Chapter 3
Reading Science: How a Naive View of Reading Hinders So Much Else

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Focus of This Chapter

Several national bodies have proposed that reading about new scientific findings could serve a useful purpose in citizens' lives. For example, groups in Canada (Council of Ministers of Education Canada 1997), the United States (National Research Council 1996), and the United Kingdom (Millar and Osborne 1998) all have expressed the viewpoint that school science education ought to provide sufficient background for citizens to read reports of new scientific findings appearing in the popular press. By this viewpoint, we assume they mean that citizens should be able to make sense of what they read and be able to make logical inferences about their existing scientific beliefs – whether to maintain or alter them in light of what they have read. However, we know from several decades of research that, even after extended classroom instruction, many scientific concepts defy easy understanding and many erroneous beliefs persist despite disconfirmatory evidence. We know disconfirmatory evidence can be misconstrued, even as confirmatory of existing beliefs. We also know that beyond the difficulty with scientific concepts themselves, readers have difficulty grasping the epistemology inherent in scientific text (such as the degree of certainty being expressed or the relationship between conclusions and reported evidence) and using it to help modulate their scientific beliefs.

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What are readers to do? At a minimum, they need to resist credulity and the tendency to accept misinformation with accurate and honest appraisals of what they understand, of the support that they have for their existing beliefs, and of the evidence in what they read both for the maintenance and the alteration of those beliefs. Such appraisals fall under the category of thought normally labeled "metacognition" (Brown 1985). In metacognition, individuals think about their own thinking, and, in the best of situations, do so critically. Reading metacognition, broadly speaking, is thinking about thinking while reading. Reading metacognition includes the monitoring and control (jointly, the regulation) of thinking while reading: "How well do I understand the last passage? Should I reread it? In what way does it relate to the first two paragraphs? Perhaps I should look up that unusual word in the dictionary. How does this article fit with the one I read last week?" The regulation occurs in the context of beliefs about reading (Baker and Brown 1984; Israel et al. 2005). More specifically, reading metacognition depends upon a normative view of reading, that is, a view of the goals of reading and of what counts as good reading. Metacognition involves making evaluative judgments about, say, the sense one has made of a passage, against a backdrop of the standards and norms provided by one's view of reading. As people's views of reading differ, their metacognitive judgments can differ in response. For example, we know there are those who believe that reading simply is being able to identify all the words. A slightly more sophisticated view of reading, but nevertheless an impoverished one, held by other readers is that reading well is being able to locate information in the text. An even more sophisticated view is that reading is constructing an interpretation that is consistent and takes into account completely the relevant evidence available in the text and the reader's background knowledge. It is easy to see how metacognitive judgments might differ according to the view of reading held. The first reader might ask: "Did I identify all of the words?" If the reader judges the answer to be positive, then the reader has the grounds to think the reading has gone well. The second reader might ask: "Can I locate the important information in the text?" The third reader might ask: "Have I made sense of the text in my interpretation?" In the second and third cases also, a positive answer leads to the judgment that the reading has been successful. Clearly, though, the grounds required for positive assessments differ across the three cases, and the reading that has taken place would also differ from case to case in both depth and breadth – the first and second readings being the most superficial and the third being the deepest.

In this chapter, we focus on two types of metacognitive judgments made by students reading the popular scientific press: Judgments about the difficulty of the texts to read and judgments about the effect of what they have read on prior beliefs. Both of these judgments relate to the monitoring function of metacognition. These judgments can affect how readers subsequently control their reading, a point that will be made clear in several examples that follow. These metacognitive judgments consistently were made poorly by students because, we argue, the students possessed a limited view of the nature and goals of reading. Their view of reading determined the stance they adopted towards the texts. Consequently, the control of their reading also was not effective.

In section "Cognitive Performance: How Well High School and University Students Read Science," we shall describe how well students actually interpreted the popular scientific reports, and where their strengths and weaknesses tended to lie. These strengths and shortcomings fall into the cognitive realm. In section "Metacognitive Performance: What Students Made of Their Reading," we turn to the metacognitive and examine what, upon reflection, the students made of their reading. In section "How to Account for the Results," we offer an interpretation of what was happening for the students to perform as they did and to make the metacognitive judgments they did. Our interpretation is offered in light of a view of reading that we have reasons to believe the students possess. Finally, in section "Educational Policy," we offer several educational policy implications of this work.

