Reading in Science: Why, What, and How

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The productive use of text in the elementary school science classroom poses intriguing problems for educators. A recent conversation with a group of upper-elementary-school teachers was revealing in this regard. These teachers, all of whom were engaged in inquiry-based instruction (as encouraged by national science education standards), expressed significant reservations about the use of text in science teaching and learning. Some of them argued that text can usurp children's own very capable thinking; that is, children will defer to the authority of the text and rely less on their own capacity to make careful observations, manipulate real-world phenomena, represent and interpret data, and, ultimately, test out and refine their emerging explanations for how the world works as it does. Other participants in this conversation maintained that the issue of how text might interfere with children's creative thinking was moot, since most science texts, with their challenging vocabulary words and dense concepts, were inaccessible to students anyway.

In this essay, I wish to address the concerns these teachers raised and describe how educators can use text in a manner that advances scientific literacy. I also wish to describe how using text in the context of learning science can advance students' general literacy skills. I begin by identifying why reading is integral to the learning of science.

Why Texts in Science?

The role of text in supporting the acquisition of scientific knowledge

"What would happen if you got too close to a black hole?" "I heard that cows have three stomachs. Why do they need three stomachs when we only have one? Do they have six lungs?" "Is the sun really going to catch the earth on fire some day?" "Can a person get blown apart in a wind tunnel?"

Children have a huge number of questions about the natural world, only a small proportion of which they can investigate in any firsthand way. Many of the phenomena that intrigue children (for example, black holes) are not accessible to them. Investigating many of their questions would take resources that are not typically available in the classroom (for example, a wind tunnel). Furthermore, the school calendar allows time for only a fraction of the investigations that children can conduct in a firsthand way. For all these reasons, text and reading are integral to the teaching of science. It is simply not possible for children to learn all there is to learn about science from firsthand investigations of the world.

The role of text in advancing scientific literacy

The National Science Education Standards (National Research Council, 1996, p. 45) call for U.S. students to "learn how to access scientific information from books . . . and evaluate and interpret the information they have acquired." This standard reminds us that an important dimension to scientific literacy is the capacity to read and evaluate written information. This goal becomes all the more pressing as information proliferates on the Web and as we confront a range of increasingly complex issues that call for an informed citizenry. Consider, for example, the interpretive skills it takes to read and evaluate two opposing views regarding the evidence for global warming, to make a sound choice regarding the short- and long-term costs of rescinding some of the provisions of the Clean Air and Clean Water Acts, to weigh in on the health-related and ethical aspects of engaging in research with human embryonic tissue, or to determine whether tax monies are well spent pursuing a human mission to Mars. The research of Norris and Phillips (1994) tells us that these interpretive skills are not developed without care and attention. Norris and Phillips interviewed students taking advanced physics courses and found that, despite having fairly advanced knowledge of scientific concepts, these students had difficulty evaluating the accuracy and completeness of scientific evidence that appeared in newspaper accounts written for the layperson. These reading and interpretation skills need to be cultivated while a child is in school.

The role of science text in supporting children's learning from informational text

Science classes are an ideal context in which to introduce students of all ages to informational texts. This is important for several reasons. For example, the lack of opportunities that young children, in particular, have to learn from informational texts —such as science texts— has become suspect in the search for an explanation for the "fourth-grade slump." The fourth-grade slump refers to the phenomenon whereby students who have previously fared well on standardized tests of reading experience difficulties when they reach fourth grade. One important shift in the fourth grade literacy curriculum is the expectation that students will primarily learn from informational text, to which most fourth graders have had minimal exposure Nell Duke (2001) analyzed the amount of time first graders in 20 classrooms experienced reading or writing informational texts and found that, typically, young children experienced informational text only 3.6 minutes a day; the preponderance of their reading and writing was narrative in nature.

Why is the dearth of expository text a problem? There are important distinctions between narrative and expository texts. These differences can be described in terms of both the features and the functions of narration vs. exposition. A narrative (that is, a story) typically has a beginning, middle, and end. It usually has a goal and an internal structure that consists of such components as characters, settings, themes, plots, and resolutions. The function of a narrative is generally to entertain or to excite. Certainly, narratives have an important role to play in science education to the extent that they can engage students in interesting ideas; biographies are important narratives that can inform students about the conduct of science and the contributions of scientists.

