How Literacy in Its Fundamental Sense Is Central to Scientific Literacy

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ABSTRACT: This paper draws upon a distinction between fundamental and derived senses of literacy to show that conceptions of scientific literacy attend to the derived sense but tend to neglect the fundamental sense. In doing so, they fail to address a central component of scientific literacy. A notion of literacy in its fundamental sense is elaborated and contrasted to a simple view of reading and writing that still has much influence on literacy instruction in schools and, we believe, is widely assumed in science education. We make suggestions about how scientific literacy would be viewed differently if the fundamental sense of literacy were taken seriously and explore some educational implications of attending to literacy in its fundamental sense when teaching science. *Sci Ed* **87:**224–240, 2003; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/sce.10066

INTRODUCTION

Discourse about the goals of science education and science education reform often is couched in terms of literacy. In the English language, literacy is understood in two related but distinct ways. In one sense, literacy means ability to read and write. In the other sense, literacy means knowledgeability, learning, and education. The two senses are related. A person can be knowledgeable without being able to read and write: individuals can learn much by trial and error, word of mouth, and apprenticeship. However, when we turn to a disciplined body of knowledge, such as western science, and sophisticated knowledge of it, the connection between knowledgeability and ability to read and write is tight. We first argue that nothing resembling what we know as western science would be possible without text; second, that because of the dependence of western science upon text, a person who cannot read and write is severely limited in the depth of scientific knowledge, learning, and education he or she can acquire. These points are why we shall refer to reading and writing when the content is science as the *fundamental* sense of scientific literacy, and being knowledgeable, learned, and educated in science as the *derived* sense. The points are also why we claim that the fundamental sense of literacy is central to scientific literacy.

We shall proceed first by showing that conceptions of scientific literacy typically attend to the derived sense of literacy and not to the fundamental sense. Second, we shall specify

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more exactly what we mean by the fundamental sense of literacy and contrast this notion to a simple, word-recognition-and-information-location view of reading that remains prominent in literacy instruction. Third, we shall reconsider scientific literacy in light of the discussion in the previous sections and suggest how it would be viewed differently if the fundamental sense of literacy were taken seriously. Finally, we shall discuss the educational implications of attending to the fundamental sense of literacy when teaching science.

CONCEPTIONS OF SCIENTIFIC LITERACY AND THE FUNDAMENTAL AND DERIVED SENSES OF LITERACY

Scientific literacy is used variously in one or more of the following ways: (a) Knowledge of the substantive content of science and the ability to distinguish science from nonscience (CMEC, 1997; Mayer, 1997; NRC, 1996; Shortland, 1988); (b) Understanding science and its applications (DeBoer, 2000; Eisenhart, Finkel & Marion, 1996; Hurd, 1998; Shen, 1975; Shortland, 1988); (c) Knowledge of what counts as science (DeBoer, 2000; Hurd, 1998; Kyle, 1995a, 1995b; Lee, 1997); (d) Independence in learning science (Sutman, 1996); (e) Ability to think scientifically (DeBoer, 2000); (f) Ability to use scientific knowledge in problem solving (AAAS, 1989, 1993; NRC, 1996); (g) Knowledge needed for intelligent participation in science-based social issues (CMEC, 1997; Millar & Osborne, 1998; NRC, 1996); (h) Understanding the nature of science, including its relationships with culture (DeBoer, 2000; Hanrahan, 1999; Norman, 1998); (i) Appreciation of and comfort with science, including its wonder and curiosity (CMEC, 1997; Millar & Osborne, 1998; Shamos, 1995; Shen, 1975); (j) Knowledge of the risks and benefits of science (Shamos, 1995); or (k) Ability to think critically about science and to deal with scientific expertise (Korpan et al., 1997; Shamos, 1995).

In these portrayals of scientific literacy, we were able to find only a very few that make any reference at all to features of scientific literacy that would fall under the fundamental sense. For example, Millar and Osborne (1998) believe that "science curriculum should provide sufficient scientific knowledge and understanding to enable students to read simple newspaper articles about science . . . " (p. 9). A similar view was expressed by the National Research Council (1996, p. 22) in claiming, "Scientific literacy entails being able to read with understanding articles about science in the popular press . . . " Shortland (1988) actually made the distinction between the two meanings of literacy in order to sharpen his focus on what he took to be scientific literacy: ". . . literacy has to do not merely with the ability to read and write but with a certain measure of learning which may reasonably be expected to flow from the application of these basic skills . . . " (pp. 313–314). In conceiving of literacy as providing independence in learning science, Sutman (1996) proposed a definition of functional scientific literacy that he saw fitting with the broader goals of language literacy. However, he did not make clear how his conception is related to literacy broadly conceived, except to imply that scientific literacy ought to mean more than memorization of the vocabulary of science. There have been some studies focussed on the reading and evaluation of scientific news briefs. The conception of scientific literacy that underlies the work of Korpan et al. (1997), for example, includes an understanding of how students read science-related materials for information and critically evaluate the conclusions contained in them. Although he did not explicitly use the notion of scientific literacy, Anderson (1999) contrasted science educators' long-standing attention to "hands-on experience as the essential core of scientific practice" with the comparative neglect of reading and writing in science. Anderson claimed that "reading and writing are the mechanisms through which scientists accomplish [their] task. Scientists create, share, and negotiate the meanings of inscriptions—notes, reports, tables, graphs, drawings, diagrams" (p. 973).