Cognitive Performance: How Well High School and University Students Read Science

In our first studies in this area (Norris and Phillips 1994; Phillips and Norris 1999), we selected students in their senior high school year who were enrolled in at least one of senior-year biology, chemistry, or physics. These students were taking or had completed on average about four senior high school science courses. We chose a leading high school in which the student population was relatively homogeneous: Virtually all students were white, middle class, and spoke English as their first language. The students sampled were among the top science students in the school. We next studied undergraduate university students, who on average had taken eight additional single terms of science beyond high school. As such, these university students had an education in science that was far in excess of the average nonscientist, and even the high school students would rank near the top of society in number of science courses completed. We selected our samples in order to get an estimate of the upper bound on nonscientists' ability to read scientific text. We assumed that the average nonscientist could not perform as well as these students.

We devised a set of interpretive tasks that were built around authentic popular reports of science that had appeared in mainstream newspapers and magazines. All of the reports were written for the general, nonscientific public. Five examples follow.

Weather Can Make You Sick

This report (Weinhouse 1992) was on the link between weather and sickness. Statements in the report were offered with varying degrees of qualification, but it was difficult to discern any systematic pattern of qualification that swayed the article either toward or away from the view that weather and sickness are causally related. A critical reader could conclude on the basis of the report that there is some scientific basis to the claim that weather can make one sick, but would know that further study is required to accept any of the causal connections suggested in the report.

New Animal Species Found in Vietnam

This report (New animal species found in Vietnam 1992) dealt with the possibility of a new species of goat having been discovered in Vietnam. Although the title of the report was quite definitive about the discovery of a new species, it is clear from qualifications throughout the report that the evidence must be examined further before its meaning is known. The critical reader would avoid being misled by the title and adopt a cautionary stance towards the discovery. (Please see the Appendix where this report may be found in its entirety.)

Breakfast of Champions

A further magazine report discussed evidence on breakfast being good for one's health (McDowell 1992). It was made clear by the report that the evidence is suggestive that eating breakfast could lower the risk of early morning heart attacks, the most prevalent kind. The critical reader would note the lack of definitiveness while also seeing the power of the evidence.

Researchers Take Theory on Cow's Milk-Diabetes Link a Step Farther

This report (Taylor 1992) was about the link between drinking cow's milk as an infant and developing juvenile diabetes. The tone of the report was cautionary, maintaining that the new evidence implies, but does not prove, that a link between cow's milk and diabetes exists, and the critical reader would interpret the report this way. Furthermore, the critical reader would note that no clear guidance about feeding cow's milk to infants was given based upon the research.

Mysterious Moon

The mysterious moon is the Jovian moon, Europa (Came 1997). The mystery concerns whether or not there is liquid water and ice on the moon. A feature of the report is that the journalistic style results in statements that clearly assert the presence of water only to be qualified substantially in subsequent parts of the report. A critical reading of the report would require that the entire document be taken into account before reaching any conclusions about the existence of water or ice on Europa.

We asked students to interpret various aspects of the pragmatic meaning of the reports, by which we refer to meanings that the authors clearly intended but did not state explicitly in the reports. These pragmatic meanings included the expressed degree of certainty with which statements were reported (truth to falsity with gradations in between); the scientific status of statements (e.g., whether the statements were causal generalizations, observations, motivations for doing the research, or descriptions of method); and the role of statements in the scientific reasoning (e.g., whether the statements were justifications for procedures, evidence for conclusions, conclusions, descriptions of phenomena, explanations of phenomena, or predictions). We chose tasks of this nature because they demanded interpretations that went beyond the literal, or surface meanings, of the text to involve discernments of the epistemology underlying what was written. It is such epistemological meanings that show whether readers grasp the connections implied among the statements in the text rather than see merely the individual meanings of statements taken one at a time. At a deep level, it is these epistemological meanings along with the substantive scientific concepts that contain the science.

Based upon our experience with the high school students, we developed an additional information-location task for the university students. For each question that required them to make an interpretation, we asked them to identify where in the reports they found the information they needed to answer it. The students' responses to these questions provided crucial insights into their performance on the interpretive tasks. Our hypothesis was that the students would be much more adept at locating the relevant information in the text than they were at interpreting that information. We knew from previous studies (see Norris and Phillips 2008) that students performed almost identically, answering the sort of multiple-choice questions found in standard tests of reading comprehension, regardless of whether those questions were based upon passages the students reasonably could be expected to understand or upon passages we knew for certain they did not understand. For instance, in one case, we based a set of questions upon a particularly esoteric passage taken from an advanced text in quantum mechanics and witnessed no degradation in their performance. Our explanation is that the types of questions found on standard tests of reading comprehension do not require readers to understand but merely to locate information. Therefore, if the interpretive tasks about pragmatic meaning that we had devised were any better at measuring understanding than standard reading comprehension tests, then the university students should have performed better on the information-location tasks than on the interpretive tasks. (Please see the Appendix, which contains more details on the tasks provided students.)

