CHAPTER 7

Integrating Literacy and Science

The Research We Have, the Research We Need

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In the summer of 2003 a group of science educators at Lawrence Hall of Science at the University of California–Berkeley began collaborating with a group of literacy educators in the Graduate School of Education to create a new kind of integrated curriculum, which we dubbed *Seeds of Science, Roots of Reading* (*Seeds/Roots*). The fundamental concept was classic integrated curriculum. The fundamental commitment was to build a curriculum that put literacy instruction (texts, routines for reading, word-level skills, vocabulary, and comprehension instruction) to work in the service of acquiring the knowledge, skills, and dispositions of inquiry-based science. Over the past several years, we have developed, evaluated, and revised the curriculum in ways that maximize the synergy between these traditionally segregated curricular enterprises. In this chapter, we report on the goals of the effort, the process of negotiating the integration, and the efficacy of the approach (compared to more traditionally encapsulated approaches to promoting science and literacy expertise). In addition, we turn to the all-important question for this volume: Where do we go next? We speculate about the kinds of research the field needs to conduct in order to move this sort of integrated curriculum to the next level of sophistication and rigor.

To foreshadow our conclusions, we are enthusiastically and unambiguously committed to the integrated approach. We think it makes more sense conceptually (literacy ought to support the acquisition of scientific expertise). We believe it achieves curricular economy (some literacy skills and strategies really can be taught in the service of acquiring scientific knowledge). And, most importantly, it stands the empirical test; the data we have gathered thus far provide compelling evidence of the efficacy of this approach.

The Roots of Seeds/Roots: Research That Influenced Our Conceptual Bases

Our work draws in part on literature from the 1980s and early 1990s examining the overlapping cognitive demands of science and literacy. In a relatively early example, Carin and Sund (1985) encouraged teachers to integrate science with language arts for the sake of efficiency. In their influential text, Carin and Sund pointed out that both language arts and science "are concerned with process *and* content" (p. 243), that they emphasize many of the same intellectual skills, and that both are "concerned with thinking processes" (p. 242). The authors identified skills such as predicting, classifying, and interpreting as being essential for both domains. Despite these insights about synergy and overlap, Carin and Sund ended up taking a relatively conservative view of integration, advocating doing read-alouds that give students opportunities to "listen to how science sounds" (p. 246) and to expand students' science vocabulary.

Baker (1991) attempted to connect reading and science through metacognition, suggesting that science and literacy share a concern with fostering independent learning. Baker suggested that, while metacognition ("the awareness and control individuals have over their cognitive processes") is widely recognized as an essential component of reading, the connection to science has not been explored, even though many science process skills can be regarded as metacognitive skills (e.g., formulating conclusions, analyzing critically, evaluating information, recognizing main ideas and concepts, establishing relationships, applying information to other situations). Baker contended that attention to metacognition in science can help teachers foster independence through "lectures, discussion, laboratory work, and hands-on activities" (p. 2).

Padilla, Muth and Lund Padilla (1991) detailed a shared set of intellectual processes (e.g., observing, classifying, inferring, predicting, and communicating) between discovery science and reading. They claimed that these are some of the very same problem-solving processes used "whether [students are] conducting science experiments or reading assigned science texts" (Padilla et al., 1991, p. 16); their list of specific cognitive strategies included making inferences, drawing conclusions, making predictions, and verifying predictions.

Research-Based Interventions

In addition to scholars who have put forward broad conceptual claims about the science-literacy interface, a number of scholars have created and evaluated specific models of integration from which we have gained many insights.

Concept-Oriented Reading Instruction (CORI)

CORI is designed to promote sustained reading engagement—meaning that students are building on existing understandings and using cognitive strategies as they read—through the use of broad interdisciplinary themes (Guthrie & Ozgungor, 2002). CORI is built around a knowledge goal (often in science) and, within that goal, provides direct instruction of reading strategies, such as questioning, activating background knowledge, searching for information, and summarizing. CORI involves firsthand experiences, reading, strategy instruction, and peer collaboration.