In our judgement, none of the mentioned works that refer to features falling under the fundamental sense of scientific literacy sufficiently penetrates the concept to reveal its significance. Anderson's claim is a good example to help frame our point. He says that "reading and writing are the mechanisms through which scientists accomplish [the task of science]". He is, of course, correct, but he portrays reading and writing only in a functional relationship with respect to science. By way of explanation, glass windows stand in a functional relationship with respect to houses. Their functions include letting in light, keeping out precipitation and wind, and keeping in heat. However, there are houses without glass windows and even houses without structures that serve any of the functions served by glass windows. When reading and writing are viewed functionally as tools for doing science, then, just as we can imagine houses without glass windows, we should be able to imagine science without reading and writing. That is, reading and writing should be removable from science and something recognizable as science would be left.

The thesis we shall defend is that reading and writing do not stand only in a functional relationship with respect to science, as simply tools for the storage and transmission of science. Rather, the relationship is a constitutive one, wherein reading and writing are constitutive parts of science. Constitutive relationships define necessities because the constituents are essential elements of the whole. Remove a constituent, and the whole goes with it. Throw away the cover and keep the contents, and you still have a book; throw away the contents and keep the cover, and you no longer have a book.

In addition to Anderson's position, consider the positions in the *Beyond 2000* document and in DeBoer's survey of views of scientific literacy. We wholeheartedly endorse the call for a science curriculum that "enables students to read simple newspaper articles about science" (Millar & Osborne, 1998, p. 9) and that promotes "Understanding Reports and Discussion of Science That Appears in the Popular Media" (DeBoer, 2000, p. 592). However, these goals acknowledge only an instrumental link between reading and science and overlook the intrinsic connection between the two. Reading and writing are inextricably linked to the very nature and fabric of science, and, by extension, to learning science. Take them away and there goes science and proper science learning also, just as surely as removing observation, measurement, and experiment would destroy science and proper science learning. These points, presaged here, will be elaborated and defended in what follows.

THE FUNDAMENTAL SENSE OF LITERACY

"Traditionally science teachers have had little concern for text . . . [R]eading is not seen as an important part of science education" (Wellington & Osborne, 2001, pp. 41–42). Indeed, criticism of attention paid to science text and science reading has "focused the science education community's effort on eliminating text from science instruction," because of a "perception that science reading [is] a passive, text-driven, meaning-taking process" (Yore, Craig, & Maguire, 1998, p. 28). Science educators might be forgiven for these oversights because for those who know how to read well and for those whose primary area of work is not the study of reading, reading can seem a simple process and text can seem transparent. Indeed it seems there could be little more to reading than knowing the words and locating information in the text. Nevertheless, Pressley and Wharton-McDonald found it necessary in 1997 in addressing those whose direct concern is the study and teaching of reading to debunk "the myth that children will be able to comprehend a text simply because they can decode words in it" (p. 448). That is, a simple view of reading penetrates education more widely than might at first be suspected. Spiro and Myers (1984, p. 478) described well this simple view of reading:

> According to this view, readers go through a series of processing stages that progress from smaller units of analysis in text to larger ones. Roughly, features of letters are detected, letters are recognized, strings of letters are identified as words, concatenated words are analyzed to determine sentence meaning, and, finally, sets of sentences are considered together to produce the meaning of a connected discourse.

Haas and Flower (1988) reported that many students are "good" readers in the traditional sense: they know the words, read flexibly, identify and locate information, and recall content. Yet, these same students paraphrase when asked to analyze, summarize when asked to criticize, and retell when asked to interpret. What is missing from the traditional view of good reading that leads to such shallow responses?

In children's minds, the simple view engenders a belief that "reading is being able to say the words correctly, a passage of unrelated words [seem] just as readable as an intact passage" (Baker & Brown, 1984, p. 359). Even today, there is strong reason to believe that teachers are unwittingly fostering this simple view of reading, despite over five decades of research showing that skilled word recognition is not reading. "Although . . . skilled decoding is necessary for skilled comprehension . . . decoding is not sufficient . . . Despite the plethora of research establishing the efficacy of comprehension strategies instruction, very little comprehension strategies instruction occurs in elementary schools" (Collins Block & Pressley, 2002, pp. 384–385).

