified in Keller's first and most conservative critique only. The changes are all "compensatory" strategies (Howe, 1993) to provide access to science for previously underrepresented groups. Compensatory strategies treat disadvantaged persons according to their special needs, but they do so in a way that requires the disadvantaged to measure up to a standard already set by the advantaged group. The content and modes of inquiry in the science activities of Project 2061, SS&C, and NSES are not open to the kind of revisions that Keller's other three critiques suggest. In all three proposals, the nature of the science to be learned is specifically described in the content standards, and they contain, almost exclusively, the content and methods of conventional science.

If we are serious about increasing the numbers and kinds of people in science, neither outcome measures that focus on key concepts nor further attempts to encourage the practice of "real science" appear to be promising directions to take. Given the existing low level of student interest in academic work and the findings of feminists and others about the biases inherent in conventional science, efforts to involve more people, especially women and minorities, in science may fail precisely because conventional science and modes of practicing it are stressed in school. Without considering questions about the nature of science itself, such as those raised by Keller, it seems unlikely that improving the content of science education will help to attract or retain more women or minorities.

Contributions From Constructivism to the Direction of Science Education Reform

Given the research and scholarship discussed in the previous section, why have science education reforms that focus on content and traditional forms

of scientific inquiry received so much attention? One answer surely lies in the expediency of such an approach given the national political climate of the late 1980s and early 1990s. Another may lie in the forceful influence of scientists on the reform agenda and in the politics of science in the U. S. We do not have the space to pursue either angle here (but see Apple, 1992, Fenstermacher, 1994, for the first; Bybee & DeBoer, 1994, Culotta, 1994, for the second). We turn to another answer that more directly involves educators and educational researchers: The focus on content and scientific inquiry has been supported by particular readings of constructivist learning theory.

More than any other theoretical development, constructivism has been used to justify current proposals for science education reform. Generally defined as a collection of theoretical approaches sharing the idea that knowledge, beliefs, values, and meaningful behaviors are constructed in experience, constructivism has become more and more a source of ideas on which to base research and public policy in science education over the past several years. Many in the education community—both researchers and practitioners—have contributed to the development of current reform proposals and are committed to them because they promise that a constructivist view of learning will guide science education reform. Although we consider constructivism an important and powerful theoretical perspective, we think it is used in the science reform documents in a narrow way that further diverts attention from socially responsible science use and wider access.

It is quite clear that the science education reform documents use the language of constructivist learning theory. In SFAA, we read:

> People have to construct their own meaning regardless of how clearly teachers or books tell them things;...young people can learn most readily about things that are tangible and directly accessible to their senses;...[and] concrete experiences are most effective...when they occur in the context of some relevant conceptual structure. (Rutherford & Ahlgren, 1990, p. 186)

In discussing SS&C, Aldridge writes:

> evidence on learning shows that people *construct* their own knowledge....It cannot be transmitted to them. And regardless of the quality of the presentation, this transmission mode will not produce the necessary kind of learning [i. e., for understanding]. (Aldridge, 1992, p. 16)

> [Instead] concepts should be derived from experience, with students acquiring a concept from experience with [it] in different contexts. Once concepts are established, they should be symbolized and those symbols related to each other. These more complex relationships should be constructed over time. (Aldridge, 1992, p. 14)

And NRC, in NSES, states: "In learning science, students describe objects and events, ask questions, construct explanations of natural phenomena, test those explanations in many different ways, and communicate their ideas to others" (p. I-8).

Reformers have relied on two versions of constructivism to support their positions on knowledge and learning. These versions can be referred to as Piagetian and radical constructivism. A third version of constructivism, sociohistorical constructivism (sometimes called *activity theory*), has been virtually ignored in the science education reform proposals. As used by educational researchers, Piagetian and radical constructivism locate motivation to learn in individuals and the material (or content); sociohistorical constructivism, in contrast, locates motivation more broadly: in the structuring resources (nature of the work to complete, appropriate discourses, relevant goals) and opportunities to form mature identities. This difference has interesting implications for the direction of science education reform.

Piagetian Constructivism

Piagetian constructivism (as used by educators) focuses on the cognitive developmental processes by which individuals abstract conceptual understanding from experience. Relying on Piaget's theory of cognitive development, these constructivists take the position that conceptual development occurs through individual mental adaptation— that is, as emergent ideas are tested and found to work to make sense of one's surroundings (Fosnot, 1989).