Expository texts, on the other hand, make use of a wide range of text structures, such as cause/effect, compare/contrast, problem/solution, listing, or a chronology of events. Expository texts are typically used to inform—to communicate information about the world. Generally, when we read a narrative, we experience it and move on; however, when we read an expository text we typically seek to integrate what we are reading with what we already know, in essence "updating" our knowledge. In addition to the learning opportunities inherent in reading informational texts, it also appears that, contrary to popular opinion, informational texts are more motivating to certain children —even young children—than are narrative texts (Duke, 2001).

The role of metacognition in reading and learning from text

Skilled comprehenders engage in metacognitive activity, maintaining an awareness of the success with which they are constructing meaning, and drawing upon a repertoire of strategies to if they encounter impediments to their understanding. Inquiry requires a similar disposition on the part of the learner: a mindfulness about the purpose of the inquiry, attentiveness to the relationship between the question that is guiding the inquiry and the investigation itself, and the ability to monitor the progress of the inquiry in terms of how well it is advancing one’s understanding of the phenomenon under investigation. This is another way in which there is exciting potential at the intersection of the teaching of text comprehension and the engagement and support of children in inquiry-based science learning.

The role of science text in promoting general literacy skills

A final answer to the question, "Why text in science?" is that teaching from science texts can promote important general literacy skills. In addition to providing an excellent opportunity for acquiring information about the world, reading science texts provides students the chance to learn specific academic language. Borrowing a line from a parable in the Gospel according to Matthew (“For to everyone who has will more be given, and he will have abundance; but from him who has not, even what he has will be taken away”), psychologist Keith Stanovich (1986) coined the term “the Matthew effect” to describe the acquisition of reading skills. In a nutshell, Stanovich proposed, “the rich get rich, and the poor get poorer.” Thus, children who are exposed to text have opportunities to acquire knowledge of vocabulary, background knowledge, and knowledge regarding how reading material is structured that children who are not exposed to text do not have. Students with this richer knowledge base experience a bootstrapping of further vocabulary, real-world knowledge, and knowledge of and comfort with the structure of texts.

Science texts offer many opportunities to enrich children's general literacy knowledge, primarily because vocabulary is used with a mindfulness in science that sets it apart from most other content area texts. For example, reading about the water cycle in the STC *Land and Water* unit, students encounter the words *precipitation*, *condensation*, *evaporation*, and *distillation,* each of which has a very particular meaning. Science texts typically conform to an identifiable structure; for example, they may be written to inform (presenting attributes or events), to argue (via the presentation of evidence for particular claims), or to explain (to bring the reader to deeper understandings of phenomena). Teachers can take advantage of these structures to alert students to attend to text structure and to use it to support their understanding and recall of the text.

What Does "Good" Science Text Look Like?

Not all science texts lend themselves equally well to achieving the goals set forth in the preceding paragraphs. This section presents some criteria that educators might consider in evaluating science text.

- Science texts should provide rich, accurate scientific information that is central to standards based content goals (Ford, in press).

This is a tall order and one that authors and publishers of science texts have not always achieved. Science texts have been criticized because of the errors and misconceptions they present (Abimbola and Baba, 1996); the manner in which they oversimplify explanations (Brown and Palincsar, 1992; Lloyd and Mitchell, 1989); the tendency to treat too many topics superficially (Roseman, Kesidou, and Stern, 1997), resulting in the presentation of information that is "a mile wide and an inch deep"; and the inaccessible ways in which they are written (Armbruster, 1992).

Clearly, if children are going to be encouraged to use text to advance knowledge building, there has to be sufficient substance to support that knowledge building, and the information has to be presented in an accessible manner.

- Science texts should link the products of science (the knowledge base) to the producers of this knowledge and to the ways in which the knowledge base has been generated and evaluated (Ford, in press; Palincsar & Magnusson, 2001).

