Salvaging Science Literacy

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ABSTRACT: There is little evidence that the prevailing strategies of science education have an impact on the use and interpretation of science in daily life. Most science educators and science education researchers nonetheless believe that science education is intrinsically useful for students who do not go on to scientific or technical careers. This essay focuses on the "usefulness" aspect of science literacy, which I contend has largely been reduced to a rhetorical claim. A truly useful version of science literacy must be connected to the real uses of science in daily life—what is sometimes called public engagement with science. A small number of science education researchers have already begun to connect science education and the broader field of public engagement with science. Their work, as well as the work of researchers who study public engagement, suggests that it is possible to salvage the "usefulness" of science literacy by helping students become competent outsiders with respect to science. © 2010 Wiley Periodicals, Inc. *Sci Ed* **95:**168–185, 2011

THE USEFULNESS OF SCIENCE EDUCATION

When Paul Hurd popularized the phrase science literacy in 1958, he was merely providing a new label for the well-established notion that *some* mastery of science is essential preparation for modern life (Hurd, 1958). For more than a century, educators have insisted that science education is useful to all students, even those not bound for scientific or technical careers. In the years around 1900, it was fashionable to believe that science provided students with a powerful method of thinking and that studying science developed the reasoning faculties of the mind (e.g., Committee of Ten, 1894). Two decades later,

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policy makers considered science education to be useful primarily for its relevance to daily decisions, such as decisions about health and hygiene (e.g., Committee for the Reorganization of Secondary Education, 1920). Both versions of usefulness, as well as a more general sense that certain scientific theories and findings are simply "good to know," continue to percolate through educational research and rhetoric. Thanks in part to Hurd, we usually refer to all of these ideas under the ubiquitous heading of *science literacy* or *scientific literacy* (most scholars, though not all, treat the two phrases as synonyms; see Roberts, 2007).

Curiously, the triumphal progress of science literacy has for the most part taken place in an empirical vacuum. Our field has produced little evidence that any science taught in school, from Newton's laws to natural selection, helps people lead happier, more successful, or more politically savvy lives. There is an undeniable irony in this. Even researchers who dedicate their careers to promoting evidence-based educational practices seem oddly content to accept broad and unsubstantiated claims about the usefulness of science in daily life. Such claims can border on the absurd: Neil Ryder was only exaggerating slightly when he caricatured proponents of science literacy as believing that "thermodynamics is pressed into action to choose between one garment and another . . . polymer chemistry is used to decide what to spread on toast" (N. Ryder, 1993, p. 148).

This essay examines the idea that science education is useful in daily life—what might be called the usefulness aspect of science literacy. Of course, science literacy stands for many things besides everyday usefulness. In the exhaustive (and occasionally exhausting) debate about its nature and definition, science literacy has also been assigned inherent cultural worth (e.g., Donnelly, 2006) as well as aesthetic and even moral value (e.g., Bronowski, 1965). I focus on usefulness for two reasons. First, claims about the usefulness of science education are more testable than claims about its cultural, aesthetic, or moral value. In other words, when someone says science education is useful in a particular way, we should be able to find evidence for or against that claim, at least in theory. Second, the idea that science education is useful exerts a powerful political influence: People, particularly people with money and resources, seem to believe in it. Science literacy has been a singularly effective slogan in the campaign to garner support for educational projects (Roberts, 1983), and the putative usefulness of science literacy is integral to that campaign.

It is important to specify what I mean by "useful in daily life," because that phrase has several possible interpretations. I am referring to the very specific notion that science education can help people solve personally meaningful problems in their lives, directly affect their material and social circumstances, shape their behavior, and inform their most significant practical and political decisions. I am not referring to the argument that science is a "gatekeeper" subject that allows access to other things worth having. Although this may be true, it does not rely on anything intrinsic to science—Latin and ancient Greek served the same purpose in previous generations. Nor am I referring to the sort of aggregate "usefulness" measured in skyrocketing gross domestic product or robust national defense. These large-scale societal benefits are usually attributed to an expansion or improvement of the scientific and technical workforce, rather than nonprofessional science literacy. Workforce arguments have their own critics (e.g., Chapman, 1993; Drori, 2000; Lowell & Salzman, 2007; Lowell, Salzman, Bernstein, & Henderson, 2009), and I will not address them here.

It is troubling that science education, as a field, has been so willing to assert that science literacy is useful and so unconcerned with evidence about its usefulness. Instead of attempting to connect our claims with data, we have become mired in a seemingly endless discussion about the possible outcomes of science education and the curricular and pedagogical strategies that, on a purely conceptual plane, seem best suited to reach them.

We catalog the endless definitions of and rationales for science literacy; we parse them into categories and consider their political implications, while agreeing to disagree on the specifics. The result has been a profound hollowing out of the idealistic promise of science literacy. It has come to mean everything and nothing—an idea of usefulness that is taken for granted but is too vague to make a difference.

What can be done to revitalize science literacy, to take it beyond the realm of politically useful slogans and make it into a goal that is both realistic and worthy? In this essay, I suggest that we do not need to abandon the core ideal of usefulness or the vision of a competent citizenry that can cope with science-related real-life challenges. On the other hand, we do need to examine how people actually use science in daily life and redefine our ambitions based on a better understanding of what is possible. To do this, we as researchers must look up from our own journals and pay attention to research on public engagement with science. That research, combined with our own emerging study of science in daily life, can be the basis for new ideas of science literacy that are genuinely useful to our students and our society.

SCIENCE LITERACY AND SCIENCE EDUCATION RESEARCH

Two Central Questions of Science Literacy

The past decade has produced several broad reviews of scholarship on science literacy (e.g., DeBoer, 2000; Laugksch, 2000; Roberts, 2007; Hodson, 2009). The review by Roberts (2007) is particularly impressive in its international breadth and historical depth. Roberts helpfully divides the literature into two types, which he calls Vision I and Vision II. Vision I focuses on "the canon of orthodox natural science, that is, the products and processes of science itself," whereas Vision II focuses on "situations with a scientific component, situations that students are likely to encounter as citizens" (Roberts, p. 730). Roberts notes that these two visions approach the question of science literacy from different angles. What he does not observe is that these two visions are answering different educational questions.

What Roberts calls Vision II fits into a larger category of writing that is primarily concerned with the question: *What does science literacy look like?* Although Roberts cites several empirical studies, three of which I will discuss in detail below, the bulk of scholarship in this domain consists of speculative descriptions, more concerned with painting a compelling picture than justifying or articulating that picture. There are astonishingly many such descriptions—Layton, Jenkins, and Donnelly (1994), working under contract to UNESCO, collected several hundred. Benjamin Shen's brief but elegant article on science literacy (Shen, 1975) is a widely cited example of this genre. Shen outlines three forms of science literacy: practical science literacy, which helps ordinary people make health-, work-, and family-related decisions; civic science literacy, which enables citizens "to arrive at considered decisions" about science-related policy issues (Shen, p. 48); and cultural science literacy, through which nonscientists may appreciate science "as a major human achievement" (Shen, p. 49). At no point does Shen connect these forms of science literacy to social science research, nor does he provide a clear educational prescription for attaining them.