Efforts to improve teaching based on this perspective center on applications of Piagetian processes of assimilation and accommodation within a model that:

> emphasizes that learners need to be actively involved, to reflect on their learning and make inferences, and to experience cognitive conflict (Fosnot, 1989, p. 3)....A constructivist takes the position that the learner must have experience with hypothesizing and predicting, manipulating objects, posing questions, researching answers, imagining, investigating, and inventing, in order for new constructions to be developed. (Fosnot, 1989, p. 20)

Despite the attention to students' active participation in learning, the ultimate goal of educators holding this view of constructivism is to bring students' emergent understandings into accord with established thinking and practice in the academic disciplines. As described by Hewson and Hewson (1988):

> learners actively construct their own knowledge....They do this by using their existing knowledge to interpret new information in ways that make sense to them. They build their own conceptual structures in which they incorporate empirical phenomena, concepts, and explanatory patterns. This means that if they are to accept the scientists' interpretation of the phenomena, they might have to change their minds in ways which may well require restructuring of their existing conceptions, rather than simply adding new knowledge. (p. 597)

Much of the science education research in this tradition has focused on identifying the understandings that students bring to school—often referred to as "misconceptions" or "naive conceptions"—and testing instructional strategies for challenging these conceptions such that they are replaced by accepted understandings of rationality and objectivity (e.g., Carey, 1985; Minstrell, 1982; Posner, Strike, Hewson, & Hertzog, 1982).

Radical Constructivism

Radical[5] constructivism is defined among educators by the position that knowledge is constructed and legitimated whenever it makes sense to an individual in a particular experiential context. Proponents of this perspective explain their approach as follows:

> The emphasis in learning is not on the correspondence with an external authority but the construction by the learner of schemes which are coherent and useful to [him or her]. (Driver, 1988, p. 135)

> [Radical constructivism shifts] the emphasis from the student's "correct" replication of what the teacher [or any authority] does, to the student's successful organization of his or her *own* experiences. (von Glasersfeld, 1983, p. 51)

> Once this way of thinking takes root, it changes the teacher's view of "problems" and their solutions. No longer would it be possible to cling to the notion that a given task has one solution and only one way of arriving at it. The teacher would come to realize that what he or she presents as a "problem" may be seen differently by the student....[Thus] constructivist teachers would tend to explore how students see the problem and why their path towards a solution seemed promising to *them*. (von Glasersfeld, 1989, pp. 136–137).

Anthony Lorsbach and Ken Tobin suggest the implications for teaching:

> teachers often use problem-solving as a learning strategy; learning is defined as adaptations made to fit the world of experience. To learn, a person's existing conceptions of the world must be unreliable or unworkable. Non-functioning conceptions spur the individual to try to make sense out of the situation based on what is already known....[O]ther people are part of the world we experience.... Interactions with others can cause perturbations, and, in resolving

> these perturbations, individuals adapt concepts to fit their new [but not necessarily the established scientific] experiential world. (1993, p.2)

Unlike Piagetian constructivism, the ultimate goal is for students to create sensible explanations for previously anomalous phenomena. Research in science education derived from this tradition has focused on the ways in which students collaborate with peers or the teacher to construct their own understandings (e.g., Driver, 1989; Roschelle, 1991; Roth & Roychoudhury, 1992; Wheatley, 1991). Much of this work emphasizes the idea that, as students need time and opportunities to construct their own understandings, the teachers' job is to "allocate tasks to be completed" (Tobin, 1990, p. 405), rather than to bring students' naive understandings into line with currently accepted scientific conceptions.

In summary, in these two perspectives, individuals are viewed as autonomous actors who learn by building up their own understandings of their world in their heads (see also Matthews, 1993). Educational change efforts inspired by these versions of constructivism direct attention to the dyadic or small-group teaching and learning practices that occur inside classrooms. Teachers are encouraged to provide children with interesting, content-rich opportunities to explore, to make their own sense of the environment, to express their understandings, and to face challenges from other people and anomalous observations. These two views of the teaching and learning process stand in sharp contrast to traditional educational models in which the teacher dispenses information and children passively acquire what the teacher presents.

The two versions of constructivism differ primarily with respect to endpoint emphasis. Piagetian constructivists, at least as exemplified in science education research, tend to assume that the teaching and learning process is directed toward producing students who, through their own activity, come to share established scientific knowledge. Radical constructivists have a more open-ended view of an endpoint in which students have developed and can defend adaptive scientific understandings that may or may not correspond to established views.

Sociohistorical Constructivism

In neither of these two constructivist frames for addressing science education is serious attention given to the structural characteristics of schooling or science, the social organization of instruction, the tools of language and inquiry that motivate what teachers and students do in school and in science, or the identities that school science inspires. In other words, neither theoretical variant challenges the collective means of viewing and manipulating the world that preserve the status quo in schools or in science. From the perspective of radical constructivism, students may come to hold novel or idiosyncratic understandings of scientific phenomena—as long as these understandings work for the individual in coping with his or her world—but students are unlikely ever to come to hold collective understandings that differ from or challenge the way science as a field or profession is generally organized in schools or outside. For example, nothing in Piagetian or radical constructivism suggests how constructivist-oriented teachers should handle controversies about "good" uses of science, how principles of "equality" learned in mathematics classes might be applied outside the classroom, how the social meaning of being a "Black man" might correspond with the social meaning of being a "scientist," or how male biases in scientific language and inquiry might be altered.