We find a reliance on such a simple, word-recognition-and-information-location, view of reading in many science education papers. For example, Miller (1998) considers whether "scientific literacy might be defined as the ability to read and write about science and technology" (p. 203–204). He concludes that this definition is too broad because it includes everything that might be read, from simple labels to complex scientific reports. He proposes instead a concept of civic scientific literacy with two dimensions: (1) a vocabulary dimension, referring to "a vocabulary of basic scientific constructs sufficient to read competing views in a newspaper or magazine" (p. 205) and (2) a process of inquiry dimension, referring to "understanding and competence to comprehend and follow arguments about science and technology policy matters in the media" (pp. 205–206). Miller's concept of civic scientific literacy is interesting and is related to the view we are seeking, but has several limitations. First, the vocabulary dimension risks equating successful reading with knowing the meanings of the individual terms. This is the simple view of reading just described, which has been known for a long time to be flawed because concatenating the meanings of words does not yield the meaning of a proposition, and concatenating the meanings of propositions does not yield the meaning of extended text (Anderson, 1985; Goodman, 1985; Smith, 1978). Reading is not the linear process implied by such additive models, and this is precisely the point that so many experts have found themselves compelled repeatedly to make, even within the reading field. Second, the vocabulary dimension appears to assume that only scientific constructs need to be known to understand scientific text. However, we shall argue presently that many literate constructs are not specifically scientific, but, nevertheless, are needed to understand scientific text. Third, although the process of inquiry dimension could be interpreted to include the general reading competence necessary to interpret the argumentative structure of text, it really refers on Miller's conception to expository knowledge of the nature of science: the ability of individuals "to describe, in their own words, what it means to study something scientifically" (Miller, 1998, p. 213); or ability to identify better scientific approaches to solving problems. Although such knowledge and ability are important, they do not yield "competence to comprehend and follow arguments" in text, as the process of inquiry dimension is described by Miller. Such interpretive tasks include but also transcend scientific knowledge and knowledge about science.

What might all those reading experts have had in mind when they said that reading is not simply decoding words or locating information in text? The answer is found when the essential nature of reading is seen as inferring meaning from text (Norris & Phillips, 1994a). Under the concept of text, we include whatever is meant to be read, without distinction for the medium that displays the print: the panoply of literate objects including not only printed words, but also graphs, charts, tables, mathematical equations, diagrams, figures, maps, and so on. Inferring meaning from text involves the integration of text information and the reader's knowledge. Through this integration, something new, over and above the text and the reader's knowledge, is created—an interpretation of the text (Phillips, 2002). It is crucial to understanding this view to recognize that interpretations go beyond what is in the text, what was the author's intent, and what was in the reader's mind before reading it. Also crucial is the stance that not all interpretations of a text are equally good, but usually there can be more than one good interpretation. The possibility of more than one good interpretation exists for all text types, notwithstanding the fact that the leeway for proposing multiple interpretations varies from type to type. For example, a wave function may be meant to be read in one and only one way. However, no text, not even (or, maybe, especially not even) a wave function, can be written so as to avoid the need for interpretation by its readers, or so as to guarantee that they all will reach the same interpretation. Thus, the essential nature of reading—inferring meaning from text—is the same no matter what is being read, even though there may be variations in reading purposes and strategies across text types and reading contexts.

Our basic position is that reading is best understood as a constructive process. However, we are at pains to avoid the relativism associated with some versions of constructivism. Relativism is created or avoided in the way readers position themselves with respect to the text. One possible positioning is for readers to adopt a dominant stance towards the text by allowing their background beliefs to overwhelm the text information, and thereby forcing interpretations that cannot consistently and completely account for the text. In such a situation, what the text is taken to mean is entirely relative to what the readers believe. On the other hand, readers may adopt a deferential stance, either by accepting whatever the text says, or by allowing the text to overwhelm their background beliefs by reaching interpretations that are contradicted by those beliefs. In this sort of situation, what the text is taken to mean is entirely relative to what it says. Stances of both these sorts are relativistic, because neither is constrained by general standards of completeness and consistency. It is most justifiable for readers to adopt a critical stance by engaging in interactive negotiation between the text and their background beliefs in an attempt to reach an interpretation that, as consistently and completely as possible, takes into account the text information and their background beliefs (Phillips & Norris, 1999).

It is in the fashioning of interpretations that our position is constructivist, and in the fashioning under constraints that our position is not relativistic. The above conception of reading implies a relationship between authors, their texts, and the readers of those texts. Readers are pictured making an array of judgements about text that go beyond surface meaning, including judgements about what is meant or intended in contrast to what is said, what is presupposed in what is said and meant, what is implied by what is said and meant, and what is the value of what is said and meant (Applebee, Langer, & Mullis, 1987; Bereiter & Scardamalia, 1987; DeCastell, Luke, & MacLennan, 1986; Torrance & Olson, 1987). The key to reading according to this expansive model is the mastery of literate thought, which brings the thinking involved in interpretation to a conscious level. "Literate thought is the conscious representation and deliberate manipulation of [the thinking involved in reading]. Assumptions are universally made; literate thought is the recognition of an assumption *as an assumption*. Inferences are universally made; literate thought is the recognition of an inference *as an inference*, of a conclusion *as a conclusion*" (Olson, 1994, p. 280).