What Roberts calls Vision I fits into a larger category of writing that is primarily concerned with the question: *What must people know or be able to do to be science literate?* This type of writing may evoke grand visions, but it is more workmanlike in tone and structure. It often centers on lists and frameworks, typified by Hazen and Trefil's *Science Matters: Achieving Scientific Literacy* (1991), an imposing, no-frills compendium of information. A more sophisticated and influential example is the *Atlas of Science Literacy*, a mammoth document developed by the American Association for the Advancement of Science (AAAS) as the cornerstone for its education reform initiative, *Project 2061* (AAAS, 2001). The *Atlas* portrays science literacy as a web of interconnected information and skills, in which more complex concepts and capabilities are built on a foundation of less complex ones. This arrangement implies a curriculum, and the AAAS explicitly recommends teaching the contents of the *Atlas* in a particular order, at appropriate age levels.

The question "What does science literacy look like?" is inherently descriptive. Even the empirical studies that address it tend to be descriptive in nature. On the other hand, the question "What must people know or be able to do to be science literate?" is inherently prescriptive. One can imagine two ways of connecting these questions: starting with a clear description and moving backward to an educational program, or starting with an educational program and discovering what sort of science literacy it produces. There have been few coherent attempts to do either. Many authors simply present a picture of science literacy and an inventory of skills and knowledge (a description and a prescription) and assert that the latter will lead to the former. Empirical demonstrations are vanishingly rare.

Three Categories of Science Education Research

The descriptive and prescriptive questions, framed above, can be used to sort most science education research into three categories. I summarize these categories in Table 1, referring to them as *SL-rhetorical*, *SL-logical*, and *SL-empirical* based on their treatment of science literacy. Research in the SL-rhetorical category takes science literacy more or less for granted. It typically ignores the descriptive question entirely and addresses the prescriptive question by assuming that particular skills and concepts will contribute to science literacy, itself undefined. This category includes most research from the longstanding traditions of conceptual change (e.g., Posner, Strike, Hewson, & Gertzog, 1982) and mental models (e.g., Vosniadou & Brewer, 1992), as well as the more recent tradition of learning progressions

TABLE 1
Three Categories of Science Education Research, Sorted With Respect to Science Literacy

	Rhetorical Approach to Science Literacy	*Logical* Approach to Science Literacy	*Empirical* Approach to Science Literacy
The descriptive question: What does science literacy look like?	Addresses this question rhetorically or not at all	Accepts, a priori, a particular description of science literacy	Derives a description of science literacy based on when and how science is useful in daily life
The prescriptive question: What knowledge, skills and attributes produce it?	Accepts, a priori, the relevance of particular constructs or skills	Logically deduces the knowledge, skills and attributes that might contribute; studies these	Identifies skills and attributes based on in situ study; may not include educational intervention
Exemplary research traditions	Conceptual change, mental models, learning progressions	Nature of Science, argumentation, socioscientific issue discussion	Nascent traditions focused on science in everyday life

(Lehrer & Schauble, 2009). The conceptual link between this large pool of studies and science literacy, at least the usefulness aspect of science literacy, is tenuous at best. To believe that education based on this research will lead to science literacy, one must accept the starting premise that a particular construct or skill will be useful beyond narrow educational settings.

The increasingly prominent body of research in the SL-logical category makes a more convincing connection to science literacy. This work, including recent studies on argumentation (e.g., Duschl & Osborne, 2002), the nature of science (NOS; e.g., Lederman, 2007) and socioscientific issues (e.g., Zeidler, Sadler, Applebaum, & Callahan, 2009), typically begins by presenting a description of science literacy, or one piece of science literacy. Although this description is rarely grounded in evidence, it is clearer, more detailed, and more obviously connected to an idea of usefulness than the vague intimations of science literacy associated with the SL-rhetorical category. Using these a priori answers to the descriptive question of science literacy, researchers logically deduce an answer to the prescriptive question of science literacy. Although their deductive process rarely approaches the rigor of cognitive task analysis or ethnographic life study, it has an appealing, commonsense validity. Over time, however, the tentative, work-in-progress character of these commonsense premises can harden into received wisdom. For example, few researchers who study student understandings of NOS question the practical usefulness of the construct, despite the lack of evidence that understanding NOS, as typically conceived of in science education, has any positive influence on daily thinking and decision making outside of school (Bell & Lederman, 2003).

The SL-empirical category of research treats the descriptive question of science literacy as matter of evidence, basing its descriptions of science literacy on evidence from everyday life. This category includes the nascent field of research on everyday science (e.g., Bell, Bricker, Lee, Reeve, & Zimmerman, 2006) as well as some examples of classroom-based research on Science, Technology, and Society education (e.g., Pedretti, 1997; in Canada, this perspective has been formalized as STSE, with the added E standing for Environment). Such research offers a unique perspective on the usefulness of science education and an unusually clear bridge to the field of public engagement with science. I explore three illustrative examples in the next section.

Before leaving these three categories, however, it is worth addressing the small but vibrant body of research that examines science literacy from the perspective of literacy studies (e.g., Hand, Alvermann, Gee, Guzzetti, Norris, Phillips, Prain, & Yore, 2003; Hand, Yore, Jagger, & Prain, 2010). One of the best known examples of this type of research is a set of papers by Norris and Phillips that examine the important contribution of reading and writing to science literacy (e.g., Norris & Phillips, 2003). The authors describe their subject as "science literacy in the fundamental sense," but their approach might more accurately be called a literal-minded take on science literacy. Norris, Phillips, and others who write in this vein are interested in the literacy practices that contribute to understanding science, including reading, writing, and making sense of language in social context. Although their work is unusually coherent and focused, both in its methodological consistency and its theoretical emphasis on literacy skills, it is essentially a special case of SL-logical research, because it requires the a priori acceptance of a particular description of science literacy.

Educators do not promote the development of all literacy practices with equal energy. Instead, we encourage particular practices that support socially valued ends. Although it may be true that literacy practices contribute to any vision of useful science education, different descriptions of science literacy imply different literacy practices. By committing to particular practices, such as understanding science in the news, literacy scholars are accepting particular descriptions of science literacy. Then, like other SL-logical researchers, they proceed to examine the knowledge, skills, and attributes that follow from that description. They do not begin by examining how people in nonschool settings make use of science text, nor do they attempt to apply their research and intervention strategies to nonschool situations. The same could be said of researchers who focus on scientific epistemology and practice (e.g., Ford, 2008). Both schools of research make explicit and detailed reference to a particular vision of science literacy, but neither validates its vision with evidence of usefulness in daily life.

