Supporting Students in Developing Literacy in Science

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Science **328**, 456 (2010);
DOI: 10.1126/science.1182593

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Unresolved Issues

Investigation of cognitive processes during reading has provided important insights into conditions that promote or hinder the acquisition of new knowledge from science texts. However, many unresolved issues remain. One such issue is that mere coactivation of elements in working memory cannot fully account for the learning of all scientific concepts, many of which are chains of conceptual relations too long or complex to reside in working memory under the best of circumstances. It seems likely that direct relations between a few concepts accumulate into clusters of knowledge characterized by conceptual proximity. A second issue concerns the conditions that determine whether textual information overrides a misconception that the reader holds. What does it take for a single text to modify a reader's prior knowledge? A third issue concerns the variety of types of texts. As noted, much reading research has been executed in the realm of narrative texts, less with informational texts (*26*). It is likely that the essential toolbox of cognitive processes (working memory capacity, comprehension strategies, and standards of coherence) applies to all types of text, but the specific implementation may vary as a function of text type.

Using Texts to Teach Science

Texts are frequent and powerful tools for conveying scientific facts, principles, and explanations. To be effective, however, science texts need to be designed to optimize the likelihood that learning will occur. Central to comprehension of and learning from science texts is the identification of relations among the elements in the text and between these elements and the reader's prior knowledge, processes that occur while reading. Optimally designed science texts direct the reader's landscape of activations during reading in such a way that elements that should be connected do indeed get connected. When that happens, science texts are among the most effective tools we have available to teach science, to expand readers' knowledge of scientific topics, and to correct misconceptions.

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27. I thank P. Kendeou, R. F. Lorch Jr., and two anonymous reviewers for their thoughtful comments.

10.1126/science.1182594

REVIEW

Supporting Students in Developing Literacy in Science

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Reading, writing, and oral communication are critical literacy practices for participation in a global society. In the context of science inquiry, literacy practices support learners by enabling them to grapple with ideas, share their thoughts, enrich understanding, and solve problems. Here we suggest five instructional and curricular features that can support students in developing literacy in the context of science: (i) linking new ideas to prior knowledge and experiences, (ii) anchoring learning in questions that are meaningful in the lives of students, (iii) connecting multiple representations, (iv) providing opportunities for students to use science ideas, and (v) supporting students' engagement with the discourses of science. These five features will promote students' ability to read, write, and communicate about science so that they can engage in inquiry throughout their lives.

Systematic investigation of meaningful questions about natural phenomena and the development of evidence-based explanations form the foundations of science inquiry (*1*, *2*). In classrooms that emphasize such inquiry, fundamental literacy practices such as reading, writing, and oral discourse are essential to developing an understanding of the core ideas of science.

The National Science Education Standards (*1*) define scientific literacy as the understanding of science content and scientific practices and the ability to use that knowledge to participate in decision-making that is personal or that affects others in a global community. In addition, the Standards state that scientific literacy requires the ability to critique the quality of evidence or validity of conclusions about science in various media, including newspapers, magazines, television, and the Internet. The American Association for the Advancement of Science stresses the importance of scientific literacy for citizens' ability to participate with others in a global society (*3*). Underlying all of these definitions is the understanding that students must read, write, and communicate effectively to make decisions as informed citizens and engage in the critical thinking that active science learning requires. We have selected five aspects from the many features of literacy that are important to embed in inquiry science: (i) linking new ideas to prior knowledge and experiences, (ii) anchor-

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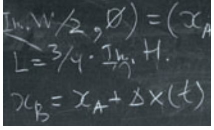


Table 1. Fostering literacy in the context of science inquiry.