According to the simple view, reading is knowing all the words and locating information in the text. By contrast, we maintain that reading is not a simple concatenation of word meanings, is not characterized by a linear progression or accumulation of meaning as the text is traversed from beginning to end, and is not just the mere location of information. Rather, reading depends upon background knowledge of the reader, that is, on meanings from outside the text; it is dependent upon relevance decisions all the way down to the level of the individual word (Norris & Phillips, 1994a); and it requires the active construction of new meanings, contextualization, and the inferring of authorial intentions (Craig & Yore, 1996; Yore, Craig, & Maguire, 1998). Understanding reading requires a view from the inside, from the perspective of someone who is approaching a text and who does not yet understand it. From that perspective, reading has a number of features (Norris & Phillips, 1987). First, reading is *iterative*. By this we mean that reading proceeds through a number of stages, each aimed at providing a more refined interpretation. A stage consists of steps, not necessarily followed in order: lack of understanding is recognized; alternative interpretations are created; judgement is suspended until sufficient evidence is available for choosing among the alternatives; available information is used as evidence; new information is sought as further evidence; judgements are made of the quality of interpretations, given the evidence; and interpretations are modified and discarded based upon these judgements and, possibly, alternative interpretations are proposed, sending the process back to the third step. Second, reading is *interactive*. Interaction takes place between information in and about the text, the reader's background knowledge, and interpretations of the text, which the reader has created. When reading, people use the information that is available, including their background knowledge, in creative and imaginative ways. They make progress by judging whether what they know fits the current situation, by conjecturing what interpretation would or might fit the situation, and by suspending judgement on the conjectured interpretation until sufficient evidence is available for refuting or accepting it. The reader actively imagines and negotiates between what is imagined and the available textual information and background knowledge. Finally, in order to carry out such negotiation, reading is *principled*. The principles help determine how conjectured interpretations are to be weighed and balanced with respect to the available information. Completeness and consistency are the two main criteria for judging interpretations. Neither criterion by itself is sufficient; they must be used in tandem. To deal with situations where there are competing interpretations, the criteria must also be used comparatively. Readers must ask which interpretation is more complete and more consistent because often neither interpretation will be fully complete and fully consistent.

Literacy on this view goes beyond skills, no matter how sophisticated those skills are. Literacy incorporates a set of realizations and fundamental understandings about text. One of the most central realizations begins with the recognition that text is a creative product, and progresses towards an implication of this mode of production—namely, that text can be subjected to critical evaluation and to judgement concerning what it means (Clay, 1972; Illich, 1987; Olson, 1986, 1996; Wells, 1987). Heath (1986) argued that the belief that text is an artifact is needed in order to have the attitude that text is something that can be evaluated and analyzed. The idea is that unless a person has the attitude and basic understanding that text can be evaluated and analyzed, then the person is unlikely to do the analysis and evaluation when it is needed. A decade later the same point was made by Kuhn (1997, p. 144) when she argued that "Understanding assertions as belief states carries the implication that they could be false." For most of us, realizations such as these are as common and as assumed as the air we breathe. However, it is not that way for many individuals who have difficulty learning to read (Adams, 1991; Astington & Olson, 1990; Gee, 2000; Phillips, 2002). Reading, then, means comprehending, interpreting, analyzing, and critiquing texts. That is what the fundamental sense of literacy encompasses. In order to engage in such processes, readers require an elaborate repertoire of basic understandings of texts and of reading strategies and processes, and value orientations towards them.

If reading is as expansive as we describe, then reading involves many of the same mental activities that are central to science (Gaskins et al., 1994). Moreover, when the reading is of science text, it encompasses a very large part of what is considered doing science. It is not all of science, because it does not include the manipulative activities and working with the natural world that are so emblematic of science. However, the relationship between reading and science is so intimate that great care is needed to maintain a distinction between scientific literacy in its fundamental and derived senses. The need for care is increased by the fact that comprehending, interpreting, analyzing, and critiquing science text requires knowledge of the substantive content of science. This is why attempts to use scientific literacy in the fundamental sense can transmute without notice into uses in the derived sense (Kintgen, 1988; Labbo & Reinking, 1999), and why the fundamental sense is so easy to overlook. Also, if reading is as expansive as we describe, science educators need to be concerned by the possibility that many students will bring to their science learning the simple view of reading. If science teachers continue to show little concern for text, see reading as merely a tool to get to science, or see reading as unimportant, then they are likely to reinforce the attraction that this simple view has. We offer an alternative view of scientific literacy in the following section that attempts to take account of both its senses.

SCIENTIFIC LITERACY RECONSIDERED

DeBoer (2000) recommended that "we should accept the fact that scientific literacy is simply synonymous with the public's understanding of science and that this is necessarily a broad concept" (p. 594). We can accept with two reservations this recommendation and the long list of goals that DeBoer includes under the rubric of scientific literacy. First, in order to achieve DeBoer's goal to have students "learn what it means to critically read accounts of science that appear in the daily press" (p. 597), then science education must take far more seriously than it currently does what it entails to pursue this goal for citizens. Second, although DeBoer claims that "There are many ways to be scientifically literate . . . [and that] within some fairly broad limits it probably doesn't matter much which path is taken" (p. 597), we maintain that at a minimum the path must intersect scientific literacy in both senses. What might this intersection entail?

In contrast to the expansive view of reading and the multilevel engagements between readers and texts that we described in the previous section, there is the much simpler view we have reported. According to this view, knowing what the text *means* is thought to be exclusively a matter of knowing what the text *says* (Olson, 1994), that is, of decoding the words. According to this view, texts that cannot be grasped immediately upon knowing what they say are problematic ones, because they introduce an obstacle between the reader and the world or theory they depict.