In his critique of science texts, Rutherford (1991) has written, "Textbooks are more of a hindrance than a help in elementary science education because *they emphasize not discovery but presentation.*" (p. 27, italics added). His critique goes to the heart of the matter that teaching science is not about the teaching of isolated facts—science is a social enterprise. Knowledge production is a process of *invention* in which the scientific community ultimately determines what is “discovered.” Furthermore, the activity of scientists is guided by norms and conventions regarding how investigations are to be conducted, how knowledge claims will be generated from those investigations, and the evaluation procedures that determine that these claims will be accepted by the community (Magnusson & Palincsar, in press).

One of the advantages of engaging students in firsthand investigations of their world is that a classroom community can emulate a scientific community, complete with identifying the norms and conventions that will guide the generation and evaluation of knowledge claims. However, it is also possible to use texts to advance students' understanding of the nature of science. The STC reading selections include a number of pieces about how scientific knowledge has been advanced and the role that serendipity, inventiveness, courage, fellow scientists, and error have played in advancing scientific knowledge. Furthermore, these texts pay considerable attention to the tools of science, which also play a significant role in advancing knowledge. Teachers can alert students to these aspects of science, encouraging them to be as alert for information about *how* scientists know what they know as they are for information about *what* scientists know.

- Science texts should serve as a model for students of investigation, scientific reasoning, argumentation, and representations of theories and data (Ford, in press; Palincsar & Magnusson, 2001).

This criterion, which is related to the one immediately above, identifies some specific ways in which text can advance students' knowledge of science. This criterion also points to some of the ways in which teachers can use texts; for example, to encourage students to identify what the text reveals about how particular investigations were designed and conducted, to help students trace the line of reasoning presented in the text, and to engage students in making their own interpretations of data presented in the text and evaluating how compelling they find the link between the data and the knowledge claims or theories generated from those data.

- Science texts should provide opportunities for readers to develop skills related to reading and interpreting graphically presented information, including data tables, illustrations, and figures (Ford, in press; Hapgood, Magnusson, & Palincsar, in press).

Graphical literacy is another important dimension of scientific literacy. Making a link from quantitative data to a relationship between variables that corresponds to aspects of the physical world is a fundamental aspect of inquiry. Gott and Duggan (1996) argue that having "concepts of evidence," such as knowing how to use tables and graphs and thinking about variable manipulation, is at least as important as is developing understandings about "substantive" scientific relationships, such as the relationship between an object's mass and its speed going down a ramp.

In her dissertation study, Hapgood (2003) documented the challenges second graders encountered (and successfully met, with the assistance of their teacher) while examining and interpreting a data table. The table presented the time it took for balls of two amounts of mass to travel down a ramp. There were four trials for each ball. The following list illustrates the richness of the learning opportunities such a data table afforded:

- Linking a value to a physical phenomenon
- Following the logic of rows and columns
- Determining to what the values in each cell correspond
- Assessing if there are anomalous data
- Evaluating the trustworthiness of data
- Comparing values, looking at columns more as a whole than as discrete parts, and
- Using comparisons to address the question driving the inquiry.

How to Use Text to Advance Science Learning

Having considered the features one might consider in selecting science text for instruction, I turn now to the topic of *how* teachers might engage in the use of text in science teaching. I will consider how teachers can use science text in optimal ways to advance students' learning of science and scientific ways of thinking and reasoning.

Determine and build upon prior knowledge and beliefs.

If there were but one message that the reader takes away from this essay, it is *the importance of knowledge building as the goal for reading text.* While texts can certainly enrich the information that students acquire about phenomena, reading is not about the accretion of isolated facts. Rather, as students read, they should be supported to recognize how their understanding is being shaped by and deepened. This means that teachers must attend to building on the initial ideas (knowledge and beliefs) that children bring to the phenomena they are encountering in text (Smith, DiSessa, and Roschelle, 1993).

One way to achieve this opportunity is to provide overviews of upcoming content, Teachers can use overviews in multiple ways, including (a) encouraging students to identify what they already know about the topics they will be reading, (b) engaging students in identifying what they wonder about related to these topics, and (c) encouraging students to identify other sources of information regarding these topics.

One concrete approach teachers can use to activate students' prior knowledge is the preparation of *anticipation guides* (Head and Readance, 1986). An anticipation guide is simply a list of three or more debatable statements about a topic that students will encounter in the text. Students are then asked whether they agree or disagree with the statements. To optimize the use of an anticipation guide, teachers should encourage students to indicate why they agree or disagree, and in so doing, indicate how they know what they think they know.

