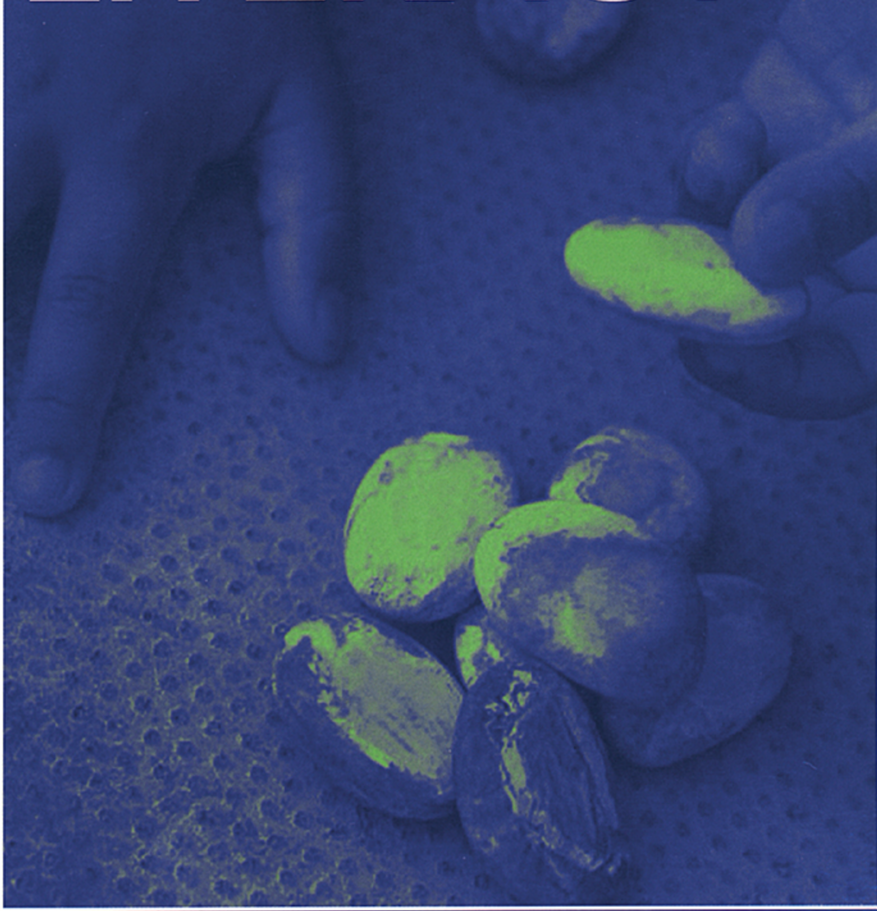
Rethinking SCIENTIFIC LITERACY



Wolff-Michael Roth
Angela Calabrese Barton

Rethinking

SCIENTIFIC LITERACY

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SERIES EDITOR'S INTRODUCTION

We live in a time when there is more and more to know. Unfortunately, all too often, sufficient time and resources are not devoted to actually learning what is considered essential in ways that might make a difference in our collective lives. At a time when a socially, ethically, and intellectually challenging critical education has never been more important, we treat education as a commodity to be placed on a market to be bought and sold like cars and television sets, or we standardize it through national or state testing and national or state curricula. Of course, the goals of these "reforms" are supposedly to create a more competitive and rigorous school system; yet, in the process, the results are often exactly the opposite of such meritorious intentions. These policies have often created even more inequalities (Apple 2001; McNeil 2000) and have cut us off from practices that have been demonstrated to be even more effective (Apple, et al. 2003; Apple and Beane 1995).

Part of the problem is the inadequacy of the ways we think about education and the knowledge that is important to know. In this society, as in so many others, education does not stand alone, a neutral instrumentality somehow above the ideological conflicts and inequalities of the larger society. Rather, it is deeply implicated in the formation of and action against the forms of differential cultural, economic, and political power that dominate a society like our own. Thus, to think seriously about education is also to think just as seriously about power, about the mechanisms in which certain groups assert their visions, beliefs, and practices. While education is not totally reducible to the political, not to deal with the ideological and structural sources of differential power and the role that education may play in reproducing and contesting such power is not to deal with education as a cultural and social act at all.

After decades of cogent analyses, these general arguments are irrefutable. Yet, even given the increasingly wide acceptance of such critical points, there are at least two problems with these arguments. First, much of the content of such arguments is exactly that—general. The arguments have not been as consistently located and developed within specific areas of expertise such as science and mathematics as they have been in, say, literacy and history, although that is changing now. Second, even if the critical arguments have been developed, what one is to do about them in terms of educational policy and practice remains a thorny issue. This is where *Rethinking Scientific Literacy* enters.

Roth and Barton make a significant contribution to our understanding of these issues and to what can be done to deal with them in critical and yet still practical ways. The authors begin with a "hard" but absolutely crucial question. What place does "school science" now have in relations of differential power? Their answer is provocative and telling, since they are clearly not at all satisfied with the roles that science and scientific literacy now play both in the larger society and schools. They then go on to do, and do well, what very few others have even attempted. They ask, and answer, the following question. How might scientific literacy be reconstructed so that it is overtly connected to the real lives of people and to the struggles for social justice that must play such a large role in these lives if such differential power is to be contested?