Text is related to thought in a more complex and circuitous way than implied by the simple view of reading. First, text is not speech written down, but rather is built upon a theory of speech (Olson, 1994). Writing, including scientific writing, is a form of idealization that leaves out much that is included in spoken communication (such as, intonation, repetition, stammers, incomplete and interrupted thoughts, facial expressions, and gesture) and is a form of construction that adds in much that is not included in speech (such as, sentence structure, punctuation, paragraphing, breaks between words, and long chains of expressions connected by tight logical links). Reading involves coping with both the expressed and unexpressed in the written word (Olson, 1994, p. 265). Readers lack the inferential cues provided to listeners by tone, gesture, facial expression, repetition, stammer. By way of compensation, they have at their disposal the characteristics of text not found in speech. In sum, speech and text are not the same, and do not impose the same interpretive demands. This latter point is crucial to science teaching. Literacy in the fundamental sense is about how readers cope with text, about how they use the resources of text to determine what they mean, or might mean. *Scientific literacy must comprise the interpretive strategies needed to cope with science text*.

Second, the same text can express different thoughts and the same thought can be expressed through different texts. This means that there is no direct connection between what a text says and what it means. What a text means always must be inferred from what it says plus other *extratextual* information. There is no alternative when reading but to bring to the text thoughts from outside of it. *Scientific literacy must be conceptualized so that neither the reader nor the text is supreme*: Each is a required source of information in the interpretive process; their relative weightings change from situation to situation depending upon, among other factors, familiarity with what is being read (Phillips & Norris, 1999).

Third, and as a corollary to the second point, although a scientific theory is independent of any given text (because the same theory can be expressed in many different ways) a scientific theory cannot exist outside of text altogether. Any scientific theory requires for its creation and expression the use of text. Any attempt to provide a scientific theory without appeal to text runs quickly into insurmountable shortcomings of expressive power, memory, and attention. Even to express such a simple theory as that of an ideal gas requires appeal to mathematical equations, graphs, and diagrams, all of which are tools of literacy. There is no possible expression of the theory, except for some isolated aspect of it (and even such expressions are parasitic on text), outside of text of some sort. For instance, it is not simply a matter of convenience that the pressure–volume–temperature surface is used centrally in expressions of the theory of ideal gases. We just do not have another way to express the complex of thoughts that this surface, portrayed in text either graphically or in mathematical functions, represents. If somebody were to invent another mode of expression, it too would be within the realm of literacy.

The only contender for the literate tradition is the oral one, and oracy does not provide the tools needed or the forms of expression required to describe scientific theories. In saying this, we do not intend to denigrate oracy. Just as text provides expressive power not available in speech, speech marshals expressive power not found in text, and speech plays a crucial and irreplaceable role in the development, critique, and refinement of thoughts that go into theories. Halliday and Martin (1993) have made the contrast very well: "Written language is corpuscular and gains power by its density, whereas spoken language is wave-like and gains power by its intricacy" (p. 118). Operating from a psycholinguistic framework, Rivard and Straw (2000) found that among eighth-grade students "Talk or discussion appears to be important for sharing, clarifying, and distributing knowledge among peers" (p. 585); while "writing is an important discursive tool for organizing and consolidating rudimentary ideas into knowledge that is more coherent and well-structured" (p. 586).

From these points we conclude that scientific knowledge has an essential dependence upon texts and that the route to scientific knowledgeability is through gaining access to those texts. Although individuals can portray and learn much science within oracy, such access to scientific knowledge is parasitic upon access gained through text. This is so, because, without literacy, the knowledge would not have existed, been preserved, and inherited in the first place. Hence, a conception of *scientific literacy must include an essential role of text in science*.

Fourth, although a scientific theory is independent of any given text, an expression of a theory through text capitalizes upon three features of textual fixity: (a) fixity of physical presentation (allowing for variation in fonts, margins, spacings, media, and some orderings);

(b) fixity of literal meaning; and (c) fixity of what is to be taken for granted. These fixities are what allow the *same* text to be transported across time and space to be traded, revisited, queried, and reinterpreted. "Writing puts language in chains; it freezes it, so that it becomes a *thing* to be reflected on" (Halliday & Martin, 1993, p. 118). "[W]riting fixes language, controls it in such a way that words do not scatter, do not vanish or substitute for one another. *The same words, time and again*. The mystery [that all readers need to see through in learning to read] lies to a large extent in this possibility of repetition, reiteration, re-presentation" (Ferreiro, 2000, p. 60). Yet, although the text is fixed, the interpretations of it are not. The interpretations are made against the backdrop of the relative fixity of physical presentation, literal meaning, and what is taken for granted. As Olson (1996) has said, "Consciousness of the fact or possibility that utterances can be taken literally—according to the very words—is at the heart of literate thinking" (p. 149). Although literal meaning is only relatively stable, it affords a level of stability unprecedented in oracy. As argued by Tishman and Perkins (1997), "Written language, stabilized on paper, invites kinds of reflection not so natural to oral exchanges. The written statement is more easily examined, checked, contradicted, doubted, challenged, or affirmed" (p. 371). We would go further than "invitation" and argue that written language is what makes these activities possible in any depth. *Scientific literacy must capture the recognition that texts, although fixed, invite and allow interpretation and reinterpretation.*