Anticipation guides cans serve other purposes as well; for example, they can heighten interest, provide a purpose for reading (to confirm or revise one's thinking), and, by checking on the relationship between one's prior thinking and the information in the text, encourage readers to monitor the sense of the text.

Approach the reading of text as an inquiry.

There are a number of parallels between scientific inquiry and reading that teachers can exploit for the purpose of enhancing student learning from text. Perhaps the most salient requisite to both text comprehension and learning from inquiry-based instruction is the construction of knowledge and understanding. In both text comprehension (Goldman, Coté, and Saul, 1995; Chan, Burtis, Scardamalia, and Bereiter, 1992, and Chi, 1994) and science inquiry learning (Clement, 1993; Magnusson and Palincsar, 1995; Schwab, 1962), children construct meaning by integrating new information with prior knowledge and by building representations or mental models of the referential situation. In the course of reading science texts, teachers can draw attention to the ways in which language in general, and words in particular, are being used to communicate scientifically (e.g., through argumentation).

An instructional technique that pairs well with the ideas just described is the use of graphic organizers, which include semantic maps, webs, and other devices that engage students in depicting relationships among ideas that are presented in the text. Mapping may be presented in a variety of ways. Typically, the teacher would initiate the construction of a map by identifying one or more key concepts that are central to the topic the students will read about. In keeping with the idea of activating prior knowledge, students would then brainstorm other words or ideas that are prompted by the key terms the teacher has identified. The pool of words or ideas is then clustered, so that ideas are categorized. The power in this activity is the discussion regarding *why* and *in what ways* ideas go together. The teacher can post the map students have generated before the actual reading of the text and add to it as students read the text.

Another parallel between reading and scientific inquiry is that both call for coordinating information across texts. For example, in the course of inquiry experiences and in reading, children have opportunities to compare: (a) information presented by peers with their own thinking, (b) lab notebook entries (within and across students' notebooks), and (c) their own experiences and ideas with those reported in science texts (Goldman, 1997, Hartman,1995; Perfetti, Britt, and Georgi, 1995; Pappas and Varelas, 2004).

An old favorite of teachers that is also an effective means of achieving this type of coordination is the use of KWL (Know, Want to Know, and Learn) Plus (Ogle, 1989). KWL begins in a way that is similar to the semantic mapping described above. Given a topic, students generate what they believe they know about it and proceed to categorize these ideas. For example, presented with the topic of "plants," students may identify the names of plants, the things plants need to survive (for example, water, soil, proper temperature), and the medicinal and nutritional uses of plants. The third step in enacting KWL is identifying questions regarding what one would want to learn from the reading. These questions can be paired with the categories that have been identified, although new categories may emerge in this process. Finally, as students read, their inquiry is guided, in part, by the questions they have identified. Concurrently, they are adding to the information they are learning and comparing the "What they know" list with the information encountered in the text. The "plus" stage of KWL is the identification of new questions that are prompted by the reading.

The role of language in successful reading of text

A significant literature speaks to the importance of vocabulary knowledge in advancing text comprehension (Stahl and Fairbanks, 1986). In fact, the relationship between vocabulary knowledge and comprehension is remarkably robust across ages and populations. Furthermore, research syntheses (for example, the National Reading Panel, 2000) suggest that the context in which words are learned is critical to the success of vocabulary instruction. To that end, the opportunity to build vocabulary knowledge is an important dimension of the successful use of text in science teaching, particularly since one of the hallmarks of science is the very precise ways in which language is used.

Beck, McKeown, and Kucan (2002) offer a number of helpful ideas for thinking about the teaching of vocabulary in the context of subject-matter learning. Specifically, they encourage teachers to make distinctions among three tiers of words. Tier One words are basic words that are used frequently and that seldom require explicit teaching. Tier Two words are high-frequency words that are used by mature language users across content areas. Tier Three words are low-frequency words that are often limited to specific content areas. Under the topic of plants in the STC unit *Experiments with Plants*, for example, Tier Three words might include *pistil*, *stamen*, *stigma*, and *angiosperm*.