A Closer Look at the Empirical Approach to Science Literacy

In this section, I use three examples to illustrate the emerging themes and findings of educational research on science in daily life. Each of these examples has conceptual and methodological weaknesses; taken together or separately, they are not *proof* of anything. Instead, they reveal how a focus on science in daily life is capable of transforming science literacy. They also foreshadow the convergence between science education and public engagement with science. Although these studies and others like them are comparatively recent, they have roots in a venerable pragmatist tradition of science education dating back to Dewey and perhaps earlier.

Inarticulate Science: A Prescient Early Work on Everyday Science. The book *Inarticulate Science* (Layton, Jenkins, MacGill, & Davey, 1993) is hardly a new work of scholarship, but it offers an unusually subtle treatment of science literacy, and in both methods and conclusions it neatly illustrates the general approach of SL-empirical research. Instead of starting with a prescriptive list of scientific concepts or an a priori description of science literacy, Layton et al. began "with the particular problems and situations with which members of the public had to cope, and [then] considered the possible contributions of science to the amelioration of these situations" (Layton et al., p. 28). They conducted four case studies, each focusing on a different group of people: elderly people planning their heating budgets, parents of children with Down's syndrome, town councilors considering a methane-capture strategy for the local landfill, and residents of a town adjacent to a large nuclear power plant. The diversity of these cases is the principal strength of the research, as it enabled the authors to explore emergent themes across several contexts. All of the studies took place in the United Kingdom. Although the research participants were not ethnically or culturally diverse, they did span a broad socioeconomic and generational range.

After hundreds of interviews and extensive qualitative analysis, the authors concluded that the participants in all four case studies were rarely inclined to frame their challenges in terms of science. Although a minority of participants was interested in the scientific aspects of Down's syndrome, convection heating, and so forth, even these people had other concerns that made scientific rationales for action seem beside the point. For example, the elderly citizens who were interviewed about their heating and air conditioning practices spoke more about the social obligation of "keeping up appearances" and the emotional comfort they took from brightly glowing space heaters than they did about efficiency and insulation. Along similar lines, the town councilors who were debating methane capture had to manage local concerns about pumping noise as well as their constituents' trust in their openness and accountability. For them, public perception of risk was more salient to their work than any technical evaluation.

Do these findings simply reflect the pervasive absence of science literacy? Did the participants in each of the four case studies fail to invest in scientific explanations or seek science-based solutions to their problems because they had received an inferior science education? To reach these conclusions, the authors argue, we would have to ignore the powerful subjective experience of the participants—in particular, the way in which they defined their own circumstances and the problems they faced. Among parents of children with Down's syndrome, Layton et al. found that "information about chromosomes was irrelevant and of little practical use to new parents," and that "what the parents were seeking was knowledge which articulated with their perceptions of what needed to be done, short term, immediately, within their own particular setting" (Layton et al., p. 44). When they *were* interested in scientific research, these parents were more concerned about research on treatment. Their perfectly understandable preference for clinical research is at odds with the majority of writing on science literacy. Almost all of the research in the SL-rhetorical and SL-logical categories focuses on the principles, processes, and outcomes of "basic" scientific research rather than the mix of politics and probability that drive clinical research (e.g., Epstein, 1996; Fujimura, 1996).

In everyday situations and times of need, people did not think of their problems in terms of science. Across all four case studies, the number of individuals interested in scientific explanations was small, and even the descriptive terms used by scientists to define a situation seemed tangential. Layton et al. conclude that, for the people in these disparate contexts, "the problem [of having a child with Down's Syndrome, planning a heating budget, etc.] lacked shape and structure, and had to be constructed by them, initially on the basis of information provided and subsequently from their practical experiences of coping" (Layton et al., 1993, p. 121).

In light of this evidence, the authors argue persuasively that any claims about the daily relevance of science should be viewed with skepticism. They do not suggest that science, scientific explanations, and scientific constructs are *never* relevant to the challenges of daily life. Instead, they encourage their educational audience to work backwards from real life, examining the authentic situations in which science is or could be useful and finding pedagogies that anticipate the demands of these situations. They call this type of education Science for Specific Social Purposes (SSSP).

By examining the situations in which we expect science to be useful and finding far less science than expected, Layton et al. challenged the basic premise that science literacy is useful in everyday life. What *Inarticulate Science* did not do, however, was identify a clear set of common practices that might bring people into closer contact with science and help them make meaningful use of it. In other words, *Inarticulate Science* emphasizes the descriptive question—what does science literacy look like? It offers only the most general of answers to the other, prescriptive question—*What must people know or be able to do to be science literate?*

Roth: Moving Away From Individualistic Notions of Science Literacy. Among North American science educators, Wolff-Michael Roth is perhaps the most vocal proponent of nontraditional perspectives on science literacy. Like the authors of *Inarticulate Science*, Roth argues that the usefulness of science literacy can only be defined and evaluated in the context of everyday life. In searching for meaningful uses of science, however, Roth eschews the idea that science literacy is something a single person can have or be. Instead, he suggests, science literacy is *collective praxis*: something that a group of people do or accomplish, particularly when working together on shared projects or overlapping interests.

The clearest statement and best-known portrayal of this idea is Roth's often-cited 2002 paper with Stuart Lee. In this paper, Roth and Lee draw on multiple ethnographic case studies to support their assertion that "scientific literacy is a property of collective situations and characterizes interactions irreducible to characteristics of individuals" (Roth & Lee, 2002, p. 34). All of the case studies were conducted as part of a long-term ethnographic study of "science as it related to the precarious water situation" in a rural, agricultural town in the Pacific Northwest (p. 36). Roth and Lee followed two communities: environmental activists dedicated to preserving the ecological health of the local watershed, and children and teachers from the town's middle school. Relying on videotapes, transcripts, and artifacts such as newspaper articles, the authors describe several scenarios in which a nuanced understanding of the local environment was collectively constructed from the scientific and nonscientific knowledge of community members. Rather than finding science to be largely absent, as Layton et al. did in *Inarticulate Science*, Roth and Lee found that science

> was distributed across the individuals and situation. Different individuals contributed to the emerging conversation as fibers contribute to a thread . . . Furthermore, the scientific literacy that emerges as the thread of the conversation could not be predicted from the scientific literacy of the individual participant fibers—scientific literacy in conversational interaction is an irreducibly social phenomenon. (Roth & Lee, 2002, p. 39)

Accepting and even celebrating the diversity of expertise and attitudes within a community, Roth and Lee contend that the true project of science literacy, and a more worthy aim for science educators, is bringing communities together in an ongoing discourse that capitalizes on their collective knowledge and expertise.

One fair critique of these conclusions is that Roth and Lee appear to have started with the assumption that knowledge is collectively held and meaning socially constructed. As the authors themselves note, their analysis is grounded in activity theory, which leads them to emphasize "the fundamental role of the division of labor in the make-up of society" (p. 35). They are also studying a well-defined geographic community and focusing on issues of established concern to that community—a scenario that seems far more likely to confirm than refute their theoretical premises. Whether or not one agrees with the fervor of their conclusions, however, Roth and Lee succeed in pushing the conversation away from individuals and toward groups. They make the important points that people rarely act in isolation, that ideas are shaped through conversations, and that social groups have the singularly useful habit of pooling their skills and knowledge. Whether or not it is helpful to think about the science literacy of individuals, science literacy inevitably plays out in social context.

