# Literacy and Science: Each in the Service of the Other

P. David Pearson, *et al.*

*Science* **328**, 459 (2010);
DOI: 10.1126/science.1182595

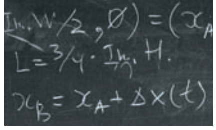



**Fig. 2.** A teacher helping a middle school student interpret text related to an in-class activity. [Photo credit: Mike Gould]

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.

### References and Notes


1. National Research Council, *National Science Education Standards* (National Academy Press, Washington, DC, 1986).
2. D. Hammer, R. Russ, R. E. Scherr, J. Mikeska, in *Teaching Scientific Inquiry: Recommendations for Research and Application*, R. A. Duschl, R. E. Grandy, Eds. (Sense Publishers, Rotterdam, Netherlands, 2008), pp. 138–156.
3. American Association for the Advancement of Science, *Science for All Americans: Project 2061* (Oxford Univ. Press, New York, 1990).
4. J. D. Bransford, A. L. Brown, R. R. Cocking, Eds., *How People Learn: Brain, Mind, Experience and School* (National Academy Press, Washington, DC, 1999).
5. R. E. Yager, in *Crossing Borders in Literacy and Science Instruction*, E. W. Saul, Ed. (International Reading Association, Arlington, VA, 2004), pp. 95–108.
6. S. Kesidou, J. E. Roseman, *J. Res. Sci. Teach.* **39**, 522 (2002).
7. L. M. Sutherland, *Elem. Sch. J.* **109**, 162 (2008).
8. Y. Shwartz, A. Weizman, D. Fortus, J. Krajcik, B. Reiser, *Elem. Sch. J.* **109**, 199 (2008).
9. J. Krajcik, B. J. Reiser, L. M. Sutherland, D. Fortus, *Investigating and Questioning Our World Through Science and Technology* (Regents of the Univ. of Michigan, Ann Arbor, MI, 2008).
10. P. Blumenfeld, T. Kempler, J. Krajcik, in *The Cambridge Handbook of the Learning Sciences*, R. K. Sawyer, Ed. (Cambridge Univ. Press, New York, 2006), pp. 475–488.
11. S. Magnusson, A. S. Palincsar, *Theory Pract.* **34**, 43 (1995).
12. G. Ivey, *Read. Res. Q.* **34**, 172 (1999).
13. E. Fox, *Rev. Educ. Res.* **79**, 197 (2009).
14. G. N. Cervetti, P. D. Pearson, M. A. Bravo, J. Barber, in *Linking Science and Literacy in the K-8 Classroom* (National Science Teachers Association, Washington, DC, 2006), pp. 221–244.
15. S. P. Norris, L. M. Phillips, *Sci. Educ.* **87**, 224 (2003).
16. R. F. Lorch, E. P. Lorch, W. E. Inman, *J. Educ. Psychol.* **85**, 281 (1993).
17. R. E. Mayer, *Multimedia Learning* (Cambridge Univ. Press, New York, ed. 2, 2009).
18. J. Lemke, in *Handbook of Literacy and Technology: Transformations in a Post-Typographic World*, D. Reinking, L. Labbo, M. M., Kiefer, Eds. (Erlbaum, Hillsdale, NJ, 1998), pp. 283–302.
19. M. C. Linn, B.-S. Elyon, in *Handbook of Educational Psychology*, P. A. Alexander, P. H. Winne, Eds. (Erlbaum, Mahwah, NJ, ed. 2, 2006), pp. 511–544.
20. H. Lee, M. C. Linn, K. Varma, O. L. Liu, *J. Res. Sci. Teach.* **47**, 71 (2010).
21. J. P. Gee, *Social Linguistics and Literacies: Ideology in Discourses* (Falmer, Bristol, PA, 1996).
22. J. L. Lemke, *Talking Science: Language, Learning, and Values* (Ablex, Norwood, NJ, 1990).
23. R. A. Duschl, H. A. Schweingruber, A. Shouse, *Taking Science to School: Learning and Teaching Science in Grades K-8* (National Academies Press, Washington, DC, 2007).
24. L. M. Sutherland, K. L. McNeill, J. Krajcik, K. Colson, in *Linking Science and Literacy in the K-8 Classroom* (National Science Teachers Association, Washington, DC, 2006), pp. 163–181.
25. K. L. McNeill, J. Krajcik, *J. Learn. Sci.* **18**, 416 (2009).
26. K. L. McNeill, J. Krajcik, in *Thinking with Data: The Proceedings of the 33rd Carnegie Symposium on Cognition*, M. Lovett, P. Shah, Eds. (Erlbaum, Mahwah, NJ, 2007), pp. 233–265.
27. J. Wellington, J. Osborne, *Language and Literacy in Science Education* (Open Univ. Press, Philadelphia, PA, 2001).