So, what did we find? There were several salient results from our interpretive tasks. First, the high school students demonstrated a certainty bias that skewed their interpretations of the expressed degree of certainty of statements towards being more certain than their authors had written them. That is, if a statement was expressed as likely being true, students would tend to interpret it as true; if it was expressed as uncertain, students would tend to interpret it as likely to be true or even true; if the statement was expressed as false or likely to be false, students would miss this meaning altogether and interpret the statement as having some degree of truth. Second, students were less able to interpret the role of statements in the scientific reasoning of the reports than they were able to interpret the scientific status of statements taken one at a time. The difference was quite large, with less than one half able to interpret the role of statements and about 90% able to identify the nature of statements that could be assessed independently of others. The difference seemed to be due to a weaker ability to interpret statements whose role could be inferred only by recognizing the implied connections to other statements. For example, when literal interpretation alone provided significant cues, such as frequently is the case with observation statements ("We observed that…"; "We saw that…"; "We noticed that…") and reports of method ("We measured the…"; "We attached the probe to…"), their performance was good. However, when faced with such questions as whether a statement was evidence for a conclusion in the report or a conclusion based on evidence, an explanation of a phenomenon described in the report, a prediction from an idea being tested, or a motivation for doing the research, their performance deteriorated substantially. This result suggested to us that students read for meaning only at a superficial and local level, rather than at a deeper level that examined for connections across the text.

We found that the university students performed almost identically to the high school students. They showed the same certainty bias, systematically overestimating the degree of expressed certainty in the reports; the same strength in identifying observation and method statements; and the same weakness interpreting the role of statements in the reports' reasoning, confusing statements providing evidence for conclusions with the conclusions themselves, and misinterpreting descriptions of phenomena with explanations of those phenomena. The key for us was the fact that their substantially increased science education did not help them on any of these tasks. However, whereas the university students answered only about one-half of the interpretive questions correctly, they correctly identified the place in the report with the needed information (the information-location tasks) about three-quarters of the time. This finding confirmed our suspicion that the students would perform better on the information-location tasks than on the interpretive tasks, and provided evidence that our interpretive questions were tapping an aspect of reading performance normally not measured by standard reading tests. In the following section, we begin to forge links between these cognitive aspects of students' performance and their metacognition.

Metacognitive Performance: What Students Made of Their Reading

We first turn to the metacognitive tasks that were presented to the university students (Metacognitive tasks for both university and high school students may be found in the Appendix). They were asked for each report how difficult they found it to read (very difficult, difficult, about right, easy, and very easy). This is a metacognitive task that requests students to think about their thinking while they were reading and to report the extent to which they faced interpretive difficulties. Although the task was retrospective, it was presented right after reading the reports and thus can be taken as a good approximation of their perceived reading difficulty while reading (Norris 1990). At most, only 5% judged that any report was very difficult to read, more than one half claimed finding the reports easy or very easy, and more than 90% found the reading difficulty to be at least about right. That is, their metacognitive self-assessments of the reading difficulty of the reports underestimated dramatically the demands of the report and the cognitive difficulty they experienced with the interpretive tasks. Moreover, there was only the weakest of relationships ($R^2 = 0.06$) between the students' perceived difficulty in reading the reports and their performance on the interpretive tasks, that is, between their metacognitive judgments and their cognitive performance. For instance, although about 40% of the students found the axis of the universe report (one given only to the university students) very difficult or difficult to read (all the other reports were below 8% on these categories), the students performed hardly any differently on the interpretive tasks between the axis of the universe report and the other reports. We believe that these results are key to understanding the difficulty that students experience reading scientific text. If students make inaccurate judgments when monitoring their reading, for example, about the difficulty they are experiencing, then they are unlikely to take effective control of their reading, for example, to adopt strategies that might ease or compensate for their difficulty.