Although this idea represents a striking departure from most work on science literacy, it is strongly reminiscent of John Dewey's perspective on scientific expertise and civic discourse. Writing 75 years before Roth and Lee, Dewey stated that the primary "problem of the public" posed by the growing influence of expertise in society was "the improvement of methods and conditions of debate, discussion and persuasion" (Dewey, 1927, p. 208). Roth and Lee echo this contention in an almost uncanny fashion when they suggest that "our real problem then becomes one of how to facilitate democratic conversations among individuals with different expertise and with different locations in social space" (Roth & Lee, 2002, p. 51).

Barton: Understanding the Appropriation of Science. In both of the examples described so far, the researchers started with a situation where science seemed likely to be relevant. In neither case did the researchers attempt to guide or facilitate the science-related thinking and learning of the individuals and groups they studied. The work of Angela Calabrese Barton is markedly different. Barton's work, too, belongs to the nascent tradition of research on everyday science, yet unlike Roth, Layton, and their collaborators, Barton focuses on contexts where few people expect science to be relevant: the lives and pastimes of minority youth in high poverty urban environments. Across multiple studies, she has sought to demonstrate how marginalized young people find meaning and usefulness in science by interweaving it with their own experiences (Barton, 1998, 2001; Basu & Barton, 2007; Barton & Tan, 2008)

Barton's recent research with Sreyashi Jhumki Basu is a particularly clear example. In their 2007 study of sustained interest in science among urban minority youth, Basu and Barton focus on the role of a young person's community in shaping his or her interest in science, and the ways in which educators might fruitfully collaborate with the community to promote such interest. Working with a diverse group of secondary school students in an afterschool science program, they used interviews and ethnography to explore how the "funds of knowledge" available to students through their communities (Gonzales & Moll, 2002) could be used to foster sustained interest in science. They concluded that the young people in their study were more likely to sustain an interest in science when

> (1) their science experiences connected with how they envision their own futures; (2) learning environments supported the kinds of social relationships students valued; and (3) science activities supported students' sense of agency for enacting their views on the purpose of science. (Basu & Barton, 2007, p. 466)

In a sense, this conclusion simply returns them to the place where Layton et al. (1993) started: the idea that science is not inevitably a part of daily life and only becomes so when people see it as useful in light of their pre-existing commitments and motivations. Basu and Barton push on the idea of "useful science," though, discarding narrow notions of utility and emphasizing the subjective value of science to the young people in their study. They found that their participants' widely variable ideas about the usefulness of science

> often framed how they participated in after school science. Some students felt that useful science was science that could be applied to the things students cared about every day. Some students felt that science was useful if it allowed them to have some control over their lives or made their lives easier. Some students thought science was useful if it helped to justify activities that were not as valued in the academic sphere, such as sports and pop culture. Finally, some students felt that science was useful if it actually helped people or solved problems, either personal or social. (Basu & Barton, 2007, p. 485)

Students did not begin their afterschool science experience perceiving science to be useful in all of these ways. Instead, they began to appropriate scientific ideas and discourse through their participation in educational activities that encouraged them to "develop skills that advanced them toward their visions of their own futures" (Basu & Barton, 2007, p. 479) and to "cultivate relationships with people and in ways that reflected their values of relationships and community" (p. 483).

The deeply personal and contingent nature of the connections that these young people felt with science is the most compelling aspect of Basu and Barton's work. It also presents a thorny conceptual challenge for anyone seeking to draw broader conclusions about the nature and usefulness of science literacy. If each student found science useful in a different way, is there anything general that can be said about the "science literacy" that they gained? Also, from a more traditional perspective, it is sometimes difficult to see the science, per se, in the experiences and pastimes of these young people. Is it sufficient that they felt more comfortable with and interested in science *as they interpreted it*? Even when the science content of their interests is clear, it can seem too context specific. When the interests of young people shift, will science learned for earlier pastimes do them any good? These questions point to an apparent tension between the limitless particularity of daily life and the need for a broadly useful science education. I explore this tension below.

Summarizing Across the Three Examples. Taken together, these three examples provide an interesting account of how empirical study can transform the way we think about science literacy. Layton et al. (1993) show that the usefulness of science in daily life can be surprisingly elusive, thereby challenging longstanding assumptions about the contribution of science literacy to personal, professional, and political decisions. Roth and Lee (2002) argue that a truly useful version of science literacy can be found in the work of groups, rather than the knowledge and skills of individuals. Basu and Barton (2007) bring the discussion back to more familiar educational contexts; they show that students find science useful in unanticipated ways, and willingly appropriate scientific ideas and discourse when encouraged to ground science in personal ambitions, supportive relationships, and valued cultural and community contexts.

The picture of science literacy that emerges from these studies, and from other examples of educational research on everyday science (Azevedo, 2005; Bricker & Bell, 2007; Crowley & Jacobs, 2002; Rahm, Moore, & Martel-Reny, 2005) diverges from the familiar rhetoric that has long characterized this field. In this slowly emerging picture, we can still see science as useful to people, but the connotations of "science," "useful," and "people" have all shifted. Science arises in unpredictable ways that are shaped by personal motivations and cultural context. While it does not provide complete answers, it contributes a significant element to a more complicated process of meaning making, a process in which people act together rather than alone. "Science literate people," to the extent that they can be extricated from their groups or communities, reappear in this picture as people who can connect science with their own curiosities and crises in ways that are satisfying to them.

CONVERGENCE: SCIENCE EDUCATION AND PUBLIC ENGAGEMENT WITH SCIENCE

Parallels in the Field of Public Engagement

I have argued above that the ideas emerging from the study of everyday science have the potential to transform our notions of science literacy. These ideas, although they are relatively novel in the context of science education, are not new to social research. In particular, they echo some of the central findings from another field: public engagement with science. Consider, for example, the close parallels between the findings of *Inarticulate Science* and this conclusion from Helen Lambert and Hilary Rose's work with hyperlipidaemia patients:

> People clearly develop situated understandings of medical science through intensive experience of a specific domain (in this case, familial hyperlipidaemia). While these understandings may differ in significant respects from the received scientific/medical orthodoxy, such situated understanding adds meaning to formal knowledge by locating it within the individual's personal and social context. (Lambert & Rose, 1996, p. 80)

Here, as in the work of Layton et al. (1993), science is one stream of meaning flowing into the mix of socially situated understanding, a mix that is primarily defined by intimate personal experience. Elsewhere, Lambert and Rose anticipate Basu and Barton's conclusion about the subjectivity of usefulness:

> Thus, although from the outside we can prioritise different contributory domains of scientific and medical knowledge according to their direct relevance for personal management of the condition, this is not how patients weave the knowledge together. Among both groups of interviewees, what is regarded as 'relevant', 'useful', or 'necessary' for the management of this condition in terms of scientific knowledge and information varies greatly between individuals, and so does their cloth of understanding. (Lambert & Rose, 1996, p. 70)

In this same paper, it is also possible to find a parallel to the collective praxis ideas of Roth and Lee (2002):

> ... many of the patients we interviewed employed informal networks to acquire new information. In particular, where several members of a family or kin group have been diagnosed as having the condition, a number of them invariably discuss their treatment, compare their current cholesterol levels and their understandings of the nature of their condition, and exchange new information. (p. 70)

Lambert and Rose do not make the specific claim that families are practicing science literacy, but their data show the same synthesis of knowledge and intimate experience that Roth and Lee (2002) cite as evidence that science literacy is located in the group rather than the individual.