In formulating their response, the authors recognize that concepts such as literacy are what might be called "sliding signifiers." They have multiple meanings, depending on which group is using them for what purposes. Literacy itself is a socially constructed form, shaped by and reflecting wider social practices, relations, values, goals, and interests; however, increasingly, the meaning has become fixed around functional definitions and viewed as a set of skills that would lead to economic progress, discipline, and achievement on internationally comparative tests. Yet, as I argue in an earlier book of my own, our aim in education should not be to create "functional literacy," but *critical* literacy, *powerful* literacy, *political* literacy that enables the growth of genuine understanding and control of all spheres of social life in which we participate (Apple 2000). This more substantive vision of literacy is exactly what underpins this important new book.

Roth and Barton prove to be excellent storytellers as well. They provide richly detailed and powerfully evocative examples of children and adults engaged in practices of critical scientific literacy. From children who are "living" in homeless shelters, to those who are labeled "intellectually challenged," to schools in other nations, to adults in local communities—each group is shown in action as it engages in a rich practice of serious scientific literacy that, when reconstructed, enables individual and collective action to make the world in which they live a better place. I know of no book in science education that does this better.

But this is a book that is not "only" for those in science and science education. *Rethinking Scientific Literacy* deserves a wide readership both from all those who are concerned about creating more socially, ethically, and intellectually responsive educational institutions and from all citizens who are, justifiably, worried that our definitions of literacy have become so truncated, so limited, that education is in danger of becoming simply memorization of facts for tests or reduced to work skills for an increasingly unequal labor market. In a time of conservative reconstruction of our schools and society, we need good arguments for and good examples of an education that is worthy of its name. Roth and Barton provide us with these arguments and examples.

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SCIENCE AS COLLECTIVE PRAXIS, LITERACY, POWER, AND STRUGGLE FOR A BETTER WORLD

Time is out of joint. We cannot avoid remembering September 11, 2001—on that day we were forced to experience the negative results that the work of science educators can bring forth. By means of technology enabled by science, enabled by science education, we watched an act of horror—perpetrated by technology enabled by science, enabled by science education—as the Twin Towers of the World Trade Center were destroyed and thousands working there were killed. Watching the news a few weeks later, we were forced to experience the response. Again live, we saw more acts of horror as B-52 bombers, developed by engineers and built by technicians, who had been trained by science educators, destroyed Afghan villages and maimed more innocent people, mostly women and children. There were, of course, other responses in the wake of these events, the redirecting of funding from humanistic programs, increased efforts in the areas of science that feed the technologies of "star wars," of "exoatmospheric kill vehicles" and other "hit to kill" technologies, and of bomblets of the type that littered Afghanistan and functioned as antipersonnel landmines.

Speaking at the Centennial Nobel Peace Prize Symposium on December 6, 2001, the Chairperson of Amnesty International thought that the government's response to the horrific human rights abuses of September 11, would be a restriction of civil liberties and human rights, ostensibly to promote security. The means of restricting civil liberties and human rights were again linked to technologies that automatically record and recognize ordinary citizens'[1] faces as they pass airport security, which, once implemented broadly, is a means of tracking frequent travelers in every move they make. Again, scientists and scientifically trained engineers and technicians are involved in designing and developing these technologies. Further development of weapons and "security systems" that destroy human lives and restrict human freedoms are in the making, if we believe the U.S. Secretary of Energy Spencer Abraham when he spoke on homeland security:

> Our world-class scientific and engineering facilities and creative researchers have helped make our nation more secure for over 50 years. These same resources have been trained on the threats posed by terrorism for some time, and because of this foresight, technologies such as these are in deployment today.[1]

And again, scientists were at the forefront of the development as the Lawrence Berkeley National Laboratory offered its expertise and program experience to the US leaders charged with "strengthening homeland security" and "countering terrorist activities." That is, the causes, results, perceptions of, and responses to the horrors of terrorism, war, and resistance are deeply about science and technology as well as people, culture, mores, and ethics. Science is deeply enmeshed with all aspects of our world—in both good and bad ways—and events like the attack on the World Trade Center, the subsequent anthrax scare in the United States, the mass killings of livestock in Britain, the fears concerning genetically modified organisms (GMOs) and economic globalization make this apparent. They make imperative an articulation of scientific literacy that is deeper and more critical than that espoused in current science education initiatives.

Every night, science- and scientist-related images flash across the television screen. A drug is pulled off the shelves after thirty years on the market because it has now proven to be cancerous. Geneticists manufacture plants whose seeds are infertile and cannot be used to plant for a crop during subsequent years. Few other than those in the anti-GMO and anti-globalization efforts seem to be concerned and challenge scientists to account for their actions. Time and again, industry, which often uses scientists as their mouthpieces, tells television audiences to leave them with all decisions because, so they say, they know best. Looking at the history of scientific "advances" (nuclear arms, GMOs, drugs), we doubt that scientists individually or as a community know best what is good for society. Unbridled support for development-happy science that lacks parallel development of ethical-moral dimensions will not keep in check the technoscientific advances made. As citizens and science educators we ask ourselves before, during, and after the nightly news, "How and where do we provide opportunities for this and future generations to engage scientists in a dialogue about what they do and what they produce?" "How and where do we currently allow scientific literacy to emerge?" The traditional answer to the question about scientific literacy is to expose children and older students to a faint and distorted image of scientists' science. This science is claimed to be a pure subject, often taught in special, physically separated rooms, unsullied by common sense, aesthetics, economics, politics or other characteristics of everyday life. Science education often is a form of indoctrination to a particular worldview so that young people do *not* question the very presuppositions that underlie science. Scientific literacy currently means to question nature in ways such that do *not*, reflexively, also question science and scientists. The worst is the other part of the current rhetoric about scientific literacy—it is to be for *all*. All individuals (e.g., Americans), so goes the idealist rhetoric, have to learn and exhibit certain basic facts and skills. Just imagine, every individual taking the same ("scientific") perspective on GMOs, genetic manipulation of the human genome, or use of drugs (such as those used to dope certain kinds of children, labeled with Attention Deficit Hyperactivity Disorder to make them compliant). Conventional approaches to scientific literacy, knowing, and learning are based on an untenable, individualistic (neo-liberal) ideology that does not account for the fundamental relationships between individual and society, knowledge and power, or science, economics, and politics. There is a need to rethink some of our educational goals in terms of society. Scientific literacy cannot be prepackaged in books or delivered to students away from the lived-in world. It must be understood as community practice, undergirded by a *collective* responsibility and a social consciousness with respect to the issues that threaten our planet. We need to treat scientific literacy as a recognizable and analyzable feature that emerges from the (improvised) choreography of human interaction, which is always a collectively achieved, indeterminate process.