CORI provides direct instruction of reading within a context that allows students to develop in-depth knowledge and become experts. Guthrie and Ozgungor (2002) suggest that the learning of strategies is supported by students' rich bank of background knowledge. The content context supports "both the cognitive and motivational aspects of reading engagement" (p. 280). One of the important characteristics of CORI is coherence, or the linking of activities, contexts, and materials in ways that enable students to make connections between experience and reading, strategies and content, and literary and scientific texts. Firsthand science experiences often serve as the "real-world" interaction ingredient for the CORI model. Guthrie, Anderson, Alao, and Rinehart (1999) reported on a year-long CORI intervention in five third- and fifth-grade classrooms, comparing CORI students with those in traditionally organized classrooms. They found that the CORI program increased students' strategy use, conceptual learning, and text comprehension.

Guided Inquiry Supporting Multiple Literacies (GIsML)

Palincsar and Magnusson (2001) have a long-standing program of research regarding secondhand or text-based experiences in science and the ways that secondhand investigations can prepare students for firsthand investigations and provide common inquiry to advance students' conceptual understandings. The context of Palincsar and Magnusson's work is the GIsML program of professional development. In GIsML, teachers establish the classroom as a community of inquiry and engage students in cycles of investigation guided by specific questions. GIsML combines firsthand and secondhand experiences, particularly through the use of a scientist's notebook. The notebooks provide models of data and provide students with opportunities to interpret data along with the scientist. The texts also model scientists using text materials, reading critically, and drawing conclusions based on multiple sources of data. After students investigate scientific questions, they consult text to learn about others' interpretations.

Palincsar and Magnusson (2001) report on a quasi-experimental study to compare fourth graders studying light. Palincsar compared the learning of students in classrooms using GIsML, including the scientist's notebook, with students in classrooms using considerate expository text. Text genre did make a difference in the knowledge that students developed from reading, with the result that students learned more in the GIsML instruction using notebook texts (they recalled more information and were better able to make inferences based on the text) than when they read the considerate expository text. Palicsar and Magnusson found that the notebooks encouraged instructional conversations that reflected the inquiry process and provided opportunities for students to engage in co-construction of understandings about light.

In-Depth Expanded Applications of Science (IDEAS)

Romance and Vitale (1992, 2001) developed the IDEAS model of integrated science and language arts instruction. IDEAS replaced the time allocated for traditional literacy instruction with a 2-hour block of science instruction that included attention to reading and language arts skills. The science instruction was concept-focused and involved firsthand experiences, attention to science process skills, discussion, reading, concept mapping, and journal writing. Teachers implementing IDEAS typically engaged students in reading activities after hands-on activities in order to ensure "that students had the learning experiences needed to make critical reading more purposeful" (Romance & Vitale, 1992, p. 547).

Romance and Vitale have demonstrated through a long-standing program of research that IDEAS students outpace students receiving their regular language arts and science programs on nationally normed standardized measures (the Metropolitan Achievement Test—Science, the Iowa Test of Basic Skills—Reading and the Stanford Achievement Tests—Reading). Participating students also consistently displayed significantly more positive attitudes and self-confidence toward both science and reading. They suggest—and we concur—that there is reason to rethink the emphasis on basal reading materials, simply because there is an absence in them of structured conceptual knowledge.

Wondering, Exploring, and Explaining (WEE)

Anderson, West, Beck, Macdonell, and Frisbie (1997) designed the WEE program, an integrated science and reading program for grades 3–9. WEE involves students in three phases of scientific investigation:

- *Wondering*: Students pose wonderments, choose wonderments to explore, use books to find information about their wonderments, and turn wonderments into questions that could be researched in a firsthand way.
- *Exploring*: Students discuss prior knowledge, make exploration plans, and gather information through firsthand exploration, additional reading, consultation with experts, etc.
- *Explaining*: Students summarize the activities undertaken, what they found out, and what they still wonder, and they give presentations to their classmates.