Another metacognitive task addressed the interest in how students' beliefs can be altered by scientific views of the world represented in text (McCloskey 1983; Park and Pak 1997). We asked the high school students questions that probed the relationship between the content of the reports and their beliefs. Before reading each report, they were asked a question about their background beliefs on the topic. For instance, before reading the weather and sickness report, students were asked the following: "Do you believe that the weather can make you sick? Why do you say that?" Before the report on breakfast and heart attacks, they were asked whether breakfast is good for one's health and why they believed what they did. Before the report on the possible discovery of a new animal species, they were asked whether they believed new animal species were still being discovered and why they believed what they did. Before the report on cow's milk and diabetes, they were asked: "Do you believe that women should breast feed their babies? Why do you say that?" Having answered the questions, they were instructed to turn the page and read the reports. After reading each report, they were asked the metacognitive question whether they were now more certain, less certain, or equally certain of their previous view, and to say why.

It is instructive to analyze students' responses in light of the nature of the reports. Consider first the breakfast report. That report supported a "yes" response to the question of whether breakfast is good for one's health, and 95% of students gave a "yes" response before reading the report. After reading the report, slightly more than one half of the students were more certain that breakfast is good for one's health, about one third were equally certain, and fewer than 10% were less certain.

We interpret this response pattern as follows. Almost all the students thought before reading the report that breakfast is important. After reading a report that confirms this point of view, slightly more than half of the students were more certain of their opinion. This is a reasonable metacognitive judgment, because they have found confirmation for their view and have thus become more confident in it. About one third of the students were equally certain in their view after reading the report. This is also a reasonable position. The report confirmed their original view, but confirmation does not lead necessarily to greater certainty. Sometimes, for example, confirmation is redundant, which could have been the case for these students. A small minority of students was less certain in their view, and the vast majority of these had also responded originally that they thought breakfast was good for one's health. These students thought before reading that breakfast is important, read a report that confirmed this view, and then claimed to be less certain afterwards. This clearly is not a logical position to take. Perhaps, given the small proportion of students involved, the result could be attributed to a misinterpretation of the report or to some other source of response error. Although these possibilities are interesting, we are more interested in other conflicts that appeared in students' responses. To such matters, we now turn.

Focus now on the new animal species and cow's milk reports. The response patterns for these two reports were almost identical to the breakfast report, that is, roughly the same proportions of students replied affirmatively to the questions asked prior to reading, and roughly the same proportions were more, less, and equally certain of their original positions after reading. However, and here is the rub, neither the new animal species nor the cow's milk report supports a "yes" or a "no" response to the questions asked prior to reading. That is, the reports are neutral on whether new animal species are being found and on whether mothers should breast feed their babies. Yet, nearly all of the students responded "yes" to the original questions, and more than one half of them claimed to be more certain of their views after reading the reports, even though the reports did not support any increased certainty. These results for the new animal species and cow's milk reports call into question the reasonableness of the response pattern to the breakfast report, making us wonder whether the reasonableness of that pattern is more a matter of coincidence than some underlying level of reading competence.

Finally, consider the weather and sickness report to see how the students' responses can be even more puzzling, even perverse! This report also supports a "yes" answer to the initial question of whether weather can make one sick, but this was the report for which the smallest proportion of students responded "yes" and for which the highest proportion of students expressed qualifications. We also see a different pattern of expressed certainty after reading the report, with the largest proportion of less certain students for any of the reports, nearly one third compared to less than one tenth in all other cases. We examined students' responses to this report more closely. Of the students who responded "no" originally (about 14% of the total number of students), three fourths were less certain of their original response after reading the report. This is a logically sound position given the report's support of a "yes" response. However, of the students who responded "yes" originally (about 80% of the total number of students) nearly one fourth were less certain after reading the report. We examined their reasons, and nearly all of these students gave the same type of response. The students' reasons tended to derive from local lore about weather and health, such as that damp weather aggravates arthritis. In no case, however, were the reasons offered by the report contradictory to the reasons offered by the students – they merely were different. Thus, even though the students gave "yes" responses to the original question, and even though the report supported those responses, they were less certain in their responses after reading the report because the report had offered different reasons than they had offered.

At this point, we struggle to discern any understandable connection between students' prior beliefs, their cognitive interpretations of what they read, and their metacognitive judgments of how what they read bears upon their prior beliefs. In no way can we understand the connection as reasonable. If such connections are not reasonable, effective metacognitive control of reading appears to us impossible. If sensible connections are not made between prior beliefs, the information in the text, and beliefs after reading, then sensible judgments cannot be made about whether one's reading is adequate or requires some corrective action.

In the following section, we attempt to pick up the pieces – to explain the unreasonableness of the connection between the high school students' prior beliefs and their judgments of how their reading bears upon those beliefs, and to explain the mismatch between university students' expressed ease in reading the reports and the actual standing of their interpretive performance. Both phenomena, we will argue, are traceable to the same underlying cause – students' metacognitive views of the nature of reading.