Sociohistorical constructivism focuses squarely on these wider issues and argues that they *constitute*, or form (rather than *affect*), what teachers and students do and learn at school. As such, this version of constructivism is a lens for thinking differently about the current reform proposals and how scientific literacy might be pursued.

Sociohistorical constructivism emphasizes that knowledge construction, in addition to being active and adaptive work on the part of individuals, is historically and culturally constituted. Here, attention is directed to *external* forces that make or produce the ways in which people think, feel, and act. James Wertsch and colleagues write:

> A fundamental claim of this school is that cognitive development is explained largely by what Leontiev (1972) termed the "appropriation" of socioculturally evolved means of mediation and modes of activity (Wertsch, Minick, & Arns, 1984, p. 152)...."One must seek the origins of conscious activity and 'categorical' behavior not in the recesses of the human brain or in the depths of the spirit, but in the external conditions of life. Above all, this means that one must seek these origins in the external processes of social life, in the social and historical forms of human existence." (Luria, quoted in Wertsch et al., p. 153)

Although these "external processes of social life" have their origins in history and large social phenomena, they are thought to be instantiated in the activities of institutions, such as schools. "Activity" becomes the central unit of analysis, and, for this reason, sociohistorical constructivism is commonly referred to as *activity theory* (after Leontiev's theory of activity, 1978). In this perspective, "activity" can be generally defined as the unit of life in which social and material conditions are mediated by mental reflection (Wertsch et al., p. 154, after Leontiev). Wertsch et al. write: "Leontiev defined activity as 'the unit of life that is mediated by mental reflection. The real function of the unit is to orient the subject in the world of objects'" (Wertsch et al., p. 154).

Because of the Marxist roots in activity theory (and in all versions of constructivism linked to Soviet psychologists of the 1920s and 1930s), the "mental reflection" that "orients the subject" refers to something quite different from what many educators or psychologists assume. Following Leontiev (1981), mental reflection derives from labor—that is, from work (of which activity is the basic unit)—from the process, both material and intellectual, of making a product. Put another way: As individuals learn to produce (to work), they become oriented to objects in their world, and thus, they learn to think. Individuals do not come to know these objects in some "natural" or objectively real sense, rather individuals come to know "mediated" objects—that is, known by their placement and use in labor, in the making of products, in the doing of tasks to accomplish some end.

It is in this conceptual context that Vygotsky's famous claim that development "appears twice, or on two planes...[first] between people as an interpsychological category, and then within the child as an intrapsychological category" (Vygotsky, cited in Wertsch, 1991, p. 26) should be understood. First and interpsychologically, individuals learn to know in and through social forms that are not simply aggregates of people apperceiving their environment. These social forms are activities and mediational devices sedimented from history and culture and indelibly marked by them.

A key insight from activity theory research is that products (or endpoints) are *built into* (anticipated or implicated in) an activity's "mediational devices"—for example, its speech genres, divisions of labor, work procedures, and technological tools,[4] that individuals use as they participate in activities (see, e.g., Hutchins, 1993; Scribner, 1984; Wertsch, 1991). By "taking up" or using the mediational devices in activity, individuals come to "know" *in the way of* the (historic structural and cultural) motives, products, or endpoint of the activity.

One mediational device with special importance for motivation to learn is identity—the meaning of self in context. In sociohistorical constructivism, motivation to learn depends on the availability of an "authentic" context—that is, a context in which an "identity encompass[es] the activity in which newcomers participate and [a] field of mature practice [exists] for what is being learned" (Lave & Wenger, 1991, p. 112). Identities are mediational forms that enable novices to think about themselves and where they are headed in the future: their *possible selves* (Markus & Nurius, 1987). The promise of a mature identity in an actual field of practice is what motivates the desire to learn. Without this promise and genuine opportunities to pursue it, learning will be superficial and, at its root, coerced by others (Lave & Wenger, 1991).

This view of motivation differs substantially from the one used in the reform proposals and in Piagetian or radical constructivism, as the following statement by Aldridge suggests:

> A fundamental requirement for an effective science education reform effort is to provide the necessary student motivation....Hands-on experience with phenomena before terms are defined or concepts named is motivating. Sequencing over time at successively higher levels of abstraction provides a familiar experience that is motivating. Challenging student preconceptions by providing experiences for which their metaphors must be adapted (in the direction of those used by scientists) is also motivating. Relevance [i.e., a field of mature practice] may well be a key component of good motivation, but practical problems are often very complex, and variables identified are almost impossible to isolate or control. Student interest in personal or societal problems is highly individual, and group learning in a classroom setting appears very difficult. The range of problems, issues, and concerns could easily spread into areas beyond the natural sciences, leading to a blurring of distinctions in areas where such distinctions are very important, such as between science and technology, or between science and philosophy and religion. (1992, p. 18)

To summarize, activity theorists would expect that knowledge of science is taken up by students in the "ways of getting the work of school science done" and in the "ways of envisioning self" in the process—that is, in the ways of doing the work, categorizing the laborers, using the tools, and identifying one's place and prospects toward some end.