The work of Lambert and Rose provides an apt point of comparison not because it is unique but because it is representative, in both focus and findings, of a considerable body of social research on science in daily life. It also appeared in a book (Irwin & Wynne, 1996) and at a moment in time that marked turning points in this body of research. Prior to the mid-1990s, research on "public understanding of science," as it was typically known, was dominated by deficit-oriented, survey-based studies that took the daily relevance of scientific knowledge for granted and measured the degree to which different samples of "the public" possessed such knowledge (e.g., J. D. Miller, 1983). This type of research, which continues to the present day (e.g., J. D. Miller, 2004), closely parallels the SL-rhetorical category of science education research, though as a rule it is less sensitive to complex cognitive structures and prior knowledge. In the 1990s, however, the balance of scholarly opinion began to shift. As Steve Miller observed,

> a more reflective approach to public understanding of science was developing. This approach drew from sociology and history, and sometimes from philosophy, too. Scientific facts and their public assimilation were not as unproblematic as the deficit modelers assumed (S. Miller, 2001, p. 117).

In 1996, Wynne and Irwin assembled a collection of relevant research from this emerging tradition and published it as the book *Misunderstanding Science: The Public Reconstruction of Science and Technology* (Irwin & Wynne, 1996). Lambert and Rose were among the contributors, who, in Miller's words, saw public knowledge about science "much more as a dialogue in which, while scientists may have scientific facts at their disposal, the members of the public concerned have local knowledge and an understanding of, and personal interest in, the problems to be solved" (S. Miller, 2001, p. 117).

Irwin and Wynne's book was not the beginning of a trend, but a sign that the trend was already well established in academia. It had also gained a foothold in the policy arena, at least in the United Kingdom, where the phrase "public understanding" fell from fashion and was steadily replaced by words like "dialogue" and "engagement" (Pitrelli, 2003). Public engagement with science, as a rhetorical frame, remains popular today, and although few individuals identify as public engagement researchers per se, a loosely defined field has emerged around journals such as *Public Understanding of Science*.

Convergence and the Critical Boundary Object: Engagement

The convergence of science education and public engagement with science is not a coincidence. Although research on public engagement is rarely referenced in science education journals, each of the three examples above draws on this research, or on related work from the interdisciplinary field of Science and Technology Studies (a field whose acronym I will avoid because it is identical to the educational acronym for Science, Technology, and Society). In fact, one of the characteristic features of educational research on everyday science is its consistent and explicit attention to Science and Technology Studies. This attention comes with a delay. Despite the precocious appearance of *Inarticulate Science* (and notwithstanding the somewhat exceptional trajectory of British educational policy), contemporary educational research is only now identifying themes that research on public engagement explored years earlier.

Furthermore, science education has paid only limited attention to the public engagement literature, and much highly relevant work has not yet filtered through. A comprehensive summary of this research, even the pieces of it most relevant to science education, would be a paper in itself. It is relatively easy, however, to point to a few particularly fruitful topics for exploration. The exceptionally rich literature on public discourse and science controversy (e.g., Gieryn, 1999; Kleinman, 2000) is a wonderful starting place. Another topic with considerable educational promise is the study of science-related risks and uncertainty (e.g., Hornig, 1993; Wynne, 2010). If we truly wish students to pay attention to the scientific issues that run through major personal and political decisions, we should do our best to learn from research on the surprisingly powerful ways in which laypeople become involved in science, whether they develop their own knowledge and expertise (e.g., Epstein, 1996; Collins, Evans, & Gorman, 2007) or work together to become expert consumers and interpreters of scientific expertise (Brown et al., 2004). Numerous points of departure can be found in the third edition of *The Handbook of Science and Technology Studies* (Hackett, Amsterdamska, Lynch, & Wajcman, 2007) and in the edited collection by Irwin and Wynne (1996), mentioned above. Jim Ryder's review of research on "functional science literacy" (J. Ryder, 2001) is one of the few attempts to synthesize public engagement research for educational audiences; though somewhat dated, it remains both useful and provocative.

Communication between fields is no simple thing, but there are reasons to be optimistic about scholarly exchange between researchers who study science education and public engagement with science. First, pioneers who study everyday science have already made some important interdisciplinary connections. Second, the convergence of science education and public engagement with science may be facilitated by shared respect for theoretical works that are foundational to both fields, such as Jean Lave's writing on everyday cognition (e.g., Lave, 1988) and Thomas Kuhn's *Structure of Scientific Revolutions* (Kuhn, 1962). The third and perhaps most promising reason to be optimistic about the convergence of science education and public engagement is the rising popularity of the word "engagement" among educational researchers (e.g., Barton & Tan, 2008; Pugh, Linnenbrink-Garcia, Koskey, Stewart, & Manzey, 2010).

Shared terminology does not in itself indicate a substantive rapprochement, but the fact that both fields are talking about engagement may make it easier for researchers to join each others' conversations. In effect, the word engagement could serve as a *boundary object*, an idea passed back and forth between two social groups that both find interesting, albeit for different reasons. In the 1989 paper where they introduced the concept, Star and Greisemer observe that boundary objects

> have different meanings in different social worlds but their structure is common enough to more than one world to make them recognizable, a means of translation. The creation and

> management of boundary objects is a key process in developing and maintaining coherence across intersecting social worlds. (Star & Griesemer, 1989, p. 393)

Engagement is a fairly obvious candidate. The word has distinct and well-established uses in several disciplines (e.g., Maslach, Schaufeli, & Leiter, 2001; Irwin & Michael, 2003; Carpini, Cook, & Jacobs, 2004), all of which draw on an underlying idea of connectedness. Educational researchers often use it as part of the phrase "engagement *in*," which implies both participation and emotional investment and has roots in motivational psychology (e.g., Pugh et al., 2010). Public engagement researchers prefer the phrase "engagement *with*," which invokes confrontation and dialogue among social groups and shows the strong influence of sociology. Yet the growing influence of sociocultural theory guarantees that educational researchers will confront both "engagement in" and "engagement with" science as they examine the relationship between motivation and social identity, individual participation and group interaction. Exploring the educational power of engagement will provide many opportunities for educational researchers to join the discussion of public engagement with science—and vice versa.