By using text to inspire investigations that are then conducted by students, the WEE program encourages students to answer questions for themselves rather than relying on text as the ultimate authority in science. In studying the implementation of the WEE program in fifth-grade classrooms, Anderson et al. (1997) found that students showed high levels of excitement, involvement, and learning.

Dialogically-Oriented Read-Alouds

While not a complete "program," the use of books in the work of Pappas, Varelas, Barry, and Rife (2002) has been quite helpful to us. In their work, Pappas and her colleagues explore the use of collaborative, dialogically oriented read-alouds using science texts in first- and second-grade classrooms. Pappas and colleagues examined the dialogues that took place around science information books embedded in 4- to 6-week units that also involved hands-on explorations, writing, literature circles, and at-home parent–child explorations. Pappas et al. were interested in examining the intertextual links made by students during the read-alouds—links among texts, discourse, and experiences. They suggest that the use of information books in science supports students' construction of conceptual understanding and helps students to appropriate the linguistic registers needed to express these understandings. In particular, they found that intertextuality played a variety of roles in the first- and second-grade classrooms, including engaging students in sense-making about science (e.g., offering possible scientific explanations) and promoting scientific understanding and the use of scientific registers.

Mining the Work of Our Predecessors

Taken together, the work of our predecessors suggests that science-literacy integration is a promising path for advancing student learning in both science and literacy. Individually, each line of work offers insights into the interface between science and literacy. It was in part because of this work that we began to explore the overlapping goals and cognitive strategies of science and literacy. In particular, we owe our focus on secondhand textual investigations to the work of Palincsar and Magnusson and our interest in intertextuality (bringing together text, experience, discourse, etc.) to the work of Pappas and her colleagues. From Romance and Vitale, we learned that literacy might have as much to gain from being embedded in science as science did from being supported by literacy. We gained many insights into combining firsthand experiences with text investigations from the work of Guthrie and colleagues on CORI and the work of Anderson and colleagues on WEE.

Our Current Project: Seeds of Science/Roots of Reading

The Context

Our work on interdisciplinary science–literacy curricula has taken place in the context of the Seeds of Science/Roots of Reading program. Seeds/Roots is a curriculum and research project designed to explore the potential and limits of science and literacy integration. It was initiated as a revisioning of the Lawrence Hall of Science (UC–Berkeley) Great Explorations in Math and Science (GEMS) inquiry science program.

The science educators and literacy educators on our team had different motives for joining an effort focused on curricular integration. For the science educators, Seeds/Roots is an opportunity to advance students' learning by supporting firsthand inquiry with authentic scientific uses of reading and writing, to strengthen the standing of science in the school day, and to bring more teachers to inquiry science by capitalizing on what many teachers know and do well.

For literacy educators, Seeds/Roots is an opportunity to use science to provide an engaging and authentic context for literacy learning and to test our collective theories and beliefs about the advantages that accrue to reading, writing, and language activity when they are embedded fully in subject-matter learning. We believe that situating reading, writing, and language within inquiry science invites reading and writing to serve just the right role as tools for learning. In our view, science not only provides a forum for students to apply discrete reading and writing skills and strategies, it also provides opportunities for the sophisticated and dynamic enactment of these strategies in the service of developing understandings about the world. Reading and writing are taught and applied as means to build these scientific understandings and to participate in the world of scientific inquiry. Further, the vocabulary and world knowledge that students develop during their scientific inquiry spur on literacy development. In addition, students develop their capacity to engage in informational literacy, which is key to success in later schooling and is imperative in life outside of school. Literacy instruction should prepare students for the reading and writing that they will do inside and outside of school, the majority of which will involve informational text, not the literary text that constitutes the majority of the textual diet in current elementary reading programs. Right now, informational reading and writing are scarce in elementary classrooms, but literacy educators are increasingly suggesting that they should not be (Duke & Bennet-Armistead, 2003; Kamil, Lane, & Nicolls, 2005).