Fifth, although the fixities of text make interpretation and reinterpretation possible, they also make some interpretations, if not impossible, then highly implausible. That is, the fixities impose constraints on interpretations that readers are obliged to take into account. The result is that text in a context cannot mean anything at all. If every text could mean anything at all, then the logical conclusion is that every text means exactly the same thing. Clearly, this implication is absurd. In a context where no constraints exist, no interpretation is possible. So, the very fixities of text that make interpretation possible are the same features that ensure that not everything goes, by providing constraints on what can be meant. Therefore, the reader must take note of the very words, the very data, and other textual elements, and bears the burden of delivering interpretations under the constraints of those fixities. There is always room to maneuver, but the degrees of freedom are restricted. *Scientific literacy must imply that the very words and other textual elements matter as constraints on allowable interpretation.*

Sixth, Halliday, and Martin (1993, pp.118–119) have expanded the notion of the fixity of text to the fixity of what is taken for granted:

> Until information can be organized and packaged in [written language] . . . knowledge cannot accumulate, since there is no way one discourse can start where other ones left off. When I can say
>
> > the random fluctuations in the spin components of one of the two particles
>
> I am packaging the knowledge that has developed over a long series of preceding arguments and presenting it as "to be taken for granted—now we can proceed to the next step." If I cannot do this . . . I will never get very far.

Therefore, the notion of *scientific literacy must hold that science is a result of cumulative discourse that trades on the fixities of text and on what is taken for granted by that text*. This is not to imply that scientific knowledge accumulates linearly as in building a monument brick-by-brick, but to say that scientific discourse always attaches to and is dependent upon discourse that has gone before, even if it rejects the former, and serves as an attachment for discourse that is to come, even if it itself is rejected by that subsequent discourse.

The implication of the above six points about the relationship between text and thought (that coping with speech and coping with text are not the same; that supremacy lies with neither the text nor the reader; that text is an essential vehicle for the expression of scientific thought; that, although fixed, texts permit interpretation and reinterpretation; that the very words matter as constraints to interpretation; and that scientific knowledge relies upon the cumulative discourse made possible by text) is that science would not be possible without text and without literacy in the fundamental sense. Science is in part constituted by texts and by our means of dealing with them. Without the expressive power and relative fixity of text; and without the comprehension, interpretive, analytical, and critical capacities we have developed for dealing with texts; then western science as we know it could never have come into being. The only alternative to literacy, oracy and the oral tradition, simply does not have at its disposal the tools for developing and sustaining science as we know it, although, as we have said, it plays an irreplaceable role in the development, critique, and refinement of scientific thought. Without text, the social practices that make science possible could not be engaged: (a) the recording and presentation and re-presentation of data; (b) the encoding and preservation of accepted science for other scientists; (c) the peer reviewing of ideas by scientists anywhere in the world; (d) the critical reexamination of ideas once published; (e) the future connecting of ideas that were developed previously; (f) the communication of scientific ideas between those who have never met, even between those who did not live contemporaneously; (g) the encoding of variant positions; and (h) the focussing of concerted attention on a fixed set of ideas for the purpose of interpretation, prediction, explanation, or test.

These practices are general, are engaged by all disciplined fields of knowledge, and are independent of scientific knowledge. "[Writing is] destructive of one fundamental human potential: to think on your toes . . . [But] in destroying this potential it creates another one: that of structuring, categorizing, disciplining. It creates a new kind of knowledge . . . " (Halliday & Martin, 1993, p. 118).

This is what we mean when we say that one sense of literacy is fundamental and the other derived: the latter is derivative of the former, both at the level of knowledgeability in general, and at the level of discipline-specific knowledgeability.

EDUCATIONAL IMPLICATIONS

Scientific literacy is different from other literacies because of its substantive content. However, the comprehension, interpretive, analytical, and critical capacities required to deal with science text are largely, if not entirely, the same as those required for texts with different substantive contents (Norris, 1992). Thus, scientific literacy in its fundamental sense is not unique at all, save that the texts are scientific. This conclusion has major implications for science education, because it means that the educational goal of scientific literacy has a common purpose with literacy goals in other substantive content areas. It means that all teachers can unify their efforts in fostering literacy in its fundamental sense. It also means that we can deal with the effects of not recognizing the two senses of scientific literacy. Conceiving of scientific literacy only as knowledgeability in science has nurtured a focus upon the substantive content to the neglect both of the texts that carry that content and of the interpretive capacities required to cope with them. Furthermore, focussing upon the derived sense of literacy as knowledgeability in science has, for reasons that are unclear to us, created a truncated and anemic view of scientific knowledge as facts, laws, and theories in isolation from their interconnections. Evidence that measures of scientific literacy are directed in this manner can be found in the way in which the National Science Board assesses an understanding of basic scientific concepts (NSB, 1998, Ch. 7). However, it is almost universally believed in the science education community that knowledgeability in science includes knowledge of how the specific pieces of science fit together. The connections, we maintain, are found in the texts of science and in the pragmatic meanings (Norris & Phillips, 1994b; Phillips, 2002; Phillips & Norris, 1999) that are expressed in them by their authors.