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.


[1]University of California, Berkeley, Berkeley, CA 94720, USA. [2]University of Michigan, Ann Arbor, MI 48109, USA. [3]WestEd, Oakland, CA 94612, USA.

*To whom correspondence should be addressed. E-mail: ppearson@berkeley.edu


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 simultaneously learn how to read and write science texts and to do science (*5*, *6*, *10*).

### Literate Practice as Inquiry

In many reform-oriented science classrooms in the United States, texts are deemphasized to avoid the common practice of reading about science in lieu of doing science (*2*, *8*, *9*, *11*, *12*). Yet scientists use reading and writing to inquire about scientific phenomena. No scientist simply walks into a lab and starts manipulating materials, tools, and phenomena. Investigations are always framed by other investigations. Texts are the artifacts of those past investigations and are used for inductive reasoning about scientific phenomena. Scientists use texts to generate new research questions and to provide the background necessary for research design and investigation.

"…the sense-making tools of science are consistent with, if not identical to, those of literacy…"

Science literacy instruction should engage children and youth in making sense of scientific texts as one form of scientific inquiry. Inquiry-driven literate practice is not simply passive receipt of information about science but rather a process of actively making meaning of science; these inquiries are best regarded as investigations in their own right. When reading and writing are cast as tools for investigating phenomena, students can learn how to build on and expand the work of other scientists by reading about the designs and findings of others (*10*). We can also engage students in producing texts that represent the ways they make sense of investigations, thus helping students understand how and why scientists think, write, and shape arguments the way they do. For example, in one project with middle- and high-school youth (*13*, *14*), teachers regularly ask students to evaluate whether their written claims refer back to the hypotheses they made, whether they made the data evident, and whether they have provided reasoning for their claims. Students can also learn to use writing in the way that scientists do for both journaling (*15*) and public reporting (*13*, *16*). In short, literacy has a role to play in both firsthand (hands-on) and secondhand (text-based) investigations (*15*).

Careful comparisons of the reasoning tasks required of K-12 (kindergarten through high school) students when they engage in hands-on and text-based inquiries reveal a number of shared processes and skills (*9*, *17*, *18*). Science and literacy use many of the same reasoning processes: setting purposes, asking questions, clarifying ambiguities, drawing inferences from incomplete evidence, and making evidence-based arguments (*10*, *19*, *20*).

### Science as a Setting for Enhancing Literacy

Just as literacy tools and artifacts can enhance the acquisition of knowledge and inquiry in science, so too can science provide an ideal context for acquiring and refining literacy tools. Several scholars (*7*, *21*–*23*) have argued that without systematic attention to reading and writing within subjects like science and history, students will leave schools with an impoverished sense of what it means to use the tools of literacy for learning or even to reason within various disciplines. Science provides a setting in which students are intellectually obligated to make sense of data, draw inferences, construct arguments based on evidence, infer word meanings, and, of course, construct meanings for text—the very dispositions required as good readers and writers. Students fine-tune their literacy tools not only when they read and write science texts but also when they engage in science investigations precisely because so many of the sense-making tools of science are consistent with, if not identical to, those of literacy (*24*), thus allowing a setting for additional practice and refinement that can enhance future reading and writing efforts.

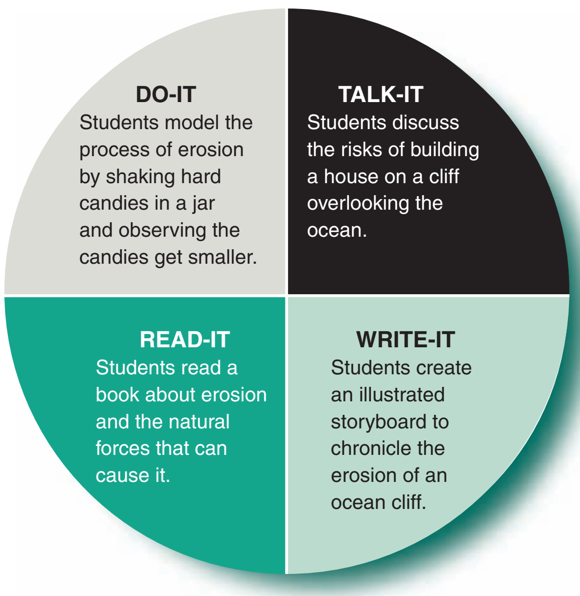


**Fig. 1.** A multimodal approach to learning about the concept of erosion. Reprinted from (*60*). [Copyright 2010 by The Regents of the University of California]