In this light, the changes outlined by AAAS, NSTA, and NRC are minor indeed. The work of science in school remains virtually unchanged: to acquire the tenets of established science and to ignore or put off their use in real-world or "mature" contexts. The basic conceptual and methodological tools of science inquiry have not been affected. The ways of talking about the characteristics of good scientists and distinguishing them from others are unaltered. No new ways of talking about how or why women and minorities are good at science are offered. No valued image of a mature, science practitioner, who is *not* a scientist, has been developed. In other words, the *means* of pursuing scientific literacy suggested by current reforms do not seem to anticipate diverse groups of people who put science to use in broader, different, or socially responsible ways.

From the perspective of activity theory, different mediational tasks, tools, and identities must be found or developed, before a reform such as scientific literacy (broadly construed) is likely. Alternate activity systems must be found or built that instantiate the broad vision of scientific literacy in the mediational devices with which students work and thus come to know and learn. In the next section, we consider a few activity settings in which some of these conditions are realized.

Alternate Routes to Scientific Literacy

As stated earlier in this article, we agree with the broad vision of scientific literacy represented in the AAAS, NSTA, and NRC documents. What concerns us are the conventional content-driven *means* which are being formalized to pursue this vision. As Robert Donmoyer has recently pointed out (1995), decisions about means are the hard choices of public policy. Visions or ends can be made broad and inclusive. They often are written to appeal to constituencies with numerous and varied perspectives. In consequence, they tend to be general and vague. Decisions about means, in contrast, require taking a position on priorities and making trade-offs. Those who promote content-driven means have taken one position. We take another.

Retaining the Ends of "Scientific Literacy"

Some have suggested that the first step toward an alternative to content-driven reform is to replace *scientific literacy* with another term (image). There are several reasons why we think scientific literacy should remain the abstract image that leads science education reform. First, although there is no single definition of *literacy*, scholars in various fields suggest its importance and appropriateness as an overarching goal for education (e.g., Apple, 1993; Ferdman, 1990; Heath, 1983; Lankshear & Lawler, 1987; Scribner, 1986). Some time ago, Sylvia Scribner (1986) suggested that three different metaphors could capture the central meanings of literacy. The first metaphor, literacy as adaptation, captures functional literacy—that is, the proficiencies necessary for effective performance in a range of settings. The second metaphor, literacy as power, refers to literacies that enable groups to claim a place and voice in the world. The third metaphor, literacy as a state of grace, represents the self-enhancing potential of literacy—that is, the special virtues attributed to a literate person. At the end of her article, Scribner suggests that "ideal" literacy, for the purpose of setting long-range social and educational goals, "is simultaneously adaptive, socially empowering, and self-enhancing" (p. 19). From this perspective, scientific literacy is properly a broad image that sets a high and desirable ideal standard for education.

In Scribner's image, literacy implies no fixed essence and is not the special province of only some groups. Rather, literacy is a social achievement that varies and evolves in space, time, and social purposes; "what qualifies as individual literacy varies with them" (Scribner, 1986, pp. 8–9; see also Ferdman, 1990).

A final reason to retain scientific literacy is that, regardless of definition or metaphor, the image of literacy suggests the ability to act (not merely to know) and the promise of widespread use. Literate persons not only possess knowledge, but they use their knowledge in varied contexts and for worthwhile purposes.

In reasserting this broad image of scientific literacy as an ideal standard for education, we wish to distance ourselves from those such as E. D. Hirsch (1988) who would define *cultural literacy* as a list of facts and concepts that every citizen should know. In discussing science education for cultural literacy, for example, Hirsch argues that scientific facts and principles should be the priority:

> For example, in the debate over the Strategic Defense Initiative ("StarWars"), it is a serious error to expect literate citizens...to make highly technical decisions. Instead, their education should simply have provided them with the general facts and principles needed to understand the terms of the debate—how a satellite works, what a laser is and can do, and under what conditions such a system would be likely to succeed or fail....(p. 150)

As should be clear by now, we (and the authors of the major reform proposals) intend a broader image of scientific literacy than Hirsch. The question then is by what means should educators try to pursue this broad image?