SCIENCE AND LITERACY

There is no doubt that since its introduction, the notion of scientific literacy has played an important role in defining the science education reform agendas. In response to specific events—for Americans, the launching of Sputnik by their arch rivals; for Germans, the outcomes of the PISA test results; for Canadians, the poor showing on the TIMMS tests—efforts are mounted to do something about what are perceived to be national concerns. Usually, the concerns are framed in terms of the lack of knowledge and skills by students of all ages. Even at the time of this writing, we have overheard science educators mocking the responses by Harvard graduates who did not know that the sun was closer to the Earth in winter than in the summer. Reform projects and conceptual change research in science education consistently define science and scientific knowledge in terms of models, theories, concepts, and principles that all students ought to know, understand, and use. The different agendas insist that any reform, if it is to be significant and lasting must be comprehensive and long-term. The rhetoric also insists that reform must center on all children, all grades, and all subjects. Despite this apparent inclusiveness, little has changed over time in the reform rhetoric: the emphasis remains on what each individual needs to know or be able to do independent of the physical and social setting. The knowledge and skills listed are often highly technical and distinct from daily living. Take the following samples from the *Benchmarks* established by the American Association for the Advancement of Science.[2]

> Neutrons have a mass that is nearly identical to that of protons, but neutrons have no electric charge. Although neutrons have little effect on how an atom interacts with others, they do affect the mass and stability of the nucleus. Isotopes of the same element have the same number of protons (and therefore of electrons) but differ in the number of neutrons. (Physical Setting, Structure of Matter, Grades 9–12)

> A living cell is composed of a small number of chemical elements, mainly carbon, hydrogen, nitrogen, oxygen, phosphorous, and sulfur. Carbon atoms can easily bond to several other carbon atoms in chains and rings to form large and complex molecules. (Living Environment, Cells, Grades 9–12)

> Communication between cells is required to coordinate their diverse activities. Some cells secrete substances that spread only to nearby cells. Others secrete hormones, molecules that are carried in the bloodstream to widely distributed cells that have special receptor sites to which they attach. Along nerve cells, electrical impulses carry information much more rapidly than is possible by diffusion or blood flow. Some drugs mimic or block the molecules involved in transmitting nerve or hormone signals and therefore disturb normal operations of the brain and body. (Human Organism, Basic Functions, Grade 12)

The need for a general scientific and technological literacy is often based on the argument that an effective workforce participation in the twenty-first century requires a certain amount of scientific knowledge. But whereas (science) educators appear to accept it as perfectly normal that we do not learn about the principles underlying the functioning of a small engine (e.g., gas-powered lawn mower, electric mixer) or how to fix it, they insist that we acquire specialized knowledge about the world that is simply inaccessible to our experience. These things are not only inaccessible but also irrelevant to most of our lives. On the other hand, we do frequently encounter a broken small engine, bicycle, or appliance. As a mother living with her two high-school-aged boys in a family homeless shelter once told us:

> In my opinion, what does it teach your kids today? Unless they're gonna become mathematical geniuses or they're going to go into science, a lot of it doesn't make sense because they're not preparing them to go out into the workplace. Even college these days because they're so centered on learning from books—I understand that it's important—but they have too many different things to learn that seriously, they're never gonna use in life. I mean, to me, a good education involves bending over backwards and giving that individual child what they need to succeed in life. Not what maybe ten kids or twenty kids or the top one hundred kids are going to need. What about those other nine hundred kids? It all boils back to the way the school system is set up. They are not offering our kids any alternatives, but going to college or fail. Now that's not an alternative; that's an ultimatum.

Despite the rhetoric of scientific literacy for all students, science in schools remains virtually unchanged; students are confronted with basic facts and theories, such as those featured in the previous examples from the *Benchmarks*. The standards of warrants for science knowledge claims often differ dramatically from the standards characteristic of First Nations people, residing in the authority of the cultural historical developments of oral teachings, or of women, who may approach science with "a feeling for the organism." That is, the poor, people of color, and women may fail in school science (or be failed by school science) exactly because of the nature of science practices and forms of knowing that are stressed in teaching. Unsurprisingly, minorities (e.g., African Americans, First Nations) and women are often discouraged from studying science because its ways of knowing and its everyday practices privilege white middle-class and male standpoints or from moving into science trajectories (as if scientific literacy had no other outcomes). Students opt out of science or are counseled out of science because success in that field of study means acting white or masculine or because a science trajectory is incommensurate with their life goals or current needs. Science class has become a mechanism for controlling what it means to "know and do science" rather than an empowerment zone where students are valued for their abilities to contribute to, critique, and partake in a just society. Indeed, the pursuit of scientific literacy promoted by recent national agendas does little to address the diverse audiences, many of which have been squeezed out of science in traditional approaches.