### Challenges to Science Literacy Instruction

With all of these reasons for valuing science literacy instruction, one might wonder why such practice is not de riguer? And given that it is not, what needs to be done to make it possible for young people to regularly read and write texts as an aspect of scientific inquiry?

A number of current realities prevent teachers from engaging in integrated science literacy instruction. One is the view of text held by many science educators described earlier—that our text-centric focus has overshadowed science inquiry (*9*, *12*, *25*). Both science and literacy educators agree that text-only science is weak science instruction, but most recognize that doing science involves reading and writing print and other symbol systems and graphic representations (*7*, *26*). Scientists cannot conduct scientific investigations or represent their findings without text-based inquiry tools (*10*, *14*).

A second challenge is the poor quality of texts available for science instruction. Typical science textbooks are dense and disengaging to inexperienced science readers (*9*, *11*, *22*, *27*). Science teachers have little access to well-designed texts that readers can understand given their developing knowledge base and varying reading skill levels (*27*).

This leads to a third challenge: Both teachers and students could be better at reading, writing, teaching, and learning from science texts. Students struggle with the abstract concepts, with a challenging scientific lexicon and set of discourses, and with complex images, graphs, and charts (*22*, *28*, *29*). Teachers, for their part, are often not well educated in science (at the elementary level) or in scientific-specific modes of literacy instruction (at the secondary level).

When reading is not conceptualized as inquiry, texts are complex, students' reading skills are weak, and teacher knowledge is uncertain, teachers often resort to telling students about science rather than actively engaging students in making sense of it (*30*, *31*). Likewise, when high-stakes testing drives teachers to cover content rather than actively engage students in the learning process, lectures offer an efficient form of delivering science information; thus, reading about science is replaced by listening to someone talk about science (*25*, *32*). Avoiding the challenge of engaging students with texts may seem efficient, yet it ultimately undermines student learning. Instead of confronting reading problems head on, it breeds student dependence on the teacher for science knowledge and places the learner in a passive role (*33*, *31*). At the same time, simply making texts available in print or online is not enough to ensure that students engage with them; rather, students need explicit support to acquire the composing and comprehension processes needed for successful reading and writing in science (*34*–*36*).

Other major challenges to developing scientific literacy in the United States are the accountability systems that schools and statehouses are beholden to in today's policy environment. First, at the elementary school level, thanks largely to the zeal with which the No Child Left Behind (NCLB) initiative promoted reading and math over science and other subjects, there is precious little time for science (*37*). A 2008 national survey revealed that a majority of elementary schools decreased the time allotted to science by 15 minutes per day, while time for reading and math was increased by a like amount (*37*). A 2008 survey of elementary schools in the San Francisco Bay Area (*38*) revealed an even more alarming reduction in time devoted to science in the wake of NCLB—to under 60 minutes per week (in comparison to a national average of 200 minutes per week in 2001). Second, standardized multiple-choice tests for all subjects serve as the standard for gauging student achievement in modern accountability systems (*39*). As a consequence, schools are hard pressed to promote inquiry-based teaching, irrespective of whether it is grounded in laboratory experiences or text-based investigations, in the face of tests that privilege the assessment of facts over concepts or knowledge frameworks. The combination of high stakes (rewards and sanctions based on performance) and low intellectual challenge (the factual character of the vast majority of test items) almost compels teachers to eschew deep inquiry in favor of content coverage (*31*).

"Science learning entails and benefits from embedded literary activities. . . literacy learning entails and benefits from being embedded within science inquiry."

## The Evidence Base for Integrated Science Literacy Initiatives

These realities represent daunting challenges to promoting integrated science literacy instruction. However, promising projects at various grade levels employ literacy tools, including text, to support rather than supplant the acquisition of knowledge and inquiry in science. These efforts share key ingredients: They are embedded in inquiry-based science instruction; they engage learners in text-based inquiries along with hands-on science investigations; they bring together teams of literacy and science experts; and they require extensive teacher learning through professional development and/or educative curriculum materials (*40*, *41*). In this section, we provide brief descriptions of some promising science literacy research and development projects. They move both science and literacy instruction toward a more authentic expression of the nature of science. Most important, these efforts show promise of increasing student learning in both literacy and science.