Consider an example. It is one thing to read in a media report of science the very words about the Jovian moon, Europa, that "beneath the moon's frozen crust an ocean surges" (Came, 1997, p. 42). It is quite another matter to read these words in the context of the whole report about new pictures showing jumbled icebergs and cracked ice fields, and to recognize that the statement being put forward is not a factual assertion. Rather, what is put forward is a tentative interpretation of evidence. The entire context must be examined and taken into account in order to come to this recognition. To proceed without taking into account the entire context is to act as if words and strings of words can be taken in isolation and their meaning known. Reading the entire text, we find not far removed from the previous words these additional words: "Last week, those suspicions [that there is an ocean below Europa's frozen surface] received a powerful boost . . . " and "It [pictures of jumbled icebergs and cracked ice fields] is the clearest evidence to date of liquid water and melting close to the surface . . . " Further removed from the original words, we find ones such as "The size and geometry of these features lead [sic] us to believe there was a thin icy layer covering water or slushy ice . . . " and "Not even NASA's scientists have a precise idea of what may have prompted Europa's ice to move" and ". . . it all suggests movement of some sort, like polar ice during spring thaw." What starts as an apparent assertion of an ocean below Europa's surface transforms upon further reading into a hypothesis. It is a very tentative hypothesis, because the very phenomenon the hypothesis is designed to explain—fractured, shifting, and rafting ice—is called into question. The movement of the ice is itself a hypothesis from the photographic data.

Now let us examine the results of a study in which university students were asked to interpret this media report (Norris, Phillips, & Korpan, submitted). As part of their task, students were asked to read a series of statements and judge whether, according to the report, the statements are: true, likely to be true, uncertain of truth status, likely to be false, false. One of the statements they were asked to judge was, "There is liquid water and melting on Europa." According to the report, as we have seen, the statement is *uncertain of truth status*: it represents a hypothesis that is still under early stages of testing. Only 19% of students judged it as such, while 25% judged it to be *true*, 52% *likely to be true*, 2% *likely to be false*, and 1% *false*. At the same time, about 95% of these students judged the report to be *very easy*, *easy*, or *about right* to read. Our interpretation of these findings is that the students judged the reading difficulty of the report to be manageable because they knew the words and were able to locate information: they had the simple view of reading. They did not realize that they were less able at making interconnections among incontiguous pieces of information in the same text. They were unable to interpret what Glynn and Muth (1994, p. 1060) referred to as the conceptual relations "woven into well-written scientific text."

Texts contain expressions of the wide range of degrees of doubt and certainty applied to statements in science; texts are used to differentiate the status of scientific statements, from observations, to causal generalizations, to hypotheses, to descriptions of method; and texts indicate the role in reasoning played by various statements in science, whether they be statements of evidence, predictions, or speculations. Scientific literacy in its fundamental sense refers to the capacity to interpret all of these distinctions. We propose that a conception of scientific literacy that attended to its fundamental as well as to its derived sense would address the anomalous and destructive view that scientific knowledgeability can be had by acquiring isolated bits and pieces of scientific information while acquiring no idea of how they are to be interpreted or interconnected.

We recognize that an effort to promote scientific literacy can avoid instruction on literacy in its fundamental sense by instead concentrating on scientific knowledgeability defined narrowly as knowing the isolated facts, laws, principles, and theories of science. Such an effort can appear successful despite shortcomings. For example, Norris and Phillips (1994b) studied high school students who were among the top science students in their country as measured by their success on traditional science courses, but who nevertheless performed poorly when asked to interpret everyday media reports of science. Norris, Phillips, and Korpan (submitted) found similar results in the study just discussed among university students whose success in traditional science courses was even greater. In both these studies, students were asked to make interpretive connections among pieces of scientific information in ways not always taught in the regular science curriculum. It is through the resources available in the fundamental sense of literacy that the relevant connections among otherwise isolated pieces of science are made.

We have shown that science text does not wear its meaning on the surface. Like any other type of text, it must be interpreted by the reader through an active, critical engagement (Koch & Eckstein, 1995). Therefore, in order for students to achieve scientific literacy in the fundamental sense, they must not only learn and remember what science texts say by decoding the words and locating information in them (the simplest level of reading, and the level of reading required by much traditional science instruction), but also develop the ability to read those texts from a theoretical perspective. By this we mean, not only that they attend to the substantive scientific content of the texts (the focus of traditional science instruction), but also that they read the texts so as to determine such meanings as degree of certainty being expressed, the scientific status of statements, and the roles of statements in the reasoning that ties together the elements of substantive content. Since such determinations are required of text in any disciplined domain, reading science text requires mastery of literate thought in a general sense: having the metacognitive ability to examine not only the sources of knowledge, its limits, and its certainty, but also to interpret texts in various ways, to adjudicate those ways in light of available evidence, and to adopt a stance towards the texts that is neither deferential nor dismissive but properly critical.

According to the view we are promoting, scientific literacy comprises both the concepts, skills, understandings, and values generalizable to all reading, and knowledge of the substantive content of science. This claim is consistent with much of the evidence and argument that specific knowledge is important to understanding in general, and to reading in particular (Carey, 1985; Glaser, 1984; McPeck, 1981; Nickerson, 1988; Perkins & Salomon, 1989; Resnick, 1987). Interpretation of science text involves, to be sure, knowledge of substantive scientific content. However, substantive scientific knowledge is not enough for understanding. Generalizable concepts, skills, understandings, and values are also needed for reading and other intellectual tasks (Ennis, 1992; Norris, 1989, 1992; Palincsar & Brown, 1984; Paris, Wasik, & Turner, 1991; Phillips, 1988, 1992). Determining how scientific texts are to be taken involves determining, for example, when something is an inference, a hypothesis, a conclusion, or an assumption; when something is an asserted truth, an expressed doubt, or a proffered conjecture; when something is evidence for a claim, a justification for an action, or a stated fact to be explained. If these general meanings are missed, then the reader not only has read poorly, the reader has failed to grasp the scientific meaning beyond the surface content level and failed to grasp science.