How to Account for the Results

Two features of students' views of reading are revealed in our results. These features work together to create what we have called "a simple view of reading". First, we will examine how the high school students in general demonstrated a marked deference to the reports when we asked them to relate what was in the reports to their prior knowledge. We categorized their stances toward the reports either as *text-based* (maintaining certainty in a belief solely on the basis that the report says it or that the report agrees with their preexisting beliefs), *background-belief-based* (forcing interpretations on the reports in order to bring them in line with their preexisting beliefs), or *critical-based* (adjudicating their background beliefs and the reports in light of one another and on the basis of reasons in order to construct new or revised beliefs).

The pattern of student responses described in section "Metacognitive Performance: What Students Made of Their Reading" can be understood partly by examining students' adopted position with respect to the reports. In adjudicating their prior beliefs against what they read, more than two thirds of students adopted text-based positions. They either deferred absolutely to the reports, simply paraphrased the reports to support their position, or agreed with the reports on the grounds that their own beliefs and the text coincided. Slightly fewer than 20% adopted a background-belief-based position by imposing interpretations on the text to accord with their own background beliefs. In the text-based responses, what Olson (1994) called "the world on paper" overrode the readers' worlds; in the background-belief-based responses, the readers' worlds overrode the world on paper (Phillips and Norris 1999). Both of these response types are uncritical. Only a minority of students adopted critical positions, either by giving good reasons why the reports should be believed (at most 17% for any report), or by taking issue with the text on the basis of good reasons (at most 10% for any report).

As mentioned in section "Metacognitive Performance: What Students Made of Their Reading," there was no systematic relationship between students' degrees of certainty in their beliefs and the support that the reports offer for them. In examining their reasoning, we saw that the lack of connection was due to students' failure to integrate well their background beliefs and the text information. This result is consistent with other research that has illustrated the tendency for ideas, once formulated or adopted, to persist despite disconfirmatory evidence (Beal 1990; Holland et al. 1986). The majority of students deferred to the reports by readily accepting the statements in them and by implicitly trusting the authors. Only on rare occasions did readers challenge the authority of the reports or the authors. Few students appraised the reports against their background beliefs. Thus, the agreement or disagreement between the scientific beliefs students held before reading the reports and what the reports said had extremely little to do with the scientific beliefs they held after reading the reports. If students were less certain about their initial beliefs after reading a report, then their diminished level of certainty presumably would be on the grounds that the report was sufficiently persuasive and credible to alter their initial position. For those students who expressed more certainty about their initial beliefs, the same response would be expected. However, those students who expressed either less or more certainty about their background beliefs tended to do so, not on the basis of a critical evaluation of the text, but on the basis of mere deference, echoing, or affirmation of the text. Only for the weather and sickness report did a sizable number of students who expressed either less or more certainty critically evaluate the report. The most influential factor in students' judgments seemed to be what the reports said and not whether and why the reports should be believed. Hence, for most of these students, rather than integrating the two worlds, the world on paper weighed supremely over their own cognitive worlds. Thus, the goal of students' approaching "[science] reading as an interactive-constructive process and science learning as something more than conditioned responses and rote memorization" (Holliday et al. 1994, p. 879) seems not to have been reached by these students.

We can now circle back to the university students who reported finding the media reports easy to read but performed poorly on the interpretive tasks we set for them. Why did they interpret poorly? From our experience with the ability of individuals to perform very well on standard reading assessment tasks in spite of the fact that the passages are beyond even their modest understanding, our conjecture is that the interpretive tasks we designed required these students to go beyond decoding words and locating information in the text, which is a sufficient basis for most standard reading assessment tasks (Collins Block and Pressley 2002; Pressley and Wharton-McDonald 1997), although insufficient for authentic reading. We had asked them to infer connections between statements that often were widely separated in the text; they were asked to infer pragmatic meanings that often were not literal; in short, they were unable to make interpretations that went beyond the literal. However, why did they report finding the passages of suitable reading difficulty? Our hypothesis is that their view of reading led them to this conclusion. They knew they could identify the words, and they knew they could locate information (a confidence justified by our direct assessment of their information-location ability). Therefore, all of their school and university experience told them that they had read successfully, even though they had not.