*Concept-Oriented Reading Instruction (CORI).* For nearly 20 years, Guthrie and colleagues have been refining CORI, a program designed to promote a number of literacy goals through the use of broad interdisciplinary themes (*42*), primarily drawn from science curricula, such as exploring the impact of humans on animal habitats. CORI provides explicit instruction in reading strategies, such as questioning, activating background knowledge, searching for information, summarizing, and synthesizing information in order to communicate with others. Instruction involves hands-on investigations, inquiry with text, strategy instruction, working in collaborative inquiry teams, and writing to publish and present findings. CORI has been shown to increase students' science concept learning, motivation, use of productive inquiry strategies, and overall text comprehension compared to control classrooms with separate science and literacy curricula and/or strategy instruction in reading alone (*43*). Of particular interest in the CORI research is the pivotal role that motivation, in all of its instantiations (interest, self-efficacy, and achievement motivation), plays in learning both science and literacy.

*Guided Inquiry supporting Multiple Literacies (GIsML).* Palincsar and Magnusson (*15*) engaged in a multiyear program of research on the ways that text-based (secondhand) inquiry investigations can support students' conceptual understanding in hands-on (firsthand) investigations. In GIsML professional development, teachers learn to engage students in cycles of investigation guided by specific questions, establishing the classroom as a community of inquiry. GIsML combines these firsthand and secondhand experiences through the use of a fictional working scientist's notebook. The notebook provides models of data representation and engages students in interpreting data along with the scientist. The texts also model a scientist using secondhand materials, reading and interpreting with a critical stance, and drawing conclusions from multiple sources of evidence. After students investigate scientific questions, they consult text to learn how the scientist has interpreted similar evidence. In a quasi-experiment comparing fourth graders studying the concept of light by working with either a GIsML notebook or a considerate text (i.e., especially well-written, cohesive expository text) treatment, they found that students learned more in the GIsML notebook-based instruction than in the considerate text condition, concluding that the notebooks promoted talk that led to greater engagement and, ultimately, improved understanding (*15*).

*In-depth Expanded Applications of Science (Science IDEAS).* Romance and Vitale (*44*, *45*) developed the IDEAS model of integrated science/language instruction, which replaces the time allocated for traditional literacy instruction with a 2-hour block of science that includes literacy skills. The science instruction is concept-focused and involves firsthand experiences, attention to science process skills, discussion, reading comprehension, concept mapping, and journal writing. Several multiyear efforts show that Science IDEAS students outperform students receiving segregated language arts and science instruction on a range of reading and science tests and indices of self-efficacy and attitudes toward science (*44*–*46*).

*Seeds of Science—Roots of Reading.* Seeds and Roots (*10*) began as an attempt to embed inquiry-oriented reading, writing, and language activities within the already successful GEMS (Great Explorations in Math and Science) K-8 hands-on science program. The program is based on the fundamental principle that literacy is best enacted as a set of learning tools that support knowledge acquisition rather than as a set of independent curriculum goals. Across two external evaluations comparing Seeds and Roots with content-controlled inquiry science (and, in one instance, a reading-only control), this experimental curriculum shows advantages on measures of science learning, vocabulary acquisition, and writing fluency, with a less consistent advantage for reading comprehension (*47*, *48*). (See Fig. 1 for an example.)

*Reading Apprenticeship.* Greenleaf and colleagues have been developing discipline-based literacy instruction and professional development (under the rubric of Reading Apprenticeship) to foster more engaged learning for underprepared students in secondary and post-secondary settings (*19*). In this apprenticeship model, science teachers inquire deeply into what they do to derive meaning with complex science texts, including explanation and exposition in scholarly journals, as well as the diagrams, data arrays, mathematical expressions, and graphs that convey information. Teachers then learn classroom routines for engaging students in active inquiry and sense-making with such texts: routines for mentoring students in productive reasoning processes, for fostering metacognitive awareness of comprehension problems and problem-solving processes, and for promoting collaborative discussions of science texts. A randomized experiment of high-school biology teaching and learning demonstrated that the program significantly improved the quality of biology and literacy integration and resulted in statistically significant improvements on state standardized tests in English language arts, reading comprehension, and biology for students (*49*).