Name	Description
Link to prior knowledge and experiences	Connect science ideas with students’ everyday experiences and with previous classroom experiences
Anchor in questions	Articulate questions that are meaningful and important to the lives of learners
Integrate text and visual representations	Explicitly reference visual elements in written text, and teach students to use graphics and text to support meaning making
Make use of ideas	Provide students with time, opportunities, and guidance to apply science learning to new contexts
Engage in the discourses of science	Explicitly support scientific discourses, including the language of science and its practices

ing learning in questions that are meaningful in the lives of students, (iii) connecting multiple representations, (iv) providing opportunities for students to use science ideas, and (v) supporting students’ engagement with the discourses of science. These five principles, discussed herein, are relatively consistent with the findings of others, and they repeatedly surface in our research in classrooms across the country (Table 1).

The first feature that promotes literacy as students engage in inquiry is linking new knowledge to prior knowledge. Prior knowledge forms a cornerstone of all subsequent learning, and eliciting prior knowledge becomes especially important when concepts are abstract, when scientific principles seem distant from students’ everyday lives, and when students’ experiences lead them to develop inaccurate ideas (*4*, *5*). For instance, middle school students may think of air as not made of anything, and because they conceptualize it as nothingness, they struggle to understand air as matter. However, students know that they have to add air to a basketball to make it bounce. Unfortunately, science instruction and curriculum materials often fail to explicitly link students’ prior knowledge and experiences to new learning (*6*). When instruction does not elicit experiences with air and familiar objects, students lack foundational understanding that can support them in learning that all matter, including air, is particulate.

Prior knowledge can come from either real-world experiences or previous classroom learning. The opportunity to share and connect ideas to build on them is key to constructing understanding. For example, consider the challenging concept of convection. Once students develop an initial understanding of energy and of matter as particulate, they are prepared to develop a coherent conceptual understanding of convection built on ideas already learned (*7*, *8*). Record-keeping of new understandings as they develop (such as in an individual science journal or a shared class bulletin board) becomes central to the ability to reflect on and connect ideas across time. Figure 1, taken from a sixth-grade chemistry unit (*9*), illustrates how reading materials help students connect in-class experiences with new information and generalize from those experiences to understand scientific principles. The materials suggest that students read, write, and discuss connections, using all three literacy practices to make sense of science content and to build understanding (*7*) as they investigate whether air has mass and volume.

A second important aspect of instruction and materials design for literacy in science is that to support students’ exploration of phenomena, writing about science, and reading of science text, instruction needs to be driven by questions that learners find meaningful and engaging. When learning is driven by a need to know, individuals put forth effort to understand difficult material (*10*). Motivating questions that connect to their lives help students set a purpose for engaging in scientific inquiry, as well as in the practices of reading and writing to learn. For instance, a question such as “Can good friends make me sick?” can motivate the study of the immune system and what causes diseases.

Although questions can serve to motivate learners’ engagement in both first- and secondhand investigations (*11*), many students remain unengaged by the expository text common to scientific literature and textbooks. Studies have shown that the vocabulary, complex sentence structures, use of passive voice, and other elements of scientific discourse prove challenging for many readers (*7*, *12*–*14*) and may contribute to students’ waning interest in learning science. Given that reading is of critical importance in science, those who struggle to read scientific texts are limited in the depth of understanding they can construct (*15*) and in their ability to engage in inquiry.

Posing interesting questions that motivate students to seek answers is one way to support their engagement (*10*), as the need to know drives text-based, as well as hands-on, investigation. For example, students are familiar with many chemical reactions in their everyday lives that they are not likely to recognize as chemical reactions. Raising related questions that students wonder about (such as “What makes fireworks different colors?” or “Why do people cry when they peel onions?”) might interest them in learning about chemical reactions in a way that seeing “Chapter 3: Chemical Reactions” in a textbook might not. These questions, along with original, student-generated questions, foster motivation to explore. As students progress in school, content-based questions (such as “How can two materials have the same chemical composition and molecular mass but have very different properties?”) might motivate students more than announcing “Today we begin studying isomers.”