Others, often outside the reform movement, maintain that true and lasting scientific literacy is an impossible task for all but a small fraction of the population. Thus, one critic, Norman Levitt, maintains that science is an elitist calling and that "raw intelligence and special skills that far exceed what is to be expected of the average person are required to attain it."[3] Morris Shamos, another critic, thinks that "Few responsible educators really believe that any amount of reform or tinkering with science education will ever elevate all, or even most Americans, to any reasonable state of scientific literacy, however one chooses to define it."[4] Basing his estimates on the number of scientists and engineers in society on the one hand and on the results of John Miller's benchmark studies on the other, Shamos concludes that, at best, 5 percent of American adults are sufficiently literate in science to reach independent judgments on technoscientific societal matters. Shamos concedes that the presence of one or more individuals who are scientifically literate according to his independent judgment criterion should inform and even guide the decision-making process. In this, he does not think of outside experts, who might be considered to follow agendas of some other individual, group, or agency, but they should be considered fellow group members. These experts, even if they are not asserting their knowledge and experience to others in the group, are nevertheless expected to make the real issues salient to all group members and thereby to deflect unfounded rumor and speculation. How this might occur has not been addressed—how can there be both differences in assessment and focus on the real issues?

The other often-neglected issue is that enculturation into a domain, such as science, includes appropriation of the value systems tacitly embodied in the cultural-specific ways of knowing and doing. Thus, if our goal is to allow more people (students and adults alike) to appreciate science in the way that practitioners appreciate it, there might in fact be fewer who engage science in a critical way. Learning to construct and interpret graphs may not be neutral but enculturate (in insidious ways) to the decontextualized scientific worldviews. Thus, we find problematic the request that we ought to strive for the education of an appreciative audience that supports spending on science and technology, even apart from military requirements.

CHANGING THE DRIVERS

In recent years, new ways of thinking science and science education have emerged. In "Changing the Drivers for Science Education," Peter Fensham argues that school science has been theorized from within science and its vassal, science education.[5] For too long, science educators and scientists have proposed a model according to which science for all citizens ought to look and sound like scientists' science. Fensham proposes to rethink what the drivers for science education ought to be. To make science education a viable enterprise in our world, he suggests, it needs to be theorized from a more encompassing position: society. From this position, science, which is but one of many important human endeavors, is given its due place in the overall effort of schooling.

Whereas we agree that it is important to include social issues in the consideration of education for participation in a risk society, we believe that there are limitations to Fensham's approach because it does not critique schooling and because it rethinks science education from the position of (curriculum) theoreticians. The efforts of rethinking science education from a society perspective leave intact schooling as a mechanism for reproducing an inequitable society. It is not surprising that there are arguments for the need to find ways to deinstitutionalize science education.[6] There is not only precedence that ordinary (nonscientifically trained) people can take a stand on health, environment, or controversial issues where science comes into play, but also that there are ways in which school science can be relevant to community life.[7] Pertaining to the second limitation, our long-time practical experience teaching science in school and nonschool settings have shown us that rethinking education from outside of praxis runs afoul of the theory-practice gap. It is easy to argue that a new approach won't work because it is possible in theory but not in practice. To overcome this limitation, careful studies of concrete change efforts are needed because they show pathways along which science education can actually, rather than possibly, change.

Studies in public understanding of science construct an image of the interaction between scientists and non-scientists that is much more complex, dynamic, and interactive than the traditional opposition between "scientific expertise" and ignorance or rejection of scientific knowledge may lead us to believe.[8] In the everyday world of a community, science emerges not as a coherent, objective, and unproblematic body of knowledge and practices. Rather, science often turns out to be uncertain, contentious, and unable to answer important questions pertaining to the specific (local) issues at hand. In everyday situations, citizen thinking may offer a more comprehensive and effective basis for action than scientific thinking.

CRITIQUE OF ALTERNATIVE REFORM AGENDAS

Science educators pursuing agendas according to which science education should be rethought from a societal perspective do not go far enough because they do not question some of the fundamental problems of schooling that lead to inequities along traditional lines of difference such as race, sex, and social status. Schooling is an activity system in which students are coaxed, urged, coerced, or forced into learning—the traditional discourse about objectives. In this activity system as it currently works, students are asked to engage with discipline-specific tasks, producing artifacts (lab reports, exams) that teachers can mark.[9] But in every production, an individual also produces and reproduces his or her identity and her or his role in society. Not only do students produce outcomes, evaluated by teachers, but also they are produced as subjects of a certain type—good and poor students, dropouts, or geeks. In these terms, we do not see that recent society-focused reform proposals provide any hope for change. Rather, replacing science experts with social experts does not change or abandon present forms of schooling, an activity system that reproduces inequitable societies. In many Western nations governed by the economic interests of a few, this means that it reproduces a society ridden with injustice and inequity. Science education has done its share to contribute to the reproduction of an inequitable and unjust society by using marks as a tool to rank students. Those on top of the scale have virtually unlimited access to future learning resources, whereas those who rank lower are denied access to these same resources.