*Textual tools.* In work of Moje and her colleagues with middle- and high-school youth in Detroit (*14*, *50*, *51*), teachers engage students in reading both scientific and lay-audience texts related to the phenomena under study. The teachers also engage students in translating across multiple forms of representation (e.g., as investigations require data to be logged and explanations of phenomena to be communicated). Students engage in peer review to evaluate whether their written explanations refer back to the hypotheses they made, to what extent they made the data evident, and the quality of reasoning they have provided for their claims. Students across all classrooms—regardless of entering skill level—demonstrated more developed, scientifically accurate, and rhetorically appropriate (to science) explanations when compared to their writing at the outset of the interventions, as well as significant gains in science concept knowledge (*14*).

*Summary and critique.* This body of evidence [see also (*34*, *52–54*)] demonstrates the promise of integrated approaches to literacy and science instruction. At a time when struggling students are likely to be taken out of their science classes to attend remedial reading classes, these findings suggest that a better option may be to attend to the needs of struggling readers within science class, where they simultaneously acquire subject-matter knowledge and inquiry skills, and perhaps even improve their literacy skills. But the promise we see must be tempered by the fact that this line of work is relatively young, and much needs to be learned about which of the features commonly employed in these designs are truly the active ingredients responsible for student learning and which are more peripheral.

#### Moving Forward

Greater proficiency in science reading, writing, and inquiry for all students requires knowledgeable teachers who understand the vital role literacy plays in enhancing rather than replacing science learning and who can mentor their students in these practices. Teacher knowledge is the key to advancing student achievement. However, many institutional barriers stand in the way. First, the structure of teacher education virtually guarantees isolation between literacy and science preparation. Moreover, the default practice of giving science teachers a literacy strategies toolkit is not likely to promote deep thinking and reasoning around texts and investigations that support science learning (*50*). Instead, teaching literacy in scientifically specific ways requires deep conceptual change for teachers to help them adopt new ways of thinking and acting in the classroom. Changes of this magnitude will require rethinking teacher preparation, professional development, and curriculum.

*Initial teacher preparation.* Moje and colleagues (*55*) have redesigned the secondary teacher education program at the University of Michigan to focus on building understanding of the disciplinary practices supported by reading, writing, and reasoning, rather than treating literacy methods as a separate subject. Donahue (*56*) and Braunger, with other teacher educators (*57*), have designed similar discipline-centered approaches for secondary teachers. These models offer the opportunity for preservice teachers to examine the texts of science, to plan instruction that integrates complex uses of text into inquiry, and to learn how to teach young people how to think, read, and write like scientists.

> "...schools are hard pressed to promote inquiry-based teaching... in the face of tests that privilege the assessment of facts over concepts or knowledge frameworks."

*Ongoing professional development.* Many science teachers hold misconceptions, or at the very least, limited conceptions, of literacy teaching and learning; they tend to think of reading and writing as basic and universal skills that are developed in elementary or middle school or down the hall in the English department. They do not expect to teach science reading and writing to students, yet they are confronted with students who do not comprehend science texts, their specialized language, or the many ways science ideas are conveyed through print, diagrams, images, models, graphs, and tables. Greenleaf and colleagues (*58*) have developed programs designed to challenge teachers' misconceptions, transforming them into more robust conceptions of science reading and its role in learning. Confronting teachers with highly advanced texts that place them in a struggling position (not unlike the texts their secondary students confront daily) helps them realize that reading is neither automatic nor straightforward. They typically emerge with a new appreciation for the challenges their students face and insights about how they can help students cope with those challenges. These science teachers also begin to recognize how poorly many of our textbooks represent authentic reading and writing about science (*23*) and how difficult it would be for their English language arts colleagues to assume responsibility for mentoring and engaging students in the rigors and rewards of science reading. Such opportunities to investigate science literacy practices need to be made available to teachers on a broad scale.

*Curriculum development.* Over the past 30 years, many inspired efforts to fundamentally reform the K-12 science curriculum have been launched to engage students in investigation and inquiry; however, the quality of science reading materials and the role they play in inquiry have often been overlooked in these efforts. A new generation of materials takes a different approach, assuming that science learning entails and benefits from embedded literacy activities and that literacy learning entails and benefits from being embedded within science inquiry. Further, some new curricula provide resources to learn needed science content, literacy practices, and pedagogies that support student learning (*59*). Those involved in creating and validating the efficacy of these new programs should press educational publishers to consider their approaches as viable alternatives to the status quo.