Seeds/Roots Model of Science–Literacy Integration

While we began our journey into integrated curricula with an additive assumption, emphasizing opportunities for mutually supportive science and literacy goals and activities, we have since moved to a more *synergistic* assumption, focusing on shared knowledge and strategies. Our model relies on a set of understandings about and attendant curricular implementations of this synergistic relationship: that words are fundamentally conceptual, that science and literacy share a core set of meaning-making strategies, that text can play a set of dynamic roles in the inquiry process and the "learning cycle," and that science is a discourse about the natural world. Each of these understandings is core to our approach.

Words Are Fundamentally Conceptual

Word knowledge at its most mature is conceptual knowledge—it involves understanding of words as they are situated within a network of other words and ideas (what psychologists have called *paradigmatic* relations) and their relationship to other words in spoken or written contexts (what psychologists have called *syntagmatic* relations, from Bruner, Olver, & Greenfield, 1966). From this perspective, word learning in science can and should be approached as conceptual learning—that is, words can and should be thought of *as* concepts that are connected to other concepts to form rich conceptual networks. Many science teachers are averse to text-centric approaches to science curriculum because of the heavy emphasis on learning words as definitions rather than as part of rich conceptual networks of ideas that define the knowledge base in science (Cervetti, Pearson, Bravo, & Barber, 2006). In the Seeds/Roots curriculum we treat word learning as conceptual learning. We are careful to:

- Select a limited set of highly generative and powerful discipline-specific concepts/words.
- Provide students with repeated exposure to the concepts/words in multiple modalities.
- Help students see the relationship between the concepts/words.
- Provide opportunities for students to build active understanding and control of the concepts/words.

Science and Literacy Share a Core Set of Meaning-Making Strategies

Reading and scientific investigation are both acts of inquiry—students read and investigate *to find out*—and inquiry and comprehension share goals, functions, and strategies that can be capitalized upon in integrated curricula. For example, predicting, inferring, and questioning are part of "inquiry" in the discipline of science and "comprehension" in the literacy domain. In the Seeds/Roots curriculum this means that we: target pairs of highly related inquiry/comprehension strategies in each unit; choose a set of common questions and use them repeatedly to activate these common cognitive processes; and create opportunities for students to reflect on how a strategy is used in a similar or different way in the context of conducting a firsthand investigation or reading a text.

Text Can Play a Set of Dynamic Roles in the Inquiry Process and the "Learning Cycle"

We have found a range of significant and supportive roles for text in inquiry-based science, and we have found that these roles occur at every stage of that process—before it starts, as it unfolds, and after it has ended. For example, we find that text can:

- Set the context for firsthand investigations.
- Support firsthand investigations.
- Model scientific processes and dispositions and literacy processes.
- Deliver content.

While inquiry-oriented science educators have often expressed concern about the role that text may play in eclipsing the process of scientific investigation, text can also be used in ways that support inquiry by, for example, providing access to scientific information that cannot be investigated in a firsthand way in classrooms. In our curriculum this means that we use books in each of these roles as an integral part of the unit. For instance, a book that is part of a physical science unit about substances and mixtures engages students in thinking about the relationship between properties, materials, and human-made objects by exploring imaginary and imaginative mismatches, such as rain boots made of paper and frying pans made of rubber. In this same unit, students consult a reference book that provides information about various ingredients they can use to design mixtures with specific purposes.

Science Is a Discourse about the Natural World

In addition to being a discipline, science is a social context where the language used is a powerful and specialized way of talking about the world, writing about the world, and even "being" in the world of scientists (Lemke, 1990). One of our favorite quotes about the discursive aspect of science comes from Neil Postman in the 1970s and captures perfectly the sociocultural basis of disciplinary knowledge and cultural practices: "Biology is not plants and animals. It is language about plants and animals. . . . Astronomy is not planets and stars. It is a way of talking about planets and stars" (Postman, 1979, p. 165). The specialized language of science has its own vocabulary and organization that are embodied in the ways scientists communicate about their work. This is particularly evident in the ways that scientists argue and leverage evidence to support claims. The language of argumentation and the ability to make explanations from evidence are strong emphases in the Seeds/Roots units (Cervetti et al., 2006). This means we:

- Increase the frequency, modality, and quality of opportunities for individuals, pairs, and groups to reflect and discuss.
- Provide structured opportunities to use the discourse and language of science and argumentation in the service of making evidence-based claims.
- Provide opportunities for students to present their work and critique one another's thinking.
- Provide opportunities for students to read and write in the genres of science and to use charts, diagrams, and symbols.
- Introduce students to the scientific genre of posters and poster sessions as they create their own.