Investigating the answers to questions that students find meaningful is important in the inquiry classroom, in which students experience phenomena and questions naturally stimulate learning. Using questions in the curriculum and encouraging them in instruction illustrates for students the manner in which scientists begin their own inquiry by defining the boundary between what is known and what is unknown (Fig. 1). Similarly, question-asking plays an important role in reading scientific text, as questions can establish a purpose for reading that guides comprehension. In setting a purpose for reading, questions affect which details individuals focus on and remember as they read. Scientific texts that employ questions as headers and instruction that models the use of questions to drive classroom activities can cultivate engagement and comprehension with scientific text (*16*).

Questions serve three important roles in the science classroom. First, questioning plays a critical role in science-content learning, as it sets a need to know that drives in-class or textual investigation. Second, questioning supports literacy development for science learning, as it helps to establish a purpose for reading and to guide comprehension of written text. Last, but equally as important, questioning engages students in a key scientific-inquiry practice, as scientists also initiate the discovery process by asking questions.

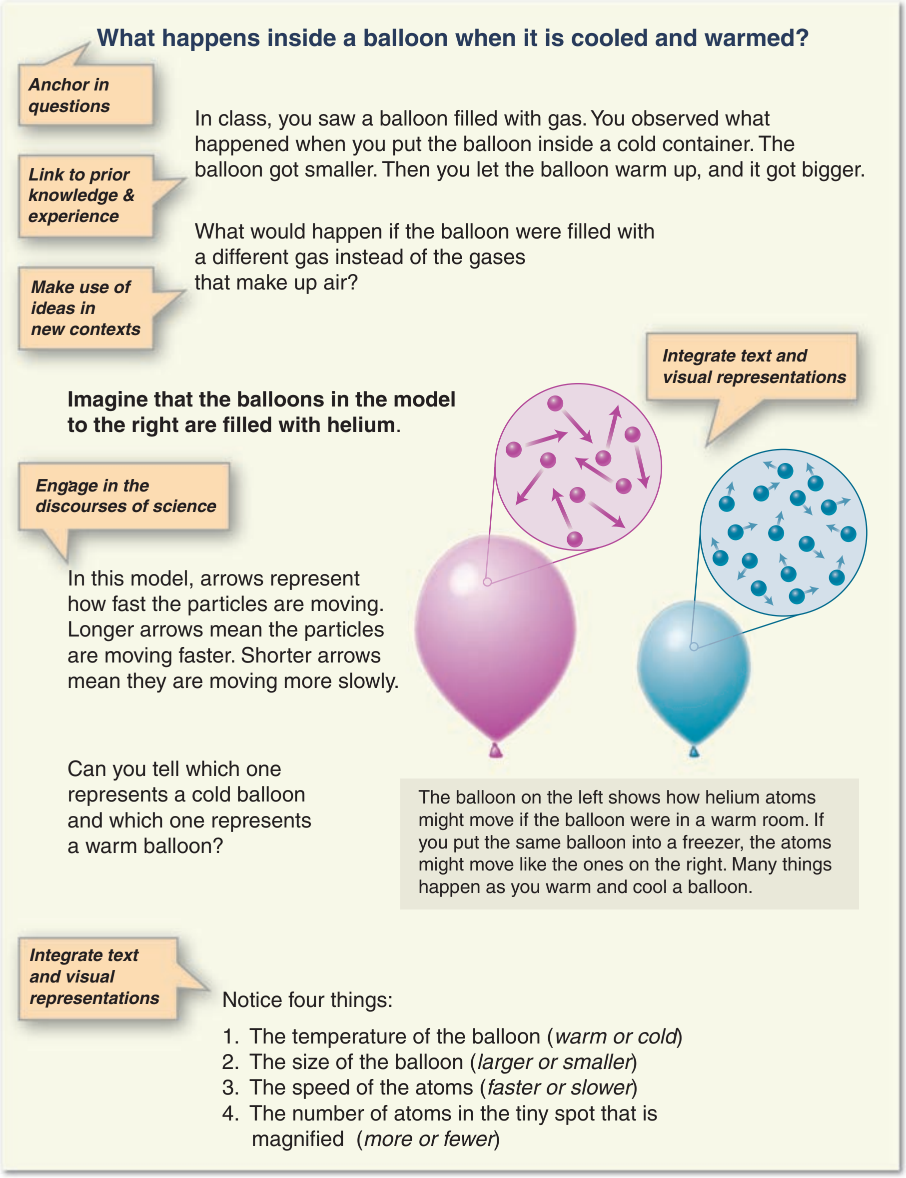
Given the complexity of many scientific ideas, a third important aspect of developing literacy in science is the ability to make sense of models, maps, diagrams, simulations, and graphs. It is difficult to explain the structure of DNA with text only, and a model of the double-helix is equally difficult to understand without text that explains it. Integrating text and representations