*Assessment.* Finally, it is important to note that all the professional development in the world will have little impact if we cannot also create more balanced assessment portfolios for our accountability systems (*39*). The inclusion of challenging performance tasks—tasks that involve extended inquiry (over several days), analysis of findings, and public reports of student work—would help to promote the very sort of inquiry that research documents as effective. However, as long as low-challenge, multiple-choice tests serve as the primary metric for measuring student learning and teacher quality, not only in science but in literacy as well, it will be difficult for teachers to take the risk of promoting genuine inquiry in their classes.

#### Inquiry As the Common Core

As a final point, we emphasize that all of our suggestions for moving ahead are really suggestions for making inquiry the common theme of reform. Teacher learning is most profound when teachers can employ the very same inquiry processes for their own professional learning that they aspire to enact with their students. By making their own learning about literacy and science pedagogy the object of inquiry, teachers can simultaneously develop the insights and pedagogical strategies they will need to mentor their students. Integrated curricula of the sort supported by empirical research require that the dispositions and practices of inquiry-based science be appropriated for inquiry in reading and writing. And finally, we must reshape our assessment systems to better reflect the nature and goals of inquiry-oriented instruction in both science and literacy. If we can manage all of these initiatives, we might be able to help teachers situate literacy and science each in the service of the other as students gain tools and proficiency in both. The agenda is surely daunting, but the costs of avoiding it are high and the rewards for pursuing it are substantial.