Because Tier Three words are low-frequency words and are typically encountered exclusively in subject-matter texts, teachers typically spend little time teaching them. Instead, they focus on Tier Two words, which students will encounter across subject-matter areas. This is generally appropriate. Nevertheless, teachers can ease students' reading of Tier Three words by introducing them in preparation for reading.

Pointing to the limitations of dictionary definitions, Beck and her colleagues urge that teachers introduce new vocabulary by *explaining* a word's meaning rather than by providing a definition for it. These explanations should characterize the word and how it is typically used (for example, "The word 'pistil' is used to identify one part of the plant that is responsible for the reproduction of plants. It is the female part of the plant and holds the seed. It is called a pistil because its shape is similar to the rod and bulb-like shape of a pestle").

Vocabulary is only one dimension of language that is relevant to learning from science text. As Gee (1996) and Lemke (1999 have pointed out, there is a whole discourse that is particular to engaging in science and communicating about scientific ideas. In our own research, we have encouraged students to use the discourse of science. For example, in our research in grades Kindergarten through five, as students engage in firsthand investigations, they are encouraged to think about the claims they wish to make from the data they have collected, to think about the strength of the evidence they have for their claims, and to think about the counter-evidence that they or others have for their claim. Similarly, as the students in our research read science text, we encourage them to identify the claims that are being made and to evaluate the confidence they have in these claims as a function of the evidence the author has provided. Finally, we encourage students to assume a skeptical stance both in the conduct of their own inquiry, as well as their reading of science text.

Coordinating the use of text and firsthand investigations

Having discussed why text is important to science instruction, what to look for in text, and how to support students' learning from text, we next consider how text can be integrated in firsthand investigations. To do so, I share the experiences of a fourth-grade teacher who integrated the use of text in the study of light interacting with materials (Magnusson & Palincsar, 2004; Palincsar, Hapood, & Magnusson, 2002). Figure 1 depicts the goals for this program of study, which was designed by Shirley Magnusson.

Scientific Content Goals	*Scientific Reasoning Goals*
▪ Light can be reflected, absorbed, or transmitted by objects. ▪ All objects reflect and absorb light. ▪ There is an inverse relationship between the amount of light reflected from and absorbed by an object. ▪ The behavior of light is related to the characteristics of the object with which it is interacting.	▪ Observe phenomena to determine how/why they occur. ▪ Record observations with precision. ▪ Decide when, how, and how often to observe in order to determine relationships. ▪ Use charts and graphs to organize and interpret data and determine patters/relationships. ▪ Conduct fair and reliable tests to answer a question. ▪ Express findings as knowledge claims. ▪ Present knowledge claims to the community (classmates). ▪ Evaluate the adequacy of knowledge claims on the basis of the strength of the evidence supporting them.

Figure 1. Goals for Ms. Freeman's unit of study about Light

Instruction proceeded through cycles of investigation, in which small groups of students (e.g, in pairs) investigated a particular set of claims that had been generated by the class based upon their experiential or background knowledge. The students designed their investigations, made and recorded their observations, prepared these data in relation to claims and then shared them with the class, prompting discussion about the set of claims developed by the class. During the course of first-hand investigations, the class generated a number of claims regarding the behavior of light, which varied in terms of the amount of supporting evidence the students had garnered.

The students then read a text that was developed for this program of study, in which they learned about the investigations of a scientist working with light. The scientist's investigations were partly a replication of what the students' had investigated, using a subset of the materials they had used in their inquiry. In addition, however, the scientist used a light meter for more precise observations of how light interacts with the objects, and for the purpose of making quantitative comparisons regarding the different ways that light behaves with objects.