A vicious cycle ensues. Students from all different kinds of backgrounds arrive at science class and are subject to a homogeneous body of knowledge upon which they are tested at the culmination of the school year. Science is defined not by how one manages, alone or collectively, to use or produce science by way of this knowledge at home or at school, in response to a need or concern or practically toward their own or their community's future. Rather, success takes the form of a predetermined response to a cooked-up problem, an abstract set of ideals, predicated upon an imposed ideology. Success (or lack of success) in this system is a form of social control, with the consequences most real for those who sacrifice most to achieve success (to be controlled) within the system, that is, acting white or masculine, privileging the demonstration of understanding locally useless knowledge over community action. Take the case of New York State as one typical example. Students must obtain a state-endorsed high school diploma to be eligible to receive state financial aid at state-sponsored colleges and universities. State-endorsed diplomas are based upon success on end-of-year high-stakes exams (called Regents exams) in academic areas (e.g., science). Thus, access to college for students most in need of college funding is tied to their ability to perform (to be controlled) on exams that favor, for example, one's ability to call up their knowledge of the circulatory system of a grasshopper. This cycle is becoming more and more important as federal funds also become tied to school performance or are sent to states through block grant programs.

There are other problems as well in traditional science education, the structures of which are untouched in society-focused reform proposals. For example, in school science (as in schooling more generally), the means of production and the curricular goals are under the teachers' control. There is therefore a contradiction between the motive of an activity and the motive of individual students, forced into the production of outcomes by focusing on curricular objects and by using tools that are of little interest to them. Such contradictions lead to the production of resistance that both interferes with achieving the teacher-desired outcomes and reproduces the very conditions that have led to the resistance in the first place.

There are further contradictions that haunt recent alternatives to traditional science education. We begin with the supposition that learning is the expansion of possibilities for acting in and toward the world. It is immediately evident that school science operates in a contradiction, for there exists considerable research that shows that competence in these microworlds (school-related tasks) bear little or no relation to levels of competence in everyday situations. In other words, there are fundamental problems with the assumption that school (microworld) learning transfers to other activity systems. It is not surprising that a critical analysis leads us to understand school learning as defensive learning, that is, learning to avert negative consequences, rather than expansive learning, learning that leads to increased possibilities for acting and control over one's life conditions. If reformers propose to conduct science education from a societal perspective while leaving intact traditional structures of the schooling activity system, we see very little change possible. On the other hand, legitimate peripheral participation does lead to robust learning. That is, if students engage in the "authentic" activities of their community, the question of transfer does not pose itself, for students are on a trajectory of legitimate participation and therefore do not need to engage in the "boundary crossing" as they do today.

SCIENCE IN THE COMMUNITY: POWER, STRUGGLE

It makes sense to conceive scientific literacy in terms of citizen science, which is a "form of science that relates in reflexive ways to the concerns, interests and activities of citizens as they go about their everyday business."[10] In our own research, citizen science is related to a variety of contexts, ranging from personal matters (e.g., accessibility to safe drinking water), livelihood (e.g., best farming practices), leisure (e.g., gardening in sustainable, organic ways), to activism or organized protest. In the community, however, citizen knowledge is collective and distributed: our lives in society are fundamentally based on the division of labor. If we need advice for a backache, we go to the doctor or chiropractor; if our cars or bicycles do not work, we go to the car or bicycle shop. In the same way, science in the community is distributed; scientific literacy in everyday community life means to be competent in finding whatever one needs to know at the moment one needs to know it.

In contrast to the current ideology of scientific literacy as a property of individuals, we further propose to think about it as a characteristic of certain everyday situations in which citizen science occurs. In such a context, the notion of *learning* merely means that "some persons have achieved a particular relationship with each other, and it is in terms of these relations that information necessary to everyone's participation gets made available in ways that give people enough time on task to get good at what they do."[11] This implies that science educators no longer seek to stack educational environments to coax *individuals* into certain performances, but that they set up situations that allow a variety of participatory modes, more consistent with a democratic approach in which people make decisions about their own lives and interests. If we wish science education to be relevant to people's citizenship or everyday lives, we do well to allow the learners to participate in a diversity of these relations. Expecting one set of relations (institutional school) to prepare students for a world of many relations does not make sense.

Throughout the different case studies that we assembled in this book, we show that critical scientific literacy is inextricably linked with social and political literacy in the service of social responsibility. The children, students, and adults that feature in our accounts are, in one way or another, involved in struggles to make this a better world, not only for themselves, but for all of those in their community or sometimes, as with teachers, in their direct care. The kind of engagement that we envision includes the confrontation and elimination of injustices along the lines of race, sex, or social class, which are just a few of the existing terrains of discrimination. We advocate substantial shifts away from the uncritical consumer, often unaware that his or her (a) vegetables have been genetically modified; (b) beef and fish have been raised in part with animal meals and antibiotics; and (c) behaviors are inconsistent with environmentally sustainable lifestyles. We advocate adopting appropriate technologies: appropriate because they are consistent with our moral-ethical principles, do not exploit or disadvantage individuals from any group, and do not have adverse impacts on the environment and on our food supplies. We agree with Derek Hodson who suggests that the ultimate purpose of education for scientific literacy is "to produce activists: people who will fight for what is right, good, and just; people who will work to refashion society along more socially-just lines; people who will work vigorously in the best interests of the biosphere."[12]

Participation in collective actions in the interest of the biosphere does not have to be in the form of being and becoming a scientist, nor must it be in the form of public protest. Individuals and groups concerned with the environment may start cultivating vegetables in their backyard or in community gardens. Each garden, in fact, each vegetable or fruit grown organically with non–genetically modified plant material constitutes an act of resistance against companies like Monsanto and their scientists that populate the world with new organisms whose long-term impact on the environment they do not know; each organically raised plant is also an act against chemical companies whose scientists develop more and more powerful compounds that eradicate "noxious" animals and plants and simultaneously increase the chemical load on each local aquifer; each homegrown produce is an act of resistance against the oil industry, whose engineers rapidly exploit the last of remaining fossil fuels; and each homegrown plant is an act of resistance against multinational companies whose productions in Third World countries exploit local soils and workers. But all these acts of resistance are also acts for an environmentally sustainable form of life in the future, consistent with a saying among some Northwest coast aboriginal peoples: "We do not inherit this land from our ancestors but we borrow it from our children."