**References**

1. Committee on Science, Engineering, and Public Policy, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (National Academies Press, Washington, DC, 2007).
2. F. J. Rutherford, A. Ahlgren, *Science for All Americans* (Oxford Univ. Press, New York, 1990).
3. M. Eisenhart, E. Finkel, S. F. Marion, *Am. Educ. Res. J.* **33**, 261 (1996).
4. No Child Left Behind Act of 2001, 20 U.S.C. § 6319 (2008).
5. S. P. Norris, L. M. Phillips, *Sci. Educ.* **87**, 224 (2002).
6. L. D. Yore, *Proc. ISEC* **2009**, 2393 (2009).
7. E. B. Moje, in *Review of Research in Education*, L. Parker, Ed. (American Educational Research Association, Washington, DC, 2007), pp. 1–44.
8. L. L. Digisi, J. B. Willett, *J. Res. Sci. Teach.* **32**, 123 (1995).
9. E. W. Eisner, *Curric. Rev.* **26**, 11 (1987).
10. G. Cervetti, P. D. Pearson, M. A. Bravo, J. Barber, in *Linking Science and Literacy in the K-8 Classroom*, R. Douglas, M. Klentschy, K. Worth, Eds. (NSTA Press, Arlington, VA, 2006), pp. 221–244.
11. National Research Council, *Fulfilling the Promise: Biology Education in the Nation's Schools* (National Academy Press, Washington, DC, 1990).
12. L. D. Yore, *J. Res. Sci. Teach.* **28**, 55 (1991).
13. K. L. McNeill, D. J. Lizotte, J. Krajcik, R. W. Marx, *J. Learn. Sci.* **15**, 153 (2006).
14. E. B. Moje *et al.*, in *Bridging the Gap: Improving Literacy Learning for Preadolescent and Adolescent Learners in Grades 4-12*, D. Strickland, D. E. Alvermann, Eds. (Carnegie Corporation, New York, 2004), pp. 227–251.
15. A. S. Palincsar, S. J. Magnusson, in *Cognition and Instruction: Twenty-Five Years of Progress*, S. Carver, D. Klahr, Eds. (Erlbaum, Mahwah, NJ, 2001), pp. 151–194.
16. J. T. Guthrie, E. Anderson, S. Alao, J. Rinehart, *Elem. Sch. J.* **99**, 343 (1999).
17. L. Baker, in *Science Learning: Processes and Applications*, C. Santa, D. Alvermann, Eds. (International Reading Association, DE, 1991), pp. 2–13.
18. M. McMahon, B. McCormack, in *Learning from Text Across Conceptual Domains*, C. Hynd, Ed. (Erlbaum, Mahwah, NJ, 1998), pp. 227–262.
19. C. Greenleaf, W. Brown, C. Litman, in *Bridging the Gap: Improving Literacy Learning for Preadolescent and Adolescent Learners in Grades 4-12*, D. S. Strickland, D. E. Alvermann, Eds. (International Reading Association, New Jersey, 2004), pp. 200–226.
20. J. Osborne, *Science* **328**, 463 (2010).
21. N. K. Duke, *Read. Res. Q.* **35**, 202 (2000).
22. C. D. Lee, A. Spratley, "Reading in the Disciplines: The Challenges of Adolescent Literacy" (Carnegie Corporation of New York, New York City, 2010); http://carnegie.org/fileadmin/Media/Publications/PDF/tta_Lee.pdf.
23. R. Shoenbach, C. Greenleaf, in *Handbook of Adolescent Literacy Research*, L. Christenbury, R. Bomer, P. Smagorinsky, Eds. (Guilford, 2009), Chapter 7.
24. S. R. Goldman, G. Bisanz, in *The Psychology of Science Text Comprehension*, J. Otero, J. A. León, A. C. Graesser, Eds. (Erlbaum, Mahwah, NJ, 2002), pp. 19–50.
25. D. G. O'Brien, R. A. Stewart, E. B. Moje, *Read. Res. Q.* **30**, 442 (1995).
26. C. W. Anderson, *J. Res. Sci. Teach.* **36**, 973 (1999).
27. M. J. Schleppegrell, *The Language of Schooling: A Functional Linguistics Perspective* (Erlbaum, Mahwah, NJ, 2004).
28. C. E. Snow, *Science* **328**, 450 (2010).
29. P. van den Broek, *Science* **328**, 453 (2010).
30. T. Sizer, *Horace's Compromise: The Dilemma of the American High School* (Houghton Mifflin, New York, ed. 4, 2004).
31. I. R. Weiss *et al.*, "Highlights Report–Looking Inside the Classroom: A Study of K-12 Mathematics and Science Education in the United States" (2003); www.horizon-research.com/reports/2003/insidetheclassroom/highlights.php.
32. D. R. Dillon, D. G. O'Brien, M. Volkman, in *Constructions of Literacy: Studies of Teaching and Learning in Secondary Classrooms*, E. B. Moje, D. G. O. Brien, Eds. (Erlbaum, Mahwah, NJ, 2001), pp. 51–75.
33. J. Bransford, S. Donovan, in *How Students Learn: History, Mathematics, and Science in the Classroom*, S. Donovan, J. Bransford, Eds. (National Academies Press, Washington, DC, 2005), pp. 397–420.
34. R. G. Miller, R. C. Calfee, *Sci. Child.* **42**, 20 (2004).
35. R. C. Calfee, R. G. Miller, in *Children's Reading Comprehension and Assessment*, S. Paris, S. Stahl, Eds. (Erlbaum, Mahwah, NJ, 2005), pp. 215–236.
36. C. Snow, "Reading for Understanding: Toward a Research and Development Program in Reading Comprehension" (RAND, Arlington, VA, 2002); www.rand.org/publications/MR/MR1465.
37. J. McMurrer, "Instructional Time in Elementary Schools: A Closer Look at Changes for Specific Subjects" (Center for Education Policy, Washington, DC); www.cep-dc.org/index.cfm?fuseaction=document.showDocumentByID&nodeID=1&DocumentID=234, 2008.