The Search for Alternate Means

Given our understanding of activity theory, we decided to undertake a search for science activity settings in which the leading outcomes seemed to be different from those stressed in the current reforms. Specifically, we sought settings where socially responsible use and broader involvement were the explicit goals. We speculated that if we could find such settings, we also might discover alternate mediational devices—including work demands, tool requirements, ways of talking, divisions of labor, and expectations about mature identities—for knowing and learning science. Because a criticism of such settings could be that they shortchange content—particularly, content that does not arise directly from experience or common sense—we were especially interested in finding settings with evidence of strong science content. Eventually, we hoped to select a small sample of these settings for in-depth investigations of context, science, social relationships, and learning.

Before we could begin our search, we needed some way to operationalize "socially responsible use" and "broad involvement." Clearly, there are many ways we might have proceeded. In our case, for broad involvement, we decided to look for places that included uncharacteristically high percentages of women. Our definition of socially responsible science requires a bit more elaboration.

Socially Responsible Science Use

In our everyday lives, all of us are called on to undertake actions that not only affect us personally but affect our communities and the environment. These actions, such as making decisions about where and how to live, participating in local-issue politics, and deliberating about land and resource use, often include the need to understand and apply knowledge about the nature and value of science. But these actions also involve more than scientific knowledge. As Fenstermacher reminds us, knowledge of content amounts to little unless it can be joined with the "understandings and insights needed to be more caring of one another, more reasonable in our relationships with one another, [and] more morally discerning in our conduct as human beings" (1994, p. 22).[5] Minimally then, using science in socially responsible ways would seem to entail: (a) understanding how science-related actions impact the individuals who engage in them; (b) understanding the impact of decisions on others, the environment, and the future; (c) understanding the relevant science content and methods; and (d) understanding the advantages and the limitations of a scientific approach.[6] We took these components to be the indicators of socially responsible science for our search.

Models of Alternate Activities

The alternate settings we found will be the subject of a forthcoming book (Eisenhart & Finkel, 1996). Here, we briefly consider three examples. One program, called Foundations of Science or FOS, is being developed by three science teachers at a midwestern public alternative high school (Huebel-Drake, Finkel, Stern, & Mouradian, 1995). Working closely with researchers from the University of Michigan[7] and modeling their initial project on the Global Rivers Environmental Education Network (GREEN) Field Manual for Water Quality Monitoring (Mitchell & Stapp, 1994; Susskind & Finkel, 1995), the three teachers have created a multigrade context in which students work with community members to investigate and take action on local environmental issues. In this program, students and teachers have adopted a local creek, where they spend most of a year collecting and analyzing the macroinvertebrates that inhabit the creek, describing and evaluating the habitats that exist within the creek, and analyzing and quantifying the quality of the creek's water. Students write and revise a series of reports on their findings, and they present their analyses to members of the local environmental agency which monitors other parts of the same watershed. In addition, students' presentations are aired on a local cable television station.

"Socially responsible science" is a primary goal of the FOS curriculum. The teachers want their students to develop a sense of science as something that is important in their lives and their community outside of school. One of the three teachers (interviewed for a research project conducted by Finkel in 1994)[8] described his goal as helping students become citizens, who would be able to ask and answer questions about science and scientific knowledge in their daily lives. He wanted the students to develop a "questioning" attitude and to be willing to "sit back and...judge the data...using a scientific yardstick." He also expected that the creek monitoring project would encourage students to think more carefully about their local surroundings—both its habitats and people—as they "internalized" ideas about water in the community.

Students in FOS were continually made aware, by their teachers and through the involvement and interest in their work by members of their community, of the relevance of their work to themselves and others in that community. Students knew that no one else was monitoring the creek that they were studying and that their analyses would be used by local officials. Members of the local environmental agency came to the classroom where

they listened and responded to student presentations of their results. The adults asked questions about the results based on their wider experience with the community and its watershed.

Through their work in this activity, the students seem to be developing a sense of themselves (an identity) as concerned citizens who can use scientific information to understand local environmental issues. As the following story indicates, students' involvement as concerned, participating citizens extended beyond the school year and school assignments; it also required them to develop considerable scientific knowledge.

Toward the end of the 1994–1995 school year, the local public transportation authority contacted the FOS teachers with a plea: A pond located on their property was in poor health, stagnant and smelly; was there anything that the FOS students could do to help? The agency had initially hired an environmental consulting firm to conduct a series of tests, and they wanted a second opinion. The three teachers put out a request for interested students, and a group of eight students and two teachers visited the pond. In the words of the student authors: "We went out to the pond...[and] performed the same tests as [the consulting firm], plus a few extras. We read [the consulting firm's report] and made a few of our own observations." In addition, students designed a survey to discover how employees of the agency wanted to use the site, developed a restoration plan which reflected the response that "people wanted a more natural look to the area...[and thought] it should be clean enough to have picnic tables...," and offered to continue working at the site. The transit authority accepted the students' offer to help, and, over the summer, student volunteers began their restoration project.