According to the simple view, reading means word recognition and information location, and it is a view that has been documented and regretted widely (e.g., Baker and Brown 1984; Collins Block and Pressley 2002). Sadly, although according to their simple view of reading they had read, they did not understand. More sadly, their view of reading was not up to the task of helping them to see that they had not understood. The simple view aims to reduce reading to word recognition and location of information, but fails because it is easy to demonstrate how the satisfaction of these criteria can be achieved without understanding in any deeper sense than grasping surface meanings.

Why did the university students perform on the cognitive tasks no better than high school students who had much weaker science backgrounds? That is, why did their science background appear not to help? It is widely believed that more background knowledge is associated with improved reading comprehension. Phillips (1988) supplies a possible explanation of the lack of relationship between students' science backgrounds and their performance on the tasks we set for them. She found that sixth grade readers' background knowledge mattered only in the context of reading proficiency defined by the use of what she called "productive reading strategies," which include questioning your interpretations and considering alternative ones. Students in her study who used such productive reading strategies were able to compensate somewhat for their lack of background knowledge, although the best reading was found in the context of both productive strategies and background knowledge. The productive reading strategies used by the children corresponded in a large measure to those identified by Collins et al. (1980) in their study of skilled adult readers, and strongly overlap with strategies often associated with the monitoring function of metacognition, because they point to ways to think about thinking while reading: Have I considered alternative interpretations? Does my interpretation take into account all of the textual information? Am I able to confirm my interpretation? Am I empathizing with the experiences of the characters? (Norris and Phillips 1987). Therefore, it is reasonable to surmise that many of the university students in our study lacked metacognitive strategies for reading the type of text found in the media reports of science. Else, they would have been able to capitalize upon their superior scientific knowledge and outperform the high school students. Needless to say, such strategies as questioning one's interpretations and seeking alternative ones are not the type employed by those readers concerned primarily with identifying words and locating information.

Consider an example. It is one thing to read in a media report of science these very words about the Jovian moon, Europa: "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, the statement 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 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 ice is itself a hypothesis from the photographic data.

Now, let us examine some additional data from the university students' responses. First, let us look at their judgment of the expressed degree of certainty in the statement, "There is liquid water and melting on Europa." We interpreted the statement as having *uncertain 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,* and 52% judged it as *likely to be true*. 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 naive, simple view of reading. They did not realize that they were not making interconnections among noncontiguous 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." Whereas in the data from the high school students we see a marked deference to text, in the data from the university students we see accomplished attention to detail without a comparable attention to the message as a whole. These two features of students' reading actually go together. Attention to word recognition and isolated pieces of information leads to an overinflated view of ability to read for those who do recognize the words and can locate the information. Also, attention to the words, without attention to what the author is trying to convey with those words (the distinction between what the words say and what the words mean), leads to an unanalytical and uncritical approach to reading. Barring analysis and criticism, all that remains is deference and acceptance.

Clearly, then, the simple view of reading does not address what we wish to achieve in science education. Sophisticated reading, in contrast to what the high school and university students tended to exhibit, requires a level of cognitive and metacognitive expertise that enables sound interpretations at a variety of levels. We like Olson's concept of literate thought as a means of capturing very significant aspects of metacognition. The key to reading on his view is the mastery of literate thought, which brings the thinking involved in reading 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). It is literate thought conceived in this way that governs performance on the sorts of interpretive tasks that we have described, because it addresses several key aspects of the monitoring function of metacognition. If readers do not recognize when they are making assumptions and inferences and drawing conclusions, they can hardly effectively monitor the quality of their reading and are missing the input needed effectively to control its direction. In addition, sophisticated reading requires metacognitive appraisal that provides an accurate gauge of the quality of one's interpretations, of how what one is reading ought to interact with what one already believes, and, more generally, of the stance that one ought to adopt with respect to a text.

In contrast to the naive, simple view of reading as decoding words and locating information, we offer a view of reading as inferring meaning from text through the integration of text information and the reader's knowledge. This integration creates something new, over and above the text and the reader's knowledge – 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 position 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 (Norris and Phillips 2003).

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 judgments about text that go beyond surface meaning: Including judgments 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 et al. 1987; Bereiter and Scardamalia 1987; de Castell et al. 1986; Torrance and Olson 1987).