RETURNING TO SCIENCE LITERACY

The Competent Outsider

Although more research would certainly be useful, I contend that we already know enough to outline a new description of science literacy. Research from both science education and public engagement tells us that people selectively integrate scientific ideas with other sources of meaning, connecting those ideas with their lived experience to draw conclusions and make decisions that are personally and socially meaningful. Engagement with science is a convenient shorthand expression for this process of connecting science with lived experience. It is, critically, the act of an outsider. People do not engage with science by removing themselves from their own social contexts and asking, "what would a scientist do?" They do not, for the most part, seek to become scientific insiders. They remain anchored outside of science, reaching in for bits and pieces that enrich their understanding of their own lives.

I propose that science literate people are *competent outsiders* with respect to science: people who have learned to recognize the moments when science has some bearing on their needs and interests and to interact with sources of scientific expertise in ways that help them achieve their own goals. It follows from this definition that the pursuit of science literacy is not *incidentally* but *fundamentally* about identifying relevance: learning to see how science is or could be significant to the things you care about most. We have historically treated the task of "making science relevant" as a pedagogical device for delivering facts and principles. I would suggest that it is time to reconceptualize it as an outcome, rather than a pedagogical tool. "Making science relevant" should not be something that the teacher does alone, but rather something that students learn to do, becoming progressively better at it through concerted practice. This practice would necessarily involve starting with their own questions, firmly embedded within their own social context, and reaching into the social worlds of science in an attempt to connect scientific ideas with lived experience.

The idea of the competent outsider also draws attention to the fact that we are currently doing something very different: producing *marginal insiders*. These are students who have sat through a long parade of concepts and theories. If they are lucky, they may have had the opportunity to test their own hypotheses, present their own results, and critique each other's findings. Their understanding of science is fairly primitive, extending to experimentation but excluding probability and peer-review, and utterly neglecting the long and messy labors of authentic scientific work. A small number will go on to be real scientific insiders, but for most, this glimpse is all they will get. As I observed at the outset of this essay, there is little evidence that such abridged familiarity with science translates into everyday competence. Worse, there is some evidence that this approach deters students from pursuing scientific careers, makes them less interested in science and less confident in their ability to seek out and use scientific information (Osborne & Dillon, 2008). Where engagement with science is concerned, creating marginal insiders may do more harm than good.

A Path Too Narrow? General Principles vs. Social Context in Science Education

I anticipate two objections to the idea of supporting students as they explore personally relevant science-related questions. The first has to do with the greater wisdom and experience of adults. Any curriculum is a statement, grounded in some form of expertise, about what knowledge is most worthwhile. Why should we abandon this expertise in favor of children's naïve inclinations and interests? The second objection has to do with the tension between the narrowness of locally relevant science and the breadth and grandeur of general scientific principles. What if students learn a smattering of disconnected ideas and miss out on the aspects of science that are more broadly relevant and, we assume, more likely to arise again in the context of their future interests and concerns?

In response to the first objection, I would argue that much of the content in any set of standards is included because it is considered important for reasons other than its inherent usefulness. As I noted in the introduction, there are other sorts of value that we place on science, including cultural, aesthetic, and moral value. I do not argue that we should jettison content that is not narrowly useful. There is undoubtedly a place in the curriculum for science that is beautiful or enlightening, or science that has changed our world. But it is difficult to square the low "utility quotient" of our standard curricula—the proportion of content that is likely to be useful in daily life—with the widely accepted claims about the daily usefulness of science education. Devoting time to students' own questions could help balance the curriculum, adding the usefulness back in.

But, as the second objection goes, why must we rely on *students* to identify useful science? Focusing on student interests seems, at first glance, like a dead-end strategy. The very specific science that arises in those contexts is unlikely to be relevant to other contexts or other students. Critics of this approach contend that the general principles and foundational findings of science are uniquely valuable because they can be applied across a wide range of situations.

The first problem with this objection is that general principles and foundational findings may not, in fact, be broadly applicable to daily life. Those who argue for the usefulness of the scientific canon typically assume that students will correctly extend general principles to specific circumstances—circumstances that are different from those in which they learned the principles. Decades of educational psychology tell us that this is a complicated and unlikely proposition (Schwartz, Bransford, & Sears, 2005). But is it possible that general principles and foundational findings will help students learn and understand more specific, situation-relevant science? It is a profound misconception that individuals make everyday decisions on the basis of formal principles and reliable knowledge built from the foundations up. Research from multiple fields demonstrates that daily action and decision making rely on heuristic devices and tailored, situation-specific solutions (Lave, 1988; Tversky

& Kahnemann, 1974). For example, parents deciding whether or not to vaccinate their children are not usually interested in how vaccines work—they want to know what the risks are, a question that can often be answered at a "good enough" level without reference to mechanism. Car mechanics do not need a scientific understanding of fluid mechanics to fix your brakes. It is unrealistic to expect that people will spontaneously transfer abstract rules to concrete situations that bear little surface resemblance to the contexts in which they learned those rules. It is doubly unrealistic to expect that a scientific understanding is an appropriate or adequate basis for everyday action.

The second problem with this objection is that it misses the reason why one would choose to focus on local issues and student concerns in the first place. In doing so, we are aiming for a general, broadly applicable outcome, but it is not, for the most part, a scientific knowledge outcome. Students who learns about pesticide pollutants in their local watershed may learn some very specific lessons about toxicity and groundwater, but as educators and theorists since John Dewey have recognized, the primary point of this exercise is to teach the students that scientific knowledge and knowledge about science are both relevant and accessible—that someone starting on the outside of a problem, without much background, can plunge into the deep water of conflicting expertise and emerge with something resembling an answer. Students may also learn a set of ancillary lessons that are equally important. They may learn about the limitations of participatory democracy (Pedretti, 1997), about institutional and political aspects of scientific research (J. Ryder, 2001), or about the fundamentally limited capacity of science to answer highly contingent, local questions (Wynne, 1992). Perhaps more important than any of these lessons, however, are the changes in identity and motivation that are hinted at in studies like Basu and Barton (2007). Whenever there have been side-by-side comparisons of curricula featuring socially contextualized and decontextualized science, the findings have indicated that students who learn science in meaningful social contexts do not do worse on knowledge measures and often do significantly better on motivational and attitudinal measures (e.g., Sutman & Bruce, 1992; Bennett, Lubben, & Hogarth, 2006). Studies like these, combined with contemporary research on science in daily life, suggest that learning about science in a deeply personal context could make students more willing to plunge into unfamiliar, science-tinged waters in the future.