Results of Seeds/Roots Research

During the 2004–2005 school year, each of three Seeds of Science/Roots of Reading units for second- and third-grade students was implemented by teachers in at least 20 classrooms. The field tests for two of these three units also included comparison conditions. A brief description of these units is included in Table 7.1. Students in the comparison classrooms used a science-only inquiry unit that taught similar science concepts (science only), a literacy curriculum that included the student science books and associated literacy activities (literacy only), or their regular science and literacy programs (no treatment). See Table 7.2 for the number of classrooms in each treatment and comparison group.

Teachers in all of the field test classrooms administered pretests and posttests of science and literacy to students. The performance of students using the Seeds/Roots materials was compared to the performance of students in the other groups on the following measures: (1) an assessment of science understanding, focused on the important concepts for the unit; (2) an assessment of science vocabulary, including picture association items and definition association items; and (3) an assessment of reading comprehension, using science, social studies, and fictional passages.

We designed the student assessments and teacher surveys with the help of the National Center for Research on Evaluation, Standards, and Student Testing (CRESST) at the University of California, Los Angeles.

TABLE 7.1. Three Seeds/Roots Units for Grades 2–3

Unit topic	Unit description
Earth science	Students learn through firsthand activities, reading, and writing about the shoreline ecosystem, the formation of sand, the organisms that live at the shoreline, and potential hazards to shoreline health, such as litter and oil spills. Students learn to use nonfiction texts to find information, to write informational reports, and to use inference making as a reading comprehension and inquiry strategy.
Life science	Students learn about plant and animal organisms and their habitats. They learn about the adaptations that help ensure organisms' survival. Students build their own habitats to learn about interdependence and decomposition. Students learn to use prediction as a reading comprehension and inquiry strategy. They learn to observe and take notes about their observations over time and to compare important features of different habitats and organisms.
Physical science	Students learn about the properties of a variety of materials and the applications of these materials, and their properties, to human problems through invention. Students design a series of mixtures. Students learn to write texts that describe their inventions and how they were made. They learn about cause-and-effect relationships. And, they learn to use summarizing as a reading comprehension and inquiry strategy.

The CRESST team also interviewed a subset of field trial teachers and analyzed the student assessment data for the earth science and life science units. The results of their analysis are reported elsewhere (Wang & Herman, 2005).

Students using the Seeds of Science/Roots of Reading units made significantly greater gains in science *and* literacy outcomes than students in the comparison conditions for both the earth science and life science units (see Cervetti et al., in preparation). While there was no comparison group for the physical science unit, the pre-post gains of the students using the Seeds/Roots materials were comparable to the overall gains made by Seeds/Roots students in the other units.

Within the earth science unit on beaches and shorelines, Seeds/Roots students exhibited consistent and statistically significant advantages over students using science-only materials on the aggregated measures of literacy (the sum of vocabulary and science text comprehension) and science (conceptual knowledge and cursory inquiry skills). These overall results were complicated by several statistically

TABLE 7.2. Number of Classrooms in Each Treatment Group by Unit

Unit	Experimental integrated unit	Science only	Literacy only	No treatment
Earth science	24	10		
Life science	20	13	12	10
Physical science	29			

significant and conceptually interesting interactions with individual difference factors. For example, on literacy measures the Seeds/Roots intervention was especially powerful (in comparison to science-only) for younger students (second-graders) on literacy measures, poorer students (those receiving free and reduced lunch), and minority students (nonwhites, but excluding Asian Americans). Perhaps the most interesting finding for the science measure for shoreline knowledge was a reliable advantage for English language learners (over English-only learners) from pre- to posttest.