What might be gained from pursuing this agenda? First, the fundamental sense of scientific literacy relates science to other bodies of disciplined knowledge, which themselves have a connection to this fundamental sense. With such relations made explicit, efforts to promote scientific literacy could be seen as part of the larger and very important project of literacy development and promotion. That project is more central to education than acquiring scientific knowledge or any other disciplined knowledge. Science education would gain by being made part of that broader and more central educational agenda.

Second, science education would gain for the instrumental reasons mentioned by Millar and Osborne (1998) and DeBoer (2000). Especially because science is in part constituted by texts, then the ability to read and write science text *is* important for the lifelong learning of nonscientists beyond their high school science education. Newspapers, science magazines, news magazines, and the internet *are* primary sources of technical and scientific information for the general public (Bisanz, 2000; Jarman & McClune, 2000). According to the United Kingdom's Select Committee on Science and Technology of the House of Lords, "most people get most of their information about science from TV and the newspapers" (Select Committee on Science and Technology, 2000, p. 54); and, according to the National Science Board in the United States, "Americans utilize numerous sources and institutions for scientific and technical information, but television and newspapers remain primary sources" (National Science Board, 1998, pp. 7–16).

The reader has perhaps gotten the impression that talk of having scientific literacy in one sense and not in the other is artificial. Indeed, this is our view. Scientific literacy in its fundamental and derived senses can be separated in thought, but even here the separation quickly becomes strained with anomalies that urge us to merge the two senses into a complete whole. How, for instance, can we imagine interpreting a science text by making interconnections throughout the text (an activity we have associated with the fundamental sense) without being knowledgeable of the substantive content of science (literate in the derived sense)? Alternatively, how can one be considered knowledgeable of the substantive content of science without being able to make sound interpretations of science text? Keeping both senses separate is important, however, for some theorizing and for educational goal-setting. How do we explain, for example, the poor interpretive skills of young adult readers who have proven themselves knowledgeable in science according to very traditional and widely accepted standards? We explain this phenomenon by appealing to their poor reading ability in science, and claim that their scientific literacy is diminished by their not having acquired scientific literacy in its fundamental sense.

CONCLUDING REMARKS

We tend to agree with the conclusion of Rivard and Straw that "writing only seems to work if talk works with it" (2000, p. 586). We also grant that a great deal of science can be learned without being able to read, or without resorting to reading. However, this is possible, only because there are others who can read. Even illiterate people in literate societies have literate minds, in the sense that they use literacy-based concepts in their thinking and talking. But oracy can take one just so far, as Olson, Tishman and Perkins, Halliday and Martin, and we have argued. Nobody can acquire a sophisticated level of scientific knowledge without being literate in the fundamental sense, and science itself could never exist without individuals literate in this way. Traditional science education does not attend to literacy in the manner we have described, at the risk that students never will fully grasp the point and significance of scientific knowledge.

When scientific literacy is conceived without attention to its fundamental sense, then a critical point of access to science is overlooked. If scientific literacy is conceived only as knowledge of the substantive content of science, there is a risk that striving to learn the elements of that content will define our goals without any appreciation for the interconnection among the elements of content, their sources, and their implications. We have seen that literacy in the fundamental sense is based upon the same epistemology that underlies science and that the reasoning required to comprehend, interpret, analyze, and criticize any text resembles in its major features the reasoning at the heart of all of science. When it is also recognized that science is in part constituted by text and the resources that text makes available, and that the primary access to scientific knowledge is through the reading of text, then it is easy to see that in learning how to read such texts a great deal will be learned about both substantive science content and the epistemology of science. Conversely, a failure to learn how to read scientific text points to a failure to understand science, no matter how much of the substantive content of science is learned. This is because text is the repository of the source of, relationships among, and implications of that content. There is a chance that a focus on the fundamental sense of scientific literacy is a way to escape from what many students feel as the drudgery of learning isolated pieces of scientific information and to capture what is truly exciting about science, namely, how it all fits together into a remarkable whole.

Wineburg (1997, p. 259) wrote the following about history, "The claim to 'know history' is a statement that one knows why an event is important, how it links to other events, what its antecedents were, and how it affected future events. Knowing any one of these aspects in isolation misses the point." We can say the same about science. The claim to know some scientific statement is a claim to know the process or likely process through which the statement was conceived, the degree of certainty that the field attaches to the statement, the role in reasoning the statement plays in connection with other scientific statements, and the implications of the statement's being true. If such interrelationships are missed in the reading, then the point of science is missed. The main source of both the substantive content of science and of the interrelationships within it is accurate interpretation of science text. Therefore, literacy in the fundamental sense is central to scientific literacy.

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