From our perspective, reading has a number of features (Norris and Phillips 1987). First, reading is *iterative*. By this we mean that reading proceeds through a number of stages that move between the cognitive and metacognitive, each aimed at providing a more refined interpretation: Lack of understanding is recognized; alternative interpretations are created; judgment 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; judgments are made of the quality of interpretations, given the evidence; and interpretations are modified and discarded based upon these judgments and, possibly, alternative interpretations are proposed, sending the process back to an earlier 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 that the reader has created, again moving between the cognitive and the metacognitive: Judging whether what they know fits the current situation; conjecturing what interpretation would or might fit the situation; and suspending judgment 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 available textual information and background knowledge. Finally, in order to carry out such negotiation, reading is *principled*. The principles guide both cognitive interpretations and metacognitive judgments. Completeness and consistency are the two main criteria in both cases. Neither criterion by itself is sufficient; they must be used in tandem. Readers must ask which interpretation is more complete, and more consistent, because often neither interpretation will be fully complete and fully consistent.

Reading, then, means analyzing, interpreting, and critiquing texts. In order to engage in the metacognition needed to monitor and control such processes, readers require an elaborate repertoire of basic understandings of texts. On our view of reading, reading resembles science, in that it involves many of the same mental activities that are central to science (Gaskins et al. 1994; Norris and Phillips 2008). 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 manipulative activities and working with the natural world. However, the relationship between reading and science is intimate. Science educators need to be concerned, therefore, by the possibility that many students will bring to their science learning the simple view of reading. If science teachers do not emphasize the expansive nature of reading, then they are likely to reinforce the attraction that this simple view has.

Educational Policy

If citizens are unable accurately to interpret popular reports of science and, furthermore, are disposed to defer to them, then teaching them more of the substantive content of science will not help. How readers appropriate the relationships within texts depends upon the cognitive and metacognitive strategies and the repertoire of knowledge they bring from their worlds, and what happens when their worlds and the world on paper meet. Students must learn to take a critical stance toward texts, or we can do no more than teach them to remember what reports of science say. Such superficial memorization is not likely to achieve the good for citizens and society that we all desire. Rather, more concerted attention to generalizable literacy skills and attitudes is a better bet.

A view that underlies this chapter is that science teaching is in part a literacy project. For many science teachers, seeing themselves as literacy teachers would require a radical shift in their self-conception. However, in adopting the role of literacy teacher, science teachers would play a role more central to education than the teaching of science. Science teachers would teach the concepts, skills, understandings, and values that are generalizable to all reading and that find application within science. In order to achieve this transformation in teacher outlook, much curriculum work and teacher education needs to take place.

First, much more emphasis is needed on teaching and learning how to read argumentative text, that is, text in which reasons and evidence are offered for conclusions. Beginning reading programs once contained almost only narrative selections for students to read. This domination by narrative is slowly coming to an end, but its replacement hardly ever includes argumentative text (Phillips et al. 2005). Rather, what is found is more informational and expository text that, like current science textbooks (Penney et al. 2003), tends to emphasize word recognition and information location – just the focus that needs to be downplayed. There is a need for more emphasis on teachable cognitive and metacognitive reading strategies for dealing with argumentative text, and for persistent pressure on the educational system to take seriously explicit instruction in the early school years on reading and writing argumentative text. Unless students recognize the need for, and know how to make, the sorts of pragmatic meaning interpretations of scientific texts that we have discussed (those concerning expressed certainty, scientific status of statements, and the role of statements in scientific reasoning), they are not likely to be able to make accurate assessments of the difficulty of texts. Likewise, they are not likely to make sound judgments about the effects of what they have read on their existing beliefs. Thus, the cognitive and metacognitive come together, with the performances of the former providing the focus for the judgments of the latter.

Second, it would be helpful to articulate for science educators a clear rationale for the scientific practices with text that ought to be brought into the science classroom. The rationale would be partly value driven by referring to and justifying the goals that would be achieved, but also empirically driven by drawing on available research on which practices work and which do not. There are many questions that need to be explored, including ones about the type of texts that might achieve the most desirable ends – genuine scientific research reports, genuine reports suitably translated for particular levels of schooling (Baram-Tsabari and Yarden 2005; Phillips and Norris 2009; Schwab 1962), or fictional texts purposely designed and created for the situation.

Third, and related to the second point, on the assumption that textbooks will be around for a long time, we need redesigned textbooks that incorporate more argumentative text and focus on the reading strategies useful for interpreting them. For this to happen, the texts themselves have to be worthy of interpretive attention and effort, so that students can move away from recall, recognition, and information location. Metacognition is hardly required unless, first, cognition is! Textbooks could start to include more explicit and frequent treatment of reasons for conclusions, examples from frontier science where the scientific community has not reached consensus on an issue, and the use of media reports of science as texts to be interpreted and critically appraised.