38. R. Dorph *et al.*, "The Status of Science Education in Bay Area Elementary Schools: Research Brief," Lawrence Hall of Science, University of California, Berkeley, California (2007). Retrieved from http://lawrencehallofscience.org/rea/bayareastudy/index.html.
39. L. Shepard *et al.*, Eds., "Standards, Assessment, and Accountability: Education Policy White Paper" (National Academy of Education, Washington, DC, 2009); www.naeducation.org/Standards_Assessments_Accountability_White_Paper.pdf.
40. D. Ball, D. Cohen, *Educ. Res.* **25**, 6 (1996).
41. E. Davis, J. Krajcik, *Educ. Res.* **34**, 3 (2005).
42. J. T. Guthrie, S. Ozgungor, in *Comprehension Instruction: Research Based Best Practices*, C. Collins Block, M. Pressley, Eds. (Guilford, New York, 2002), pp. 275–288.
43. J. T. Guthrie *et al.*, *J. Educ. Psychol.* **96**, 403 (2004).
44. N. R. Romance, M. R. Vitale, *J. Res. Sci. Teach.* **29**, 545 (1992).
45. N. R. Romance, M. R. Vitale, *Int. J. Sci. Educ.* **23**, 373 (2001).
46. N. R. Romance, M. R. Vitale, "Perspectives for Improving School Instruction and Learning: An Interdisciplinary Model for Integrating Science and Reading in Grades K-5" (University of Chicago, Committee on Education Workshop on Education Lecture Series, 2008); www.scienceideas.org/pubs-pres/articles-instructionalmodel/Improving-School-Learning-Instruction.pdf.
47. P. Goldschmidt, "Evaluation of Seeds of Science/Roots of Reading: Effective Tools for Developing Literacy through Science in the Early Grades" (CRESST, Los Angeles, CA, 2009) (http://seedsofscience.org/PDFs/CRESST_Evaluation_LightEnergy.pdf).
48. J. Wang, J. Herman, "Evaluation of Seeds of Science/Roots of Reading Project: Shoreline Science and Terrarium Investigations" (CRESST, Los Angeles, CA, 2005) (www.scienceandliteracy.org/PDFs/CRESST_Final_Report.pdf).
49. C. Greenleaf *et al.*, "Integrating Literacy and Science Instruction in High School Biology: Impact on Teacher Practice, Student Engagement, and Student Achievement," Final report to NSF, Grant #0440379 (2009), available at www.wested.org/sli/downloads/nsf-final-report.pdf.
50. E. B. Moje, L. M. Sutherland, T. E. Solomon, M. Vanderkerkof, "Integrating Literacy Instruction into Secondary School Science Inquiry: The Challenges of Disciplinary Literacy Teaching and Professional Development" (2010). Available online at www-personal.umich.edu/~moje/pdf/MojeEtAlScienceLiteracyTeachingStrategies2010.pdf.
51. Textual Tools Study Group, in *Linking Science and Literacy in the K–8 Classroom*, R. Douglas *et al.*, Eds. (National Science Teachers Association, Washington, DC, 2006), pp. 261–285.
52. T. H. Anderson *et al.*, *J. Curric. Stud.* **29**, 711 (1997).
53. L. Gomez, K. Gomez, *Phi Delta Kappan* **89**, 224 (2007).
54. C. C. Pappas, M. Varelas, A. Barry, A. Rife, *Linguist. Educ.* **13**, 435 (2002).
55. E. B. Moje, R. B. Bain, *Teacher Education for Disciplinary Literacy Learning* (Univ. Michigan, Ann Arbor, MI, 2009).
56. D. Donahue, *J. Adolesc. Adult Literacy* **47**, 24 (2003).
57. J. Braunger, D. Donahue, K. Evans, T. Galguera, *Rethinking Preparation for Content Area Teaching: The Reading Apprenticeship Approach* (Jossey Bass, CA, 2004).
58. C. Greenleaf, R. Schoenbach, in *Improving Reading Achievement through Professional Development*, D. S. Strickland & M. L. Kamil, Eds. (Christopher-Gordon, MA, 2004), pp. 97–127.
59. G. Cervetti, P. D. Pearson, J. Barber, E. Hiebert, M. Bravo, in *Shaping Literacy Achievement: The Research We Have, the Research We Need*, M. Pressley, A. K. Billman, K. Perry, K. Refitt, J. Reynolds, Eds. (Guilford, New York, 2007), pp. 157–174.
60. J. Barber *et al.*, *Seeds of Science/Roots of Reading: Light Energy Teachers' Guide* (Delta Education, Nashua, NH, 2010), p. A11.


10.1126/science.1182595

REVIEW

# Arguing to Learn in Science: The Role of Collaborative, Critical Discourse

Jonathan Osborne

**Argument and debate are common in science, yet they are virtually absent from science education. Recent research shows, however, that opportunities for students to engage in collaborative discourse and argumentation offer a means of enhancing student conceptual understanding and students' skills and capabilities with scientific reasoning. As one of the hallmarks of the scientist is critical, rational skepticism, the lack of opportunities to develop the ability to reason and argue scientifically would appear to be a significant weakness in contemporary educational practice. In short, knowing what is wrong matters as much as knowing what is right. This paper presents a summary of the main features of this body of research and discusses its implications for the teaching and learning of science.**

The goal of science is to produce new knowledge of the natural world. Two practices essential to achieving this objective are argument and critique. Whether it is new theories, novel ways of collecting data, or fresh interpretations of old data, argumentation