(*17*) enables the structure and function of DNA to become more readily comprehensible for readers.

Curriculum materials that integrate text and graphics can help middle school students understand complex topics such as the relation between temperature and the movement of particles (Fig. 1). The enumerated list below the drawing in Fig. 1 focuses attention on particular elements of the visual representation to encourage students to look back and forth between the text and graphics. For further instructional support, teachers can model the practice of looking back and forth between text and representation by reading aloud, illustrating this practice for students.

In addition, as we move further into an age of ubiquitous technologies and the use of graphics becomes more widespread, the options for visual, auditory, and tactile interaction become greater, and the need to integrate information across multiple forms of representation increases (*18*). Instead of a static representation of kinetic molecular theory as shown in Fig. 1, students could view a dynamic simulation illustrating the movement of gas particles at different temperatures. Although such interactive features are likely to promote learning by addressing the variety of ways that people learn, the need to learn how to read such representations remains.

A fourth important element that supports the development of scientific literacy depends on curriculum and instruction that asks students to actively apply ideas to new contexts (*19*, *20*). Materials and instruction need to provide students with time, opportunities, and guidance to make sense of classroom and everyday experiences that involve science (Fig. 2). Students need to articulate, represent, critique, apply, and extend their emerging understandings about science, using what they learn to make sense of new situations and solve new problems. For instance, Fig. 1 applies ideas about air developed in the classroom to a new situation that involves helium. The context (gas inside a balloon) is the same, encouraging students to generalize about gases in a balloon, whereas the text encourages them to generalize further about gases, regardless of the type of container. Instructional materials need to include tasks or question sequences that guide student interpretation and reasoning about experiences, data, and texts and that support them in considering how those ideas apply to phenomena not experienced in science class.



What happens inside a balloon when it is cooled and warmed?

In class, you saw a balloon filled with gas. You observed what happened when you put the balloon inside a cold container. The balloon got smaller. Then you let the balloon warm up, and it got bigger.

What would happen if the balloon were filled with a different gas instead of the gases that make up air?

Imagine that the balloons in the model to the right are filled with helium.

In this model, arrows represent how fast the particles are moving. Longer arrows mean the particles are moving faster. Shorter arrows mean they are moving more slowly.

Can you tell which one represents a cold balloon and which one represents a warm balloon?

The balloon on the left shows how helium atoms might move if the balloon were in a warm room. If you put the same balloon into a freezer, the atoms might move like the ones on the right. Many things happen as you warm and cool a balloon.

Notice four things:

1. The temperature of the balloon (*warm or cold*)
2. The size of the balloon (*larger or smaller*)
3. The speed of the atoms (*faster or slower*)
4. The number of atoms in the tiny spot that is magnified (*more or fewer*)

Fig. 1. Excerpt from a sixth-grade chemistry text connecting students' in-class experiences with a new example (*9*).

A fifth literacy practice essential to fostering inquiry in the classroom is engaging students in constructing explanations and arguments, which are essential components of scientific discourse. It is critical for students to have opportunities to talk and write about science and to practice supporting their ideas with evidence. Much work has been done in the area of writing and its many purposes in science, ranging from recording and organizing data to proposing written explanations and making arguments for why evidence supports one conclusion more than another. The latter, writing to explain or argue a position to an audience, is a critical aspect of engaging in inquiry. The discourse of science (*21*, *22*) includes not only precise language but also particular ways in which language is used, conclusions are drawn, ideas are put together, explanations are constructed, and arguments are presented. Each of these is of critical importance in engaging in science as a reader or writer of scientific ideas and also as a student and citizen.