CONCLUSIONS: THE LIMITATIONS OF CONVERGENCE AND WHAT REMAINS TO BE DONE

Although science education could learn a great deal from research on public engagement, the latter will never answer all of the former's questions. Most researchers who study public engagement with science are agnostic about the usefulness of science in daily life (for a more recent and nuanced discussion of this issue, see Wynne, 2007). Although they do not think in terms of science literacy, public engagement researchers are largely interested in the descriptive question: What does science literacy look like? Educational researchers have different goals. For our field, it is not enough to accurately describe a competent outsider. Sooner or later, all science educators and science education researchers must confront the prescriptive question as well. Education is a normative endeavor, fundamentally concerned with *improvement*. Because it is our job as educators and researchers to consider the good and bad in educational projects, it may ultimately be our job to distinguish among more and less desirable forms of engagement with science—distinctions that will never be entirely empirical. It will certainly be our job to help people learn how to engage with science in more desirable ways. These are tasks that public engagement researchers have left undone, and properly so, as they are tasks better suited to the expertise and inclinations of our field.

I began this essay by arguing that science literacy has been employed in an increasingly hollow manner, in which we insist on its usefulness without demonstrating how or why it is useful. I have since argued that we can salvage science literacy—make it into a meaningful educational goal instead of a mere slogan—by redefining it according to research on the actual uses of science in daily life. Finally, I offered one possible redefinition, suggesting that science literate people are competent outsiders with respect to science.

There is a note of heresy in this definition and in the prescription that it entails. It seems to suggest that the curriculum should be stripped of canonical content that students are unlikely to find relevant to their daily lives—such as, for instance, the shape of the earth. As I have noted above, I do not actually endorse this position, but I do think it is valuable to point out the difference between the assertions that "knowing X is *good*" and "knowing X is *useful*." There is room for both in science education, but we err in mistaking the former for the latter. In the context of the humanities, we do not shrink from saying that we wish students to be literate *and* well-read. I would argue that knowing the shape of the earth is part of being "well-read" in science—an excellent thing indeed, and one capable of giving us joy and satisfaction, but not one that all of our students will find useful. The more we claim that science education is useful, the stronger our duty to make it so. What I have attempted to articulate here is a new idea of usefulness, a new idea of science literacy, grounded in the realities of public engagement. Through that idea, or some other like it, I believe we can reclaim the purpose behind our field's leading metaphor and get on with the serious work of accomplishing it.

REFERENCES

American Association for the Advancement of Science. (2001). Atlas of science literacy. Washington, DC: Author.

Azevedo, F. S. (2005). Serious play: A comparative study of engagement and learning in hobby practice. Berkeley, CA: University of California, Berkeley.

Barton, A. C. (1998). Teaching science with homeless children: Pedagogy, representation, and identity. Journal of Research in Science Teaching, 35(4), 379–394.

Barton, A. C. (2001). Science education in urban settings: Seeking new ways of praxis through critical ethnography. Journal of Research in Science Teaching, 38(8), 899–917.

Barton, A. C., & Tan, E. (2008). Creating hybrid spaces for engaging school science among urban middle school girls. American Educational Research Journal, 45(1), 68–103.

Basu, S. J., & Barton, A. C. (2007). Developing a sustained interest in science among urban minority youth. Journal of Research in Science Teaching, 44(3), 466–489.

Bell, P., Bricker, L. A., Lee, T. R., Reeve, S., & Zimmerman, H. T. (2006). Understanding the cultural foundations of children's biological knowledge: Insights from everyday cognition research. In S. A. Barab, K. E. Hay, & D. Hickey (Eds.), Proceedings of the Seventh International Conference of the Learning Sciences (pp. 1029–1035). Mahwah, NJ: Erlbaum.

Bell, R. L., & Lederman, N. G. (2003). Understandings of the nature of science and decision making on science and technology based issues. Science Education, 87, 352–377.

Bennett, J., Lubben, F., & Hogarth, S. (2007). Bringing science to life: A synthesis of the research evidence on the effects of context-based and STS approaches to science teaching. Science Education, 91, 347–370.

Bricker, L., & Bell, P. (2007). "Um. . . since I argue for fun, I don't remember what I argue about.": Using children's argumentation across social contexts to inform science instruction. Paper presented at the Annual Meeting of the American Educational Research Association, Chicago, IL.

Bronowski, J. (1965). Science and human values. New York: Harper Brothers.

Brown, P., Zavestoski, S., McCormick, S., Mayer, B., Morello-Frosch, R., & Altman, R. G. (2004). Embodied health movements: New approaches to social movements in health. Sociology of Health and Illness, 26, 50–80.

Carpini, M. X. D., Cook, F. L., & Jacobs, L. R. (2004). Public deliberation, discursive participation, and citizen engagement: A review of the empirical literature. Annual Review of Political Science, 7, 315–344.

Chapman, B. (1993). The overselling of science education in the 1980s. In R. Levinson (Ed.), Teaching science (pp. 192–207). New York: Routledge.