The students' restoration plan included three suggestions that could be undertaken to improve pond water quality. These suggestions included: (a) monthly testing of pond water during the summer when algae growth is the greatest; (b) reducing the use of fertilizers on the lawn that surrounds the pond; and (c) introducing biological controls that would make use of the excess nutrients promoting algae growth. Their suggestions were based on a series of chemical tests (to determine dissolved oxygen, fecal coliform, pH, biochemical oxygen demand, total phosphate, and nitrates), and physical tests (to determine turbidity and total solids) conducted by the students.

In order to interpret the results of these tests and to develop the restoration plan, students had to be familiar with scientific concepts including the connection between oxygen, photosynthesis, and plant growth; sources of fecal coliform in fresh water systems; the relationship between fecal coliform and pathogenic organisms; the link between oxygen concentration and bacterial growth; the meaning of the pH scale; and the sources and effects of nitrates and phosphates in fresh water systems.

Of the eight students who volunteered to participate in the project, five were girls. All four principal authors of the restoration plan were girls. Finkel's observations of two of the girls suggested that prior to their participation in FOS (and even at several points during the academic year) these girls were not interested in science. In interviews conducted in September, Angela (a pseudonym), a principal author of the restoration plan, indicated her distaste for science, commenting that science in school and science teachers were "boring" and that science had no impact on her outside of school. In early February, Angela continued to indicate her aversion to science, responding to positive feedback in class with "Yeah, but I still hate science." It was not until an interview conducted in May that Angela expressed any positive attitude toward science, describing the use of a computer program (designed to help students model the creek ecosystem they studied) as "interesting" and something that "she understood...a lot better." Shortly after this interview, Angela volunteered to work on the transit authority project. When one of the researchers ran into Angela during the summer, her excitement over her work on this project was clear. The following is from the field notes recording that meeting:

> [Angela]...told me she was expecting a phone call from [one of her teachers]... about the [transit authority project]. She was very excited about the report she helped write (asked me if I'd read it yet) and was also anxious to get the phone call about their next task. She was very excited about going back to do some follow-up water testing.

Angela's excitement and enthusiasm for this project was a remarkable change from her earlier pronouncements that she didn't like science and found it irrelevant to her life outside of school.

Although FOS is only one program and our data about it are not fully analyzed, we think that its activities connect students to the community, to other people, and to science in ways distinctly different from those of conventional school science. The work demands in FOS require students to situate their tasks in a local community context, establish relationships with experts and community members beyond the school, and develop ways of talking and writing that are useful and persuasive in a real-world setting. In this motivational context, the students also cultivate understandings of scientific concepts and ideas that are both locally useful and technically sophisticated. Girls, historically underrepresented in science, seem to find this activity especially motivating. Given the promise of FOS for scientific literacy, we think it and settings like it deserve much more research attention.

As mentioned earlier, the FOS project was initially inspired by The Global Rivers Environmental Education Network (GREEN). Other curricula based on GREEN might serve as additional settings for investigation. While GREEN is not primarily a curriculum development consortium, teachers and other science and environmental educators who work with GREEN share the goals of socially responsible science and broader involvement. In particular, GREEN strives to help teachers and students develop: "attitudes, knowledge, and skills essential in helping to maintain and improve the water quality of our rivers throughout the world....The instructional model...encourages the integration of ecological, economic, political, and social disciplines essential to the resolution of critical water quality issues facing our waterways" (Mitchell & Stapp, 1994, p. 6).

A central tenet of GREEN's approach to environmental education is the involvement of teachers and students with community organizations and the development and initiation of action-taking projects by students. Regarding outcomes for students in particular, GREEN projects anticipate: "After involvement in the project, students should be able to understand the significance of different water quality parameters to overall water quality. They should also be able to integrate socio-political factors into their understanding of water quality and have acquired the skills and self-esteem necessary for effective participation in their communities" (Mitchell & Stapp, 1994, p. 176).[9]

Other issues such as public health, genetic engineering, nuclear energy, and economic growth—as they are formulated and debated in local events and circumstances—also could be focal points of school science. In ways similar to FOS and GREEN, students might be actively involved in helping to address local issues in ways that require them to develop sophisticated scientific or technical knowledge.[10]

In our search, we also were interested in sites of socially responsible science and broader involvement outside of schools. We anticipated that such sites would suggest a wider range of possible scientist identities and means of supporting them than do laboratories or research centers, the sites associated with conventional careers in science. We found two contexts in which the goals of socially responsible science and broader involvement were strongly stated: environmental action groups and environmental work places. One work place, which we call *CC*, was the site of an 18-month study conducted by Eisenhart.[11]