Within the life science unit, we had two additional comparison groups; a literacy-only group and a no-treatment (business-as-usual) control were added to the Seeds/Roots and the science-only group. The descriptive pattern of results on the combined literacy measure (vocabulary plus target science comprehension) was: Seeds/Roots literacy-only science-only no treatment. Seeds/Roots did not differ from literacy-only but did statistically outperform both the science-only and the no-treatment condition. We had no comparison groups for our physical science trial (there was no preexisting science-only curriculum for that unit), so we were able only to examine growth scores from pretest to posttest. That the growth was of the same general magnitude as in the other two units gives us reason to believe that the Seeds/Roots version had the same general features and impact as it did for the earth science and life science units.

It is also notable that all groups of students who had lower scores on the science pretest in the earth science unit made equivalent gains to those who scored higher on the pretest, suggesting that this approach was accessible to students at different levels of initial achievement. More detailed analyses are under way to learn more about the nature of these observed effects and to gain more insight on the "active ingredients" in the Seeds/Roots approach.

In terms of uptake, teachers and students were overwhelmingly enthusiastic about the integrated units, commenting on their capacity to sustain interest and engagement for long periods of time during the day and across the entire unit. Of particular interest to teachers is having books and curricular activities that support the inquiry-based science. At this point in our work, we feel confident concluding that the integrated approach yields distinct advantages for both the acquisition of science content and method as well as for the acquisition of literacy skills and processes.

The Research We Need at the Science–Literacy Interface

These promising results notwithstanding, much work and many unanswered questions remain. We close this chapter by outlining the most vexing and, in our view, the most important questions and issues in this domain of inquiry.

Vexing Questions

Opportunity Costs

A general observation of curriculum implementation is that it is a zero-sum game: when you spend more time on X, you have less available to spend on Y. We call these opportunity costs—what opportunities did we lose by emphasizing X? A fair critique of our Seeds/Roots work is that the extra time devoted to the integrated approach provides it with an unfair advantage over the comparison conditions, so it is not surprising that the students learned more science. But at what cost was that extra advantage in science learning achieved?

In fact, we estimate that it takes about 35–40% more overall time to complete the integrated than the science-only approach for a given unit. There are two ways to control for the time differential: (1) we could extend the time available to the science-only and literacy-only approaches so that the total time allocated to all three would be comparable, or (2) we could conduct careful curricular analyses (either observations or teacher logs) to determine what teachers in the comparison conditions are doing with the time savings they accrue over the integrated condition. For the science-only group, our educated hunch is that they do more reading and writing work—knowing what we know about the pressures to focus on literacy in today's policy context. But it would be useful to know just how that extra time is spent. Ditto for the literacy-only approach. And it would be even more useful to know whether those advantages produced comparable decrements in achievement in other curricular areas, most likely in literacy.

Assessment Questions

As with most curricular research, assessment questions weigh heavily in our work. The validity of our conclusions rests on the assumption of valid, relevant, and reliable assessments. And the ultimate utility of our work depends upon building useful and instructionally valid assessments that can help teachers shape instruction for both whole classes and individual students. We certainly feel as though we are "on the right track" with our science and literacy assessments. But our assessments were highly curricularly embedded; that is, they measured what we taught in the unit. Additionally, we need to develop measures that assess how far our instruction will "travel" beyond the particular contexts of these units. In short, we need an even more explicit theory of transfer than we were able to implement in this study. We need to answer this question: As an assessment moves further and further away from the content and processes taught in a given unit, what would one expect students to be able to use from that unit to solve novel problems? The ultimate transfer question would be whether any of the content and processes would aid performance in other disciplines, such as mathematics or social studies. We think these questions, their complexity notwithstanding, deserve more careful attention.