Collins, H., Evans, R., & Gorman, M. (2007). Trading zones and interactional expertise. Studies in the History and Philosophy of Science, 38, 657–666.
Committee for the Reorganization of Secondary Education. (1920). Reorganization of science in secondary schools. Washington, DC: National Education Association of the United States.
Committee of Ten. (1894). Report of the Committee of Ten on secondary school studies. Washington, DC: National Education Association of the United States.
Crowley, K., & Jacobs, M. (2002). Islands of expertise and the development of family scientific literacy. In G. Leinhardt, K. Crowley, & K. Knutson (Eds.), Learning conversations in museums (pp. 333–356). Mahway, NJ: Erlbaum.
DeBoer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship with science education reform. Journal of Research in Science Teaching, 37(6), 582–601.
Dewey, J. (1927). The public and its problems. New York: Henry Holt & Co.
Donnelly, J. (2006). The intellectual positioning of science in the curriculum, and its relationship to reform. Journal of Curriculum Studies, 38(6), 623–640.
Drori, G. S. (2000). Science education and economic development: Trends, relationships and research agenda. Studies in Science Education, 35(1), 27–57.
Duschl, R. A., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. Studies in Science Education, 38(1), 39–72.
Epstein, S. (1996). Impure science: AIDS, activism, and the politics of knowledge. Berkeley: University of California Press.
Ford, M. J. (2008). "Grasp of practice" as a reasoning resource for inquiry and nature of science understanding. Science & Education, 17(2&3), 147–177.
Fujimura, J. H. (1996). Crafting science: A sociohistory of the quest for the genetics of cancer. Cambridge, MA: Harvard University Press.
Gieryn, T. F. (1999). Cultural boundaries of science: Credibility on the line. Chicago: University of Chicago Press.
Gonzales, N., & Moll, L. (2002). Cruzando el puente: Building bridges to funds of knowledge. Educational Policy, 16, 623–641.
Hackett, E. J., Amsterdamska, O., Lynch, M., & Wajcman, J. (Eds.). (2008). Handbook of science and technology studies (3rd ed.). Cambridge, MA: MIT Press.
Hand, B. M., Alvermann, D. E., Gee, J. P., Guzzetti, B. J., Norris, S. P., Phillips, L. M., Prain, V., & Yore, L. D. (2003). Message from the "Island Group": What is literacy in science literacy? Journal of Research in Science Teaching, 40(7), 607–615.
Hand, B. M., Yore, L. D., Jagger, S., & Prain, V. (2010). Connecting research in science literacy and classroom practice: A review of science teaching journals in Australia, the UK and the United States, 1998–2008. Studies in Science Education, 46(1), 45–68.
Hazen, R. M., & Trefil, J. (1991). Science matters: Achieving scientific literacy. New York: Doubleday.
Hodson, D. (2009). Toward scientific literacy: A teachers' guide to the history, philosophy and sociology of science. Rotterdam, The Netherlands: SensePublishers.
Hornig, S. (1993). Reading risk: public response to print media accounts of technological risk. Public Understanding of Science, 2, 95–109.
Hurd, P. D. (1958). Science literacy: Its meaning for American schools. Educational Leadership, 16(13–16), 52.
Irwin, A., & Michael, M. (2003). Science, social theory and public knowledge. Maidenhead, PA: Open University Press.
Irwin, A., & Wynne, B. (1996). Misunderstanding science? The public reconstruction of science and technology. Cambridge, England: Cambridge University Press.
Kleinman, D. L. (Ed.). (2000). Science, technology and democracy. Albany: State University of New York Press.
Kuhn, T. (1962). The structure of scientific revolutions. Chicago: University of Chicago Press.
Lambert, H., & Rose, H. (1996). Disembodied knowledge? Making sense of medical science. In A. Irwin & B. Wynne (Eds.), Misunderstanding science? The public reconstruction of science and technology (pp. 65–82). Cambridge, England: Cambridge University Press.
Laugksch, R. C. (2000). Scientific literacy: A conceptual overview. Science Education, 84, 71–94.
Lave, J. (1988). Cognition in practice. Cambridge, England: Cambridge University Press.
Layton, D., Jenkins, E., & Donnelly, J. (1994). Scientific and technological literacy: Meanings and rationales; an annotated bibliography. Leeds, England: Centre for Studies in Science and Mathematics Education.
Layton, D., Jenkins, E., Macgill, S., & Davey, A. (1993). Inarticulate science? Perspectives on the public understanding of science and some implications for science education. Leeds, England: University of Leeds.
Lederman, N. G. (2007). Nature of science: Past, present and future. In S. K. Abell & N. G. Lederman (Eds.), Handbook of research on science education (pp. 831–880). Mahwah, NJ: Erlbaum.

Lehrer, R., & Schauble, L. (2009). Images of learning, images of progress. Journal of Research in Science Teaching, 46(6), 731–735.

Lowell, B. L., & Salzman, H. (2007). Into the eye of the storm: Assessing the evidence on science and engineering education, quality, and workforce demand. Washington, DC: The Urban Institute.

Lowell, B. L., Salzman, H., Bernstein, H., & Henderson, E. (2009). Steady as she goes? Three generations of students through the science and engineering pipeline. Paper presented at Annual Meeting of the Association for Public Policy Analysis and Management. Washington, DC.

Maslach, C., Schaufeli, W. B., & Leiter, M. P. (2001). Job burnout. Annual Review of Psychology, 52, 397–422.

Miller, J. D. (1983). Scientific literacy: A conceptual and empirical review. Daedalus, 112(2), 29–48.

Miller, J. D. (2004). Public understanding of, and attitudes toward, scientific research: What we know and what we need to know. Public Understanding of Science, 13, 273–294.

Miller, S. (2001). Public understanding of science at the crossroads. Public Understanding of Science, 10(1), 115–120.

Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. Science Education, 37, 224–240.

Osborne, J., & Dillon, J. (2008). Science education in Europe: Critical reflections. London: Nuffield Foundation.

Pedretti, E. (1997). Septic tank crisis: A case study of science, technology and society education in an elementary school. International Journal of Science Education, 19(10), 1211–1230.

Pitrelli, N. (2003). The crisis of “public understanding of science” in Great Britain. JCOM, 2(1).

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific concept: Toward a theory of conceptual change. Science Education, 66(2), 211–227.

Pugh, K. J., Linnenbrink-Garcia, L., Koskey, K. L. K., Stewart, V. C., & Manzey, C. (2010). Motivation, learning, and transformative experience: A study of deep engagement in science. Science Education, 94, 1–28.

Rahm, J., Moore, J. C., & Martel-Reny, M.-P. (2005). The role of afterschool and community science programs in the lives of urban youth. School Science and Mathematics, 105(6), 283–291.

Roberts, D. A. (1983). Scientific literacy: Towards a balance for setting goals for school science programs. Ottawa, Ontario, Canada: Minister of Supply and Services.

Roberts, D. A. (2007). Scientific literacy/science literacy. In S. K. Abell & N. G. Lederman (Eds.), Handbook of research in science education (pp. 729–779). Mahwah, NJ: Erlbaum.

Roth, W.-M., & Lee, S. (2002). Scientific literacy as collective praxis. Public Understanding of Science, 11(1), 33–56.

Ryder, J. (2001). Identifying science understanding for functional scientific literacy. Studies in Science Education, 36, 1–44.

Ryder, N. (1993). Vernacular science: Something to rely on in your actions? In P. J. Black & A. M. Lucas (Eds.), Children’s informal ideas about science (pp. 148–171). New York: Routledge.

Schwartz, D. L., Bransford, J. D., & Sears, D. (2005). Efficiency and innovation in transfer. In J. Mestre (Ed.), Transfer of learning from a modern multidisciplinary perspective (pp. 1–52). Charlotte, NC: Information Age Publishing.

Shen, B. S. P. (1975). Science literacy and the public understanding of science. In S. B. Day (Ed.), Communication of scientific information (pp. 44–52). New York: S. Karger and A. G. Basel.

Star, S. L., & Griesemer, J. R. (1989). Institutional ecology, “translations” and boundary objects: Amateurs and professionals in Berkeley’s Museum of Vertebrate Zoology, 1907–39. Social Studies of Science, 19(3), 387–420.

Sutman, F. X., & Bruce, M. H. (1992). Chemistry in the community—ChemCom: A five-year evaluation. Journal of Chemical Education, 69(7), 564–567.

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. Science, 185, 1124–1131.

Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. Cognitive Psychology, 24, 535–585.

Wynne, B. (1992). Misunderstood misunderstandings: Social identities and public uptake of science. Public Understanding of Science, 1(3), 281–304.

Wynne, B. (2007). Dazzled by the mirage of influence? Science, Technology & Human Values, 32(4), 491–503.

Wynne, B. (2010). Rationality and Ritual: Participation and exclusion in nuclear decision-making. London: Earthscan.

Zeidler, D. L., Sadler, T. D., Applebaum, S., & Callahan, B. E. (2009). Advancing reflective judgment through socioscientific issues. Journal of Research in Science Teaching, 46(1), 74–101.