SCIENCE: CONTESTED FIELD AND MEANS FOR STRUGGLE

Human beings are endowed with a fundamental capacity: power to act, or agency. This capacity allows us to go beyond reacting to the environment: we actively change and shape the physical and social worlds that we inhabit. We do so, however, because division of labor allows us to pursue activities that are not directly related to individual survival but to the survival of society as a whole. For example, laboratory scientists survive although most of them do not contribute to the production or gathering of food and the killing of animals. They do not need to build the laboratories, maintain and clean them, or build, install, and repair the systems that heat them. They do not need to build the bicycles and cars that take them to the university, and they do not need to know how cars and bicycles work or why they are as strong as they are. They do not need to know how the computers they use work or, in most cases, do not need to build the computers to be able to do their work. Scientists can hunt quarks, figure out the genome, or construct new macromolecules because they are, like all the construction workers, cleaners, repairpersons, computer programmers, and so on, a constitutive part of society. Scientists and all the other people contribute to the survival of society and thereby guarantee their own access to basic resources and survival. It becomes clear, then, that it is not individual knowledge and skill that is important, but knowledge and skill that are available to human endeavors at a collective level. If we accept that there are many things that scientists do not know or need to know, we should also accept that others—baker, construction worker, farmer—do not need to know that a neutron has a mass nearly identical to protons, or what neutrons and protons are in the first place. If we accept that most scientists do not know that their lawn mower has stopped working because the carburetor is clogged or how to take out and clean the carburetor, why then do we expect all to know that a living cell is composed of a small number of elements mainly carbon, hydrogen, nitrogen, oxygen, phosphorous, and sulfur?

Of course, we must balance access with how we define success, especially in societies as hierarchically organized as we find them in the industrialized world. Scientists (on the whole) have social and economic privileges not afforded to the bakers, construction workers, or repair people (on the whole). Funders of science (CEOs, major stockholders, and the wealthy) have even more privileges. While we do argue, like the homeless mother we cited earlier, that requiring (and expecting) students to learn an abstracted, highly focused body of knowledge is dangerous in how it limits the public construction of what counts as science or limits students' abilities to become scientifically literate in a powerful way, we also recognize that possessing such knowledge opens gates to economic and political privilege otherwise held from reach. In a society, like the United States, where racial minority students are disproportionately placed in "special education" classes and where white and middle-class students score disproportionately high on state and national exams, the question of success and access is of particular importance. Herein lies a fundamental paradox, and one we believe is only solvable by recasting the very essence of scientific literacy for all or for anyone.

Once we accept that education needs to focus on the individual as integral and constitutive part of the collective, and on the distributed nature of knowledge and skill, then we have to begin thinking about the modes by which individuals with different expertise coparticipate in resolving the complex problems that their communities, countries, and humanity as a whole face today. It is clear and comes out in every chapter that follows that when there are different expertise, sociohistorical and sociocultural positions, and value systems there is also the potential for conflict and struggle for power. Science itself becomes a contested field, an arena for struggle. At the same time, science is often a tool, a means to conduct the struggle. Science is therefore a dialectic entity, both the site and means for struggle.

Throughout the chapters that follow, we see people not individually but in interaction with others, always located differently within the sociopolitical field constituting the present context. In Chapters 2 and 3, we find the residents of one Canadian community engaging one another in (context) and with science (tool). For environmental activists and laypeople in Chapter 2, whose interests are aligned, the interactions are characterized by consensus and by concerns for social and collective responsibility. In the collaboration of activists, scientists, and locals (students and adults alike), science furthermore is an outcome of collective activity—the products of the work are being used to secure further funding dedicated to make the community a better place to live and to ascertain the environmental health of their watershed. For the residents in Chapter 3 who want social justice by being connected to the water main that already supplies most others in the community, the interactions are best characterized as struggle. Here it is clearly evident that science is a contested field—did the scientific consultant use appropriate method? And are his interpretations correct given other information already available? At the same time, science is also a tool, such as when the residents draw on the results of privately funded consultant studies to make counter arguments. It is also a tool in the hands of the community politicians to keep the water main away from the residents for fear that the latter will use the improvements to gain personal benefits through increases in property values. This chapter also allows a reframing of science in the community. Rather than being the pure entity and praxis that characterizes the ascetic and monastic activities in ivory towers cut off from most of public life and scrutiny, it is a living thing that comes about as people from all walks of life contribute to a collective endeavor concerned with a salient problem.