We liked the general approach we took to science assessment, which was embedded in a scripted narrative read by the classroom teacher, who would stop at key points along the way to ask students to perform a short-answer, matching, or multiple-choice task on the printed page. The benefit to this approach is that reading ability is not confounded with our capacity to assess scientific knowledge. But we don't know for sure that we gained a significant amount of information about scientific knowledge by removing this potential confound. We did, by virtue of our short-answer format, create a potential confound with writing; but, again, we don't know whether that compromised our capacity to obtain a purer and more precise estimate of scientific knowledge.

Academic Language

The issue of acquiring the discourse and vocabulary of science was very much on our minds in this work. This is why we spent so much time using the language of science in our discourse circles and weekly whole-class reflections. This is why we insisted that, if a word was worth teaching, it was worth using in every possible context—reading, writing, talking, and doing. But we did not measure word acquisition well, and we suspect others are in the same quandary. We will have an opportunity to go back to our written work samples to look for the spontaneous use of key vocabulary and even phraseology. But we did not have sufficient resources to record many of the conversations, so it is harder for us to examine the spontaneous use of scientific discourse during the conduct of inquiry activities or in the "talk about text" sessions within the integrated approach. Given the stakes associated with the acquisition of academic language, we all need to be more diligent about teaching and measuring this important feature of learning in schools.

Science Schemata

Imagine that we are in a situation in which students have encountered not one, not two, but perhaps eight of these integrated units. A question that haunts us is whether there is any cognitive savings in acquiring information in the ninth unit. There are three equally plausible theoretical explanations that might account for developing cognitive economy: (1) later acquisition is facilitated by the knowledge acquired in the earlier units; (2) later acquisition is facilitated by the procedural skills acquired in the earlier units; or (3) later acquisition is facilitated by the acquistion of a kind of "science" learning schema—a framework for organizing knowledge and activity in *any* science unit. We are not sure which of these explanations best accounts for developing cognitive economy, nor even whether cognitive economy *does* develop over time. Perhaps all three operate in concert. But we are sure that this is an important and currently underappreciated feature of research at the science–literacy interface. In fact, we would argue that it is equally as underappreciated in areas like early literacy instruction—where we teach the 15th lesson on letter sounds just like we teach the first, failing to recognize that students may be developing a letter–sound learning schema.

Cross-Curricular Synergies

A fundamental aspect of the belief system that gives rise to Seeds/Roots is synergy across the science–literacy divide. We assume, for example, that science inquiry skills are almost identical, save for the context and nature of the evidence required, to reading comprehension strategies. But we have never really tested that assumption, and we should. For example, if the assumption is true, then students should improve their reading comprehension acuity when we teach science inquiry skills—and vice versa. This question could be investigated relatively easily, and we owe it to ourselves and our curriculum development efforts to replace belief with evidence as the grounds for this important claim.

Professional Development

In our national field trial, we sent these units to teachers in the field, providing them with only a teacher guide and curriculum materials. We provided no professional development. The first question that arises is, What sort of impact might be generated by having a real professional development program to guide implementation of the Seeds/Roots approach? And the more general question of the value added of professional development is important for all curriculum implementations.

When it comes to science literacy units, an additional issue—the relative comfort of teachers in teaching literacy versus science—becomes important. One approach we have considered is building on teachers' comfort in literacy to "bootstrap" their engagement in inquiry-based science. What would happen, for example, if we gave integrated units to high-efficacy literacy teachers who varied dramatically in their perceived science efficacy? With literacy as a bridge, would the initially low-efficacy science teachers end up looking more like the high-efficacy science teachers? And how would their students do? These are important questions, ones that we hope to answer in the very near future.

A Final Word

During the 3 years that we have been on this journey to the interface between science and literacy, we have learned almost as much about the benefits of curricular integration and cognitive synergies as we have about just how difficult it is to work in this area and just how much more we have to learn. But it is a journey well worth the time and energy needed to scale the steep grades, sidestep the potholes, and stay the course. Why? Because it is a journey that leads to improved literacy, scientific knowledge, and personal efficacy for students and greater professional efficacy for teachers.