The literacy teaching practices in which Ms. Freeman engaged speak to the processes described earlier in this paper regarding supporting learning from text. For example, Ms. Freeman led the students in a quick preview of the text (less than five minutes), during which the students identified the general topic of the text (an investigation with light), and the presence of findings from the investigation. As they previewed the text, Ms. Freeman called their attention to particular features of the text (e.g., diagrams of the investigative set-up, tables that presented data), asking the students why these features were included in Lesley's notebook. A significant amount of time was devoted to examining the relationship between the information in the notebook text and the students' own experiences. This examination occurred throughout the reading of the text but was particularly prominent before the students even began the reading. Ms. Freeman accomplished this by revisiting the claims list arising from the students' own first-hand investigations. The students identified those for which there was consensus and those which were still "alive" in terms of their consideration, but for which there was insufficient evidence. There were multiple examples of the class engaging in intertextual activity with at least four "texts" referred to in the course of the notebook reading: (a) the text itself, (b) the children's individual lab books, (c) the chart of class claims, and (d) the conversations that occurred as the class investigated and shared their findings. In addition, there were numerous instances when Ms. Freeman called the students' attention to the vocabulary words that were introduced in the text and how those compared with terms the students had been using in their own writing and discussion (e.g., Lesley's use of "absorbed" to describe the "blocking" of light.)

The teacher took particular advantage of the fact that the scientist had different findings from her investigation than did the students. In the following excerpt, the students are entertaining other possible explanations for the differences in their findings and the scientist's findings. In this instance, the scientist, reporting the data for what happens when a flashlight shines on a piece of black felt, indicates that she found no light transmitted through the felt. The majority of students, however, report having seen transmitted light, and consider why there might be a difference in this finding:

Catherine: When we stuck the lamp like – not like directly next to the black but a little bit up close to the black, it came out a maroon color on the other side.

Teacher: So we were getting some transmitted. We thought we had some transmitted light, too. She's not getting – detecting that, is she, with her light meter?

Nirmela: But she would be more sure because she has a light meter and we don't.

Teacher: What might cause a difference in results from what you did and from what she did?

Student: She may have had her flashlight back father than and we had ours up very close.

Teacher: Anything else might have made a difference? Ian?

Ian: She might have either had a weaker flashlight or a thicker piece of felt or something.

Teacher: Okay, so two things there.

Student: Yeah, or maybe it was because of the light meter.

Teacher: What about the light meter? How would the light meter make it harder to detect transmitted light?

Tatsuro: Because it's in, measuring in the tens. What if it was like 0.09?

Teacher: So maybe it's not measuring to the tenth or the millicandle?

Student: Or maybe she's just rounding off.

Teacher: Maybe she's rounding it off. Maybe the little machine rounds off. Good.

Louise: Or maybe it's because like, in the diagram, it shows it had the sensor pretty far back. Maybe the transmitted light didn't go that far.

In this excerpt the students began to identify the range of variables that might explain the differences in their outcomes, when compared with the scientist's, including: differences in the set-up, the materials, the strength of the light source, the device used to record the data, and the scientist's decisions regarding the reporting of the data. This exchange is significant to the extent that the students demonstrate an appreciation for the role that variables play in the design of an investigation. With this understanding, they are now situated to consider the control of variables that is necessary so that only a single contrast is featured in an experiment (cf. Klahr, Chen, & Toth, 2001).

As we have studied teachers using text in inquiry-based instruction, we have been impressed with the ways in which successful teachers make explicit and keep present the connections between students' relevant experiences (typically acquired through their own firsthand investigations) and the information they encounter in the text. In Ms. Freeman's case, she did this by referring the children to the class claims list, by urging the students to consult the data and claims they had recorded in their individual notebooks, and by asking the children to compare their ideas with the scientist's. Second, these teachers attend to guiding and shaping the conversation about text in *multiple* ways. For example, Ms. Freeman probed to check on the depth of understanding that students were deriving from their reading of the text, and she modeled her own thinking about the similarities and differences in the scientist's investigative questions, procedures, data, and claims, and the process and outcomes of the class. Finally, she encouraged the students to see themselves as having authority relative to the information in the text, and to resist taking a deferential stance toward the science text.

Conclusion

Understanding science, like understanding any subject, requires the basic tools of reading, writing, and oral language. Thus, learning science provides an opportunity not only to build knowledge about the physical world but also to learn about the basic tools that are used to build knowledge and represent it for others. Learning what others have discovered about the world and sharing one's own discoveries can be powerful motivators for learning to read, write, and speak in particular ways. There is no better time than the present to bring these meaningful contexts to the issue of literacy development.