Written and oral communication in the context of science inquiry depend on the use of data as evidence for explanation and argumentation. To explain phenomena, scientists require evidence to support their claims, and their explanations need to employ the language and ideas of science in ways that illustrate how they reasoned from available evidence (*23*). Materials and instruction can support students in writing scientific explanations by providing a framework for this practice: Make a claim, provide evidence, use reasoning that incorporates scientific principles to explicitly link the claim and evidence, and consider the validity of alternative explanations (*24*, *25*). In any science exposition (written or oral), students must pay attention to the evidence to support claims, the ways in which the evidence is used, and whether the evidence is sufficient and appropriate (that is, whether it supports the claim and is accurate) (*26*, *27*).

Scientific literacy for a global society in the 21st century is built on understanding science concepts and principles, as well as on

Fig. 2. A teacher helping a middle school student interpret text related to an in-class activity. [Photo credit: Mike Gould]

engaging in the literacy practices that make investigation, comprehension, and communication of ideas possible. Integration of literacy practices and inquiry-science education encourages instructional strategies that build on students' curiosities about the world and support students in building fundamental literacy skills. Although most students will not pursue careers in scientific fields, most will probably read science-related materials throughout their lives. For today's students to participate effectively in tomorrow's decision-making as consumers, members of the electorate, and members of society, it is imperative that educators support students in reading, writing, and communicating in science.

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28. The opinions expressed are those of the authors. The work was partially funded by grants from the NSF (ESI 0439352 and ESI 0439494).

10.1126/science.1182593

REVIEW

Literacy and Science: Each in the Service of the Other

P. David Pearson,[1]* Elizabeth Moje,[2] Cynthia Greenleaf[3]

We use conceptual and empirical lenses to examine synergies between inquiry science and literacy teaching and learning of K-12 (kindergarten through high school) curriculum. We address two questions: (i) how can reading and writing be used as tools to support inquiry-based science, and (ii) how do reading and writing benefit when embedded in an inquiry-based science setting? After elaborating the theoretical and empirical support for integrated approaches, we discuss how to support their implementation in today's complicated curricular landscape.

Scientific literacy has been the rallying cry for science education reform for the past 20 years, yet this phrase has had multiple, and sometimes conflicting, meanings. Does it refer to the reading and writing of science texts? Is it about learning how to think and practice like a scientist? Or does it refer more generally to knowing science for everyday life? Is literacy an aspect of scientific inquiry? Equally important, why does scientific literacy matter?

The last question is, perhaps, easiest to answer. Development of a scientifically literate citizenry has been tied to the future of robust democratic society (*1*, *2*). Explicit calls for proficiency in reading and science literacy for all (*1*–*4*) envision a populace capable of fully participating in the workplace and civic demands of the 21st century. This demand for a scientifically literate populace, however, requires a clear definition of science literacy and how to develop it.

A review of the literature reveals two dominant understandings of scientific literacy. One focuses on familiarity with the natural world and with key science concepts, principles, and ways of thinking (*2*). The other, which is the focus of this essay, makes explicit connections among the language of science, how science concepts are rendered in various text forms, and resulting science knowledge (*5*). Researchers guided by this latter view are concerned with how students develop the proficiencies needed to engage in science inquiry, including how to read, write, and reason with the language, texts, and dispositions of science. The ability to make meaning of oral and written language representations is central to robust science knowledge and full participation in public discourse about science (*6*, *7*).

However, text and reading can actually supplant science inquiry through text-centric curricula; these are the very curricula that science educators criticize when they champion hands-on, inquiry-based curricula (*8*, *9*). But when science literacy is conceptualized as a form of inquiry, reading and writing activities can be used to advance scientific inquiry, rather than substitute for it. When literacy activities are driven by inquiry, students

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