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References

Anderson, T. H., West, C. K., Beck, D. P. Macdonell, E. S., & Frisbie, D. S. (1997). Integrating reading and science education: On developing and evaluating WEE Science. *Journal of Curriculum Studies, 29*(6), 711–733.

Baker, L. (1991). Metacognition, reading, and science education. In C. M. Santa & D. E. Alvermann (Eds.), *Science learning: Processes and applications* (pp. 2–13). Newark, DE: International Reading Association.

Bruner, J. S., Olver, R. R., & Greenfield, P. M. (1966). *Studies in cognitive growth*. New York: Wiley.

Carin, A. A., & Sund, R. B. (1985). *Teaching modern science* (4th ed.). Columbus, OH: Merrill.

Carver, S. M., & Klahr, D. (Eds.). (2001). *Cognition and Instruction: 25 years of progress*. Mahwah, NJ : Erlbaum.

Cervetti, G. N. (2006). *A model of science–literacy integration*. Paper to be presented at the annual meeting of the American Educational Research Association, San Francisco.

Cervetti, G. N., Barber, J., Pearson, P. D., Hiebert, E. H., Arya, D. J., Bravo, M. A., & Tilson, J. (in preparation). *Seeds of science/roots of reading: The results of a national evaluation*. Berkeley, CA: Lawrence Hall of Science.

Cervetti, G. N., Pearson, P. D., Bravo, M. A., & Barber, J. (2006). Reading and writing in the service of inquiry-based science. In R. Douglas, M. Klentschy, & K. Worth (Eds.), *Linking science and literacy in the K–8 classroom*. Arlington, VA: National Science Teachers Association.

Duke, N. K., & Bennett-Armistead, U. S. (2003). *Reading and writing informational text in the primary grades: Research-based practices*. New York: Scholastic.

Guthrie, J. T., & Ozgungor, S. (2002). Instructional contexts for reading engagement. In C. Collins Block & M. Pressley (Eds.), *Comprehension instruction: Research-based best practices* (pp. 275–288). New York: Guilford Press.

Guthrie, J. T., Anderson, E., Alao, S., & Rinehart, J. (1999). Influences of concept-oriented reading instruction on strategy use and conceptual learning from text. *The Elementary School Journal, 99*(4), 343–366.

Kamil, M. L., Lane, D., & Nicholls, E. (2005). Theory and practice of using informational text for beginning reading instruction. In T. Trabasso, J. Sabatini, D. W. Massaro, R. C. Calfee (Eds.), *From orthography to pedagogy: Essays in honor of Richard L. Vanezky*. Mahwah, NJ: Erlbaum.

Lemke, J. L. (1990). *Talking, science, language, learning, and values*. Norwood, NJ: Ablex Publishing.

Padilla, M. J., Muth, K. D., & Lund Padilla, R. K. (1991). Science and reading: Many process skills in common? In C. M. Santa & D. E. Alvermann (Eds.), *Science learning–Processes and applications* (pp. 14–19). Newark, DE: International Reading Association.

Palincsar, A. S., & Magnusson, S. J. (2001). The interplay of firsthand and text-based investigations to model and support the development of scientific knowledge and reasoning. In S. Carver & D. Klahr (Eds.), *Cognition and in-*

struction: Twenty five years of progress (151–194). Mahwah, NJ: Lawrence Erlbaum.

Pappas, C. C.,Varelas, M., Barry, A., & Rife, A. (2002). Dialogic inquiry around information texts: The role of intertextuality in constructing scientific understandings in urban primary classrooms. *Linguistics and Education, 13*(4), 435–482.

Postman, N. (1979). *Teaching as a conserving activity*. New York: Delacorte.

Romance, N. R., & Vitale, M. R. (1992). A curriculum strategy that expands time for in-depth elementary science instruction by using science-based reading strategies: Effects of a year-long study in grade four. *Journal of Research in Science Teaching, 29*(6), 545–554.

Romance, N. R., & Vitale, M. R. (2001). Implementing an in-depth expanded science model in elementary schools: Multi-year findings, research issues, and policy implications. *International Journal of Science Education, 23*(4), 373–404.