CC is the state office of a nonprofit conservation corporation devoted to preserving the state's biodiversity by protecting land where species, habitats, or ecological processes are threatened. At the most general level of social organization, CC's work is divided into two areas: the science area, including biologists, botanists, and ecologists, and the business area, including lawyers, fund-raisers, and administrators. The scientific work includes identifying endangered species; collecting, mapping, and analyzing data about plant and wildlife species—their habitats, distributions, threats, and requirements; analyzing ecological processes; and designing means for protecting and maintaining conservation sites. A management plan for one year of only one of CC's 21 conservation sites (statewide) includes:

> Map the distribution of the two highly-ranked plant associations; identify and map other plant communities; initiate inventory of vascular plants; initiate inventories of butterflies and moths, reptiles,

> and amphibians; inventory...for spotted owls; locate and map raptor nests; initiate breeding bird atlas program; continue mammal inventory; ...[Determine] how much public visitation can be conducted without affecting wildlife. [Determine] how much grazing (if any) should be allowed. [Determine whether] controlled burns [are] a good idea.

An even more extensive and ambitious management plan identifies the work necessary to conserve riparian forest, shrubland, and wetland communities in areas encompassing a third of the state. This plan, prepared by CC staffers with the assistance of a few outside experts (such as a water attorney), includes scientific analyses, protection recommendations, and specific CC tasks regarding river hydrology; geomorphology; forest regeneration; wetland restoration; water quality; endangered species protection; migratory bird corridors; threats from dams, reservoirs, agriculture, mining, tourism, highways, and residences; non-native species introductions; and changing plant, animal, and water dynamics.

Once plans have been developed, the business people take over to negotiate the land deals and raise the financial and community support necessary for the protection project. During the study, about 22 people, mostly scientists and fundraisers, worked at CC. There were about equal numbers of women and men and a roughly equal distribution of high status positions by gender (for further discussion of the impressive representation of women scientists in CC, see Eisenhart, 1994).

CC activities seem to connect participants to the community and to science in very different ways from the contexts of laboratory science (Latour &Woolgar, 1979; Nespor, 1994; Traweek, 1988). CC's work demands, similar to those in FOS, require employees to situate their science in the context of various local issues and establish working relationships with experts and community members. These situational conditions enable a specific form of scientific discourse at CC, even among the nonscientists. The following excerpt is an example of this discourse; it was taken from an interview with a woman employee—not a scientist—who was discussing a parcel of land that the corporation was considering for protection:

> It's a very high quality ephemeral wetlands site, probably the best in the Valley. In general..., the wetlands [there] have been drastically altered. What were once shallow wetlands have been drained for agricultural uses, and there's been a lot of deep water added (by the Fish and Wildlife Dept.) to make duck habitat. This has disturbed the shallow playa lakes that serve as habitat for many shorebirds, such as sandhill cranes.
>
> We knew from the beginning that the Bureau of Land Reclamation's pumping project was right next door. And, there are a lot of water issues in the Valley—arguments between farmers and developers—that have been on-going for a long time. In a sense "water" is THE

> issue in the Valley. And especially around the ephemeral wetlands which hardly exist at all there any more.
>
> Then the serious water questions came up. There were questions about whether the deep and shallow aquifers were connected, what the effects of the Bureau's project would be; these were complicated hydrologic questions. We had hired a hydrologist to do a literature study—examine the existing data—and interviews with various people and agencies in the Valley. Her report was due in January. I had talked to the landowners in December; I wanted to be honest. I said here are our concerns, and we're getting a hydrologist to do a study. Let me get back to you in January when the report is done.
>
> They said fine, but it wasn't quite that simple....The report was inconclusive, and I think we probably knew that it would be before it was in. Given the kind of work done for the report, it probably couldn't have been definitive. The report wasn't going to tell us definitively whether we should buy the land. We would have to estimate the risks.

This discourse appears to differ substantially from the literal speech genres of scientific rationality described by Minick and Wertsch (see earlier). In its pattern, it connects scientific inquiry and knowledge to a specific problem, context, locale, and family (the landowners). It acknowledges a kind of informed skepticism about the results of scientific inquiry and the need for scientific knowledge and sensitive decision-making. And, it is being enthusiastically practiced and learned by almost everyone in an organization with a deserved reputation for hiring, retaining, and promoting women.

The FOS, GREEN, and CC examples suggest some possibilities for work tasks, relationships, discourse, identities, and other tools that could constitute means of science education different from those suggested in the current reform agenda. These possibilities have come from activity settings in which the goals of socially responsible science and broader involvement seem to lead and provide the motivational context for the development of sophisticated science to follow. These examples, although few in number, at least suggest that the means to scientific literacy can be more situated, more relevant, and less exclusive than those advanced under the auspices of the current reform agenda.