The next two chapters feature teens who live in homeless shelters in different parts of the United States, engaged in contests over science but also using science as a means for struggle. As a tool, science is a means for actions, contributing centrally to the establishment of a community garden, and therefore to making a difference in high-poverty urban communities. Rather than accepting their lot and the environment where they are forced to live, they actively engaged in transforming their environment. It is in the actions of these teens that we can see the potential of science to make a difference when it is in the service of the agency of people allowing them to make changes to their life conditions. In the stories we see how entry into and access to science-related experiences are based on the teens' need to build a better world and his or her desire to express individual and community agency in ways not sanctioned or valued by those in political power. Their enactment of science in the community stands separate from their abilities to succeed in school science. Although it remains to be seen if science can be both a context and a means for these teens to move themselves and their families out of poverty, we do learn from these teens the importance of shaking up our academic notions of success (i.e., school achievement) to also include the daily struggle of their lives. As one teen stated, his participation in after-school science was important because he wanted to make his community a place people wanted to live in rather than leave (as moving up the economic ladder in Western society often means moving out of inner-city communities, leaving family and friends behind).

Chapters 6 and 7 feature seventh-grade students engaged in science-related actions in the same community as the adults in two previous chapters. In both chapters, the nature of science as a contested field and means of struggle is much less salient but nevertheless latently present. For example, one of the students found out that the coliform counts in the creek were way up immediately below two farms. Making the results of his research public during an open house hosted by an environmental activist group, however, becomes a political statement that might have consequences. Struggle is evident in a somewhat different way in our case study of the student Davie, labeled by the school system as "learning disabled." It turns out that there are situations, such as his mathematics class, where he shows the behavior that has led to the label. On the other hand, the data we gathered shows that in other situations, Davie's participation in teaching and learning about the endangered Henderson Creek cannot be interpreted along the lines of learning disability. For Davie, then, making it through school as it is therefore constitutes a struggle, one that he, if school does not change, is not likely to win. With some support, however, science could be both a field and a means to emancipate himself from the disability that has claimed him.

Acting in contested terrain and engaging in struggle often comes with dangers. These dangers are no more clearly articulated than in our last chapter, featuring three female teachers in Pakistan. We make the case that engaging in such a practice is a dangerous activity for these women because it explicitly situates their work within social, cultural, and political tensions. It also situates the science they do with children across people, within power, and as part of social processes and institutions. Yet, we also make the case that the women manage or even remake these tensions by using science as both a context and tool for change in the enactment of power and relationships—in other words, science means interactivity, pulling people and contexts together in particular ways. Situating "working for change" in the context of science gives the practice a power and validity that the lives of women and poor children might not have otherwise.

Some readers may think that the notion of science as tool or means of struggle alone is empowering. We do not think so, particularly when science is viewed in terms of what scientists normally know and do. Rather, teaching and learning science needs to be seen in dialectical terms. As tool, science can be used both for and against a particular position over a contentious issue. But more importantly, science is only a good tool if it can be used reflexively, that is, to critique and even deconstruct itself. Science leads to empowerment only when it does not lead to the adoption of the reigning ideology (decontextualized truth) but if it can be used to interrogate its own ideology, that is, when science becomes a contested field.

Above all, science needs to align itself with other fields and become but one of the many contested fields and tools in the service of a truly democratic and equitable society. We must not continue supporting the hegemony of laboratory science by unquestioningly accepting its practices and results. Science must be consistent with social responsibility, not with the exploitation of particular sections of the social (poor, Third World) and natural (farms, fish farms) environments of powerful laboratories (Monsanto). We do not have to accept genetically modified food or cattle and salmon raised on animal meal and antibiotics. Here again, science can become the fields that we want to contest *and* the tool that we want to use as one of the means for fighting our causes.

AGENCY, LEARNING, AND IDENTITY

Although rarely addressed in the discussion of science, scientific literacy, and learning of science, identity is closely associated with agency and learning. Identity refers us to the question of who is the agent in an activity. From a cultural-historical perspective, identity is both a product and a byproduct of activity. That is, through their agency, the people in an activity both produce material outcomes, and in the process produce and reproduce themselves and others *qua* participants in the relevant community. Therefore, the identity of an individual is not something that can be taken for granted as an a priori constituent of activity, but is something that is made and remade as activities unfold and when individuals participate in multiple activity systems.

The making and remaking of identities is particularly visible when people are involved in struggle both individually and collectively. Since struggles are especially visible when individuals enter new cultural fields, science lessons or contentious issues in the community are ideal sites for studying identity-producing interactions between participants. Throughout this book, the making and remaking of identities is present—sometimes explicitly, sometimes tacitly—as individuals of different ages engage in science as contested fields or use science as means for their struggle. Thus, when Davie attempts to cope with a graphing task posed by the teacher by avoiding engagement for much of the lesson, he becomes a "learning disabled" student (Chapter 6). On the other hand, when he tutors other seventh-grade students to conduct research in a local creek and, in the course of the task, assists them in producing a graph, he is made to be a "scientifically literate" student. Similarly, their contributions to the articulation, planning, and execution of the community garden allowed some students to become successful community activists rather than being just another group of urban kids caught up in the consequences of poverty, homelessness, and growing up in the inner-city. We can see this in our work with youth and adults because we have gotten to know them as individuals who use and produce science (a shift that requires us to move science out of the center of science education and into the world of individuals/humanity). Darkside (Chapter 4), for example, must confront on a daily basis a society that pegs him as poor, black, homeless, and the child of immigrant parents. Though he expresses and enacts scientific literacy in profound and mature ways in out-of-school settings, his access to more formal paths in science-making will no doubt be cluttered, perhaps impeded, with the baggage of traditional and narrow views of scientific literacy. That is, who we are is as much an outcome of our actions as of the changes in the social and material world that we bring forth by means of them. This is as true for individuals enacting science as it is for the identity of the science education community charged with guiding and monitoring this learning process.