Finally, science education needs to pay greater attention to reading science. Reading science is not about simply recognizing words and locating information, as important as these skills are at a basic level. It is mainly about seeing the structure of science in the text. However, in order to see this structure, students require a more sophisticated view of reading. The naive view of reading as word recognition and information location hinders their ability to relate what they read to what they already believe and even to grasp when they have not understood what they have read. A naive view of reading indeed hinders so much else, and the fix is too straightforward to be ignored.

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Appendix: New Animal Species Found in Vietnam

1. WASHINGTON (AP) – A "lost world" teeming with possible new species of birds, fish and an unknown dagger-horned mammal has survived a half-century of war and expanding civilization in remote Vietnam, wildlife experts say.
2. If it proves to be a new species, the U.S. and British scientists said the creature locally referred to as a "forest goat" would be one of only a handful of large mammals newly recorded in the last 100 years.
3. A recent survey of the relatively untouched Vu Quang Nature Reserve by a team from the Vietnam government and the World Wildlife Fund documented preliminary evidence of two previously unknown bird species, at least one new fish, an unknown tortoise with a striking yellow shell and the goat-like mammal. "The horns are quite unlike those of other goats previously recorded," said British scientist John MacKinnon, who led the World Wildlife Fund expedition in May. He said it could be another kind of bovid, or hooved animal.

4. "It's a lost world that modern science had never before looked at," he said in a telephone interview late last week from London.
5. With most of Indochina heavily populated and so ravaged by wartime herbicides and bombing, stepping into Vu Quang is "like opening a door into a lost and neglected place," MacKinnon said. "Biologically, it's not like the rest of Indochina." Officials of the Washington-based World Wildlife Fund said the relatively untouched Vu Quang area spreads over 168 km^2 along a steep stretch of land near the Laotian border, a 10-h overland trip from Hanoi.
6. The team found three sets of upper skulls and horns of the previously unknown mammal, MacKinnon said. While none was spotted alive, one of the skulls still had maggots crawling in it, indicating it had died recently.
7. Skin samples from the hooved beast, which is a target of hunters in the area, will be compared with those from cows, buffaloes, antelopes and goats to see where it falls scientifically, MacKinnon said. Skulls are also being examined by scientists in Vietnam, he said.
8. The Vietnamese are trying to find a better specimen, he said, "but we don't want to encourage actively shooting one because it might be a very rare animal."
9. MacKinnon said he plans to return to the area soon and will set up cameras in the forest. Elephants, tigers and leopards are among animals known to be in the area, he said.
10. In addition to the evidence of a new mammal, MacKinnon said the scientists spotted a small parrot-billed bird that they believe may not be documented, as well as a sunbird that could be a new species and at least one new fish.

Belief Questions

Do you believe that new animal species are still being found around the world? Why do you say that?

How much knowledge of the general topic of the article do you have? Please respond by checking the alternative which best applies to you: No knowledge; Very little knowledge; Some knowledge; Much knowledge. Please explain your choice.

Cognitive Questions

Set 1

Students provided with five statements from the report and instructed: "For each of the statements, decide whether according to the report the statement is, True, Likely to be true, Uncertain of truth status, Likely to be false, False."

"After each statement indicate where in the report you found information to help you decide by writing the paragraph number(s)."

Set 2

Students provided with five statements from the report and instructed: "For each of the statements, decide whether the statement reports: That one thing causes or influences another; That one thing is generally related to another; What was observed; What prompted the scientists to do the research; How the research was done. For each statement, choose only one answer. You may choose the same answer for different statements."

"After each statement indicate where in the report you found information to help you decide by writing the paragraph number(s)."

Set 3

Students provided with five statements from the report and instructed: "For each of the statements, decide whether the statement reports: A justification for what ought to be done; A phenomenon identified and explained in the report; An explanation of a phenomenon; Evidence for or against a hypothesis that has been made; A conclusion drawn on the basis of reasons; A prediction from an idea being tested. For each statement, choose only one answer. You may choose the same answer for different statements."

"After each statement indicate where in the report you found information to help you decide by writing the paragraph number(s)."

Metacognitive Questions

Now that you have read the report, are you more certain, less certain, or equally certain about your answer to [the question of whether you believe that new animal species are still being found around the world]? What made up your mind?

How easy or difficult did you find the article to read?
Very easy; Easy; About right; Difficult; Very difficult
If you chose *Difficult* or *Very Difficult*, please check all that applied to you while reading the article:

You are not familiar with the general topic of the article;
The scientific explanations were complicated;
You have little or no experience reading newspaper reports of scientific research;
The report was not clearly written;
Other (Please explain).

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