Conclusion

Throughout this article, we have argued that, although considerable time and effort have been spent on the development of new and improved curricular guidelines for science education, the thrust of the reform proposals has been too narrowly focused on key concepts and conventional science practices. We have tried to show that these priorities are not new, and, in fact, they have contributed to the conditions in science education which today arouse alarm. We have proposed, consistent with a broad reading of scientific literacy and constructivism, that something besides knowledge of key concepts and conventional science practice might serve as the desired endpoint of science education. We have suggested that alternate endpoints could be socially responsible science and broader involvement of more and diverse people in science and that the empirical examination of sites where these endpoints already lead can provide clues to the tasks, relationships, identities, and other tools needed to support these endpoints. Although we harbor no illusions that these endpoints will be easy to sell to politicians or the public, we agree with Lauren Resnick that pursuing them is a worthwhile and serious educational challenge. She wrote, "Building such civic consciousness, by long apprenticeship in the special kind of community that only school has both the distance and the engagement to create, may be the most important challenge facing educational research and reform today" (1987, p. 19).

We have implied that, were the goal of socially responsible scientific literacy for more and diverse people to lead the science education reform movement, school science activities would be radically altered toward more democratic practices and outcomes. At the very least, we hope that the alternative ideas we have suggested will expand local and national conversations about the direction of science education reform and the pursuit of scientific literacy.

Notes

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[1]The only other national-level proposal we might have included is Science/Technology/Society [STS]. However, STS is not sponsored by a major scientific association, does not have high national visibility, and currently is being either partially subsumed or ignored within the larger and more visible efforts of AAAS, NSTA, and NRC.

[2]Some reviewers of this article strongly disagreed with our characterization of these limitations. Although we are convinced that our interpretation is warranted (see the following sections of the article), we recognize that, with materials as extensive and political as these reform proposals, and among researchers with political perspectives different from ours, other interpretations are possible. We urge those who disagree to present their case.

[3]The term, *radical constructivism*, has been most consistently applied to the ideas of Ernst von Glasersfeld and those who rely on his work. Von Glasersfeld views his own work as quite close to and consistent with Piaget's (see von Glasersfeld, 1989); however, followers of his ideas in science education have often used them to support models of teaching that differ from those suggested by Piaget-identified science education researchers.

[4]Much of the research in this tradition focuses on developing and assessing new technological tools; however, it is important to note that technology is only one form of tool that enables and constrains possibilities within activities.

[5]This perspective brings to mind John Dewey. Dewey (1938) believed that education should function to expand the community of persons who can participate in democratic decisions about social life.

[6]Specifying the ends to which science is put in this way is not a new idea in science education. These ends have played a role, though often a secondary one, in debates about science education and reform in the U. S. since before the turn of the century (Bybee & DeBoer, 1994; see especially Hurd, 1969).

[7]The curriculum development project is a part of a larger, NSF-funded, project called Computation-Enhanced Science Learning: ScienceWorks as Technological Scaffolding for Model Creation. As a part of the project, researchers and other project personnel from the University of Michigan have worked with the teachers to develop a set of technological tools designed to help students collect, analyze, and synthesize scientific information.

[8]The study was supported by a grant to Elizabeth A. Finkel from the Office of the Vice President for Research at The University of Michigan. She was assisted on this project by two student researchers—Julie Yates, a graduate student in science education, and Margaret Le, an undergraduate student.

[9]GREEN is not the only organization that has made suggestions for curriculum changes that focus on socially responsible science and broader involvement. However, it seems to be one of the few that attempt to organize locally relevant, context-specific activities for students to participate in activities aimed at these goals. The American Chemical Society has developed a chemistry curriculum called "'ChemCom: Chemistry in the Community' (ACS, 1988) that emphasizes chemistry's impact on society" (p. xi). Like GREEN and FOS, ChemCom focuses on providing applications of science knowledge in nonschool contexts; unlike GREEN and FOS however, ChemCom relies on simulated or reported instances of environmental concern, and, while students do participate in decision-making exercises, these exercises are based on problems in communities which are not their own. With funding from the National Science Foundation, members of the Biological Sciences Curriculum Study (BSCS) and Social Science Education Consortium (SSEC) have teamed up to develop an integrated curriculum framework that adds the history and nature of science to more conventional science content (BSCS & SSEC, 1992; Bybee, Powell, Ellis, Giese, Parisi, & Singleton, 1991). The authors of this framework encourage teachers to teach science "in context," by addressing questions such as: "What influences do the social and cultural ambience have on the questions that scientists ask and on the problems that technologists pursue?" and "What are the relationships among gender, race, ethnicity, class, and the conduct and content of science and technology?" (p. 35). In these ways, the BSCS framework proposes the academic study of a broader range of scientific issues, but it does not establish any conditions or activities for practicing them in local contexts.

[10]Of course, this kind of activity would require significant changes in school curriculum and organization. This broadly focused, interdisciplinary approach to school activities would require different kinds and uses of experts and different ways of relating and assessing material. The FOS example illustrates some of the things that might be involved; however, development of these activities would encompass major implementation issues, which are beyond the scope of this article.

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