As we participate in the world, we expand what we can do and therefore our room to maneuver; expanded agency is equivalent to saying that learning has occurred. Rather than getting science-related stuff into the heads of children, we want them to expand their agency, the room that they have to maneuver, and the possibilities for acting and thereby changing their life conditions. In this sense, agency is a dialectic concept because it changes agency (limiting or expanding); in the process, it produces and reproduces identity.

What we envision are science-related contexts that lead to positive formative experiences for students and adults alike, and which do not have boundaries along age or school buildings. We want students to be able to build positive identities, which for some will be related to scientific careers, for others as community activists. In any event, formal and informal science education should be liberating, allowing individuals to find, struggle for, define, and take their place in a just society. The residents involved in a struggle over access to safe drinking water are not just scientists, developers, or farmers, but they are also active citizens who engage in efforts to change their life conditions. The children who dig a hole under the fence between their shelter for the homeless and a basketball court so that they can play at night also actively engage in changing their world, and with every act of resisting the oppressive rules of their shelter, they evolve identities associated with resilience.

SCIENCE FOR ALL

In schools, norms encapsulated in curricular objectives such as "students will be able to state that water is a basic constituent of life," because they make statements about all individuals irrespective of social location, contribute to the production of failure. Here, those students who do not produce particular statements in situations where they are cut off from all of the resources that are normally available to them are constructed as lesser or as failures in the attempt to make them scientifically literate. Equal competencies are not the norm in everyday life—furthermore, different individuals contribute in their own ways to make events recognizable for what they are. For example, in Chapter 3, we describe the interactions between scientific consultants and laypeople during a public hearing. Not all laypeople asked questions or critiqued the methods and interpretations by the consultants. Yet they still need to be considered as participants in making the public meeting just that. Some residents actively asked questions or interrogated a presenter. Others provided their perspectives and evidence from their daily lives that made salient the problematic nature of well water in the area. Yet others simply listened or provided supportive "yeas" and applause. These participants are not to be taken as scientifically illiterate but as important participants in the context that allowed scientific literacy to occur. Everyone present contributed to make this event recognizable as a public hearing, which led to the emergence of scientific literacy. It is the very context of a public hearing—which includes speakers, moderator, and audience, experts and laypeople, individuals with stakes in the outcome and "impartial" consultants—that makes visible and thereby allows the identification of scientific literacy. We might say that everyone was part of the choreography of a public hearing that produces moments for the public appearance of scientific literacy and citizenship. Potential problems in one consultant's methodology, and therefore the fact that scientific expertise can be questioned, were produced in this hearing as much as the cunning abilities attributed to individual citizens to expose these problems. The applause and supportive utterances, which contributed to making visible the problems and cunning abilities, were as much part of the production of the public hearing as the questions and responses and therefore the very phenomenon of scientific literacy and engaged citizenship that were exhibited and visible.

Citizenship is often mentioned in connection with the necessity of science, technology, and economy to live in today's society. However, almost all science and even science-technology-society courses take an approach that says what students do in the classroom *should be* applicable to their immediate and future lives rather than *being* immediately part of it. Furthermore, in actual practice, courses that are designed for students to make connections between science, technology, and society are intended for those students who have difficulties mastering technical material, that is, scientific concepts as treated in textbooks, and mathematics. We believe that this aspect of science education has to be rethought as well.

Teaching for citizenship and scientific literacy as praxis has the potential to challenge traditional separations in the school curriculum that relegate science, technology, mathematics, and social studies into separate classrooms, each concerned with the subject in a more or less pure form. Citizenship and scientific literacy as praxis require integrated approaches to be compatible with the ways in which the everyday world works, where people draw on those resources that come to hand and do the job irrespective of whether they are called science, mathematics, or social studies. Not every science educator will be comfortable with an integrated approach because treating science as but one of the many different strands of everyday life threatens existing aspirations of science, scientists, and science educators to have a privileged status in society. However, studies of science in everyday life show that it is intertwined with economics, politics, power, and values more generally. Science in society as enacted by citizens cannot be separated neatly and cleanly from the other subjects. Rather, central concerns and motives govern activities and people (scientists and nonscientists alike) draw on the resources that they deem to be most appropriate in the situation. We believe that the time is right to rethink science education and scientific literacy—we propose here to do this by positing citizenship and inclusive democracy and to teach science accordingly.

Before closing this chapter, let us return to the issues with which we began, September 11, 2001, the arms race, and war more generally. Many, especially European, scholars have pointed out that the events of September 11 need to be seen in the context of world politics and economics. Many Third World countries see the U.S. economy and foreign policy as the root causes of exploitation and poverty, often linked to corrupt regimes (Noriega, oil-rich emirs) that enrich themselves at the expense of their fellow countrymen. Scientists and engineers involved in the production of genetically modified foods, cigarettes, and weaponry exported to countries already in trouble currently seem to be little concerned with the ethico-moral contexts that shape the use of their productions. From our perspective, such scientists are not acting in socially responsible ways but support the status quo of exploitation, inequitable (geographic and social) distribution of benefits and costs that come with development, and non-democratic distribution of political power. The kind of science that we envision is in the service of a socially conscious democratic society. It opens itself up to be both contested terrain and means to conduct such contest. Science and science education must advocate a free democratic society where all, rather than only a few, have access to basic necessities and resources. Our own ideological commitments include improving and extending social justice and democratic practices, especially how these play out across traditional difference markers such as race, class, gender, age, and so on.

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