The Journal of Educational Research, 103:262–273, 2010
Copyright © Taylor & Francis Group, LLC
ISSN: 0022-0671 print / 1940-067 online
DOI:10.1080/00220670903383051

Improving Middle School Students' Science Literacy Through Reading Infusion

ZHIHUI FANG
University of Florida

YOUHUA WEI
Educational Testing Service

ABSTRACT. Despite recent calls for border crossing between reading and science, few studies have examined the impact of reading infusion in the science curriculum on students' science literacy. In this quasi-experimental study, the authors investigated the effects of an inquiry-based science curriculum that integrated explicit reading strategy instruction and quality science trade books on the development of science literacy among middle school students. Students in 10 sixth-grade science classes from 1 public middle school in the United States were randomly assigned to 2 conditions: inquiry-based science only (IS) and inquiry-based science plus reading (ISR). Results from the analyses of covariance showed that the ISR students significantly outperformed their IS peers on all measures of science literacy. It was suggested that even a modest amount of reading infusion could have a positive impact on middle school students' science literacy. The limitations and implications of the study were also discussed.

Keywords: science literacy, content area reading, middle school

With the national spotlight on adolescent literacy in recent years, there has been a renewed interest in integrating reading in secondary content areas such as science. A flurry of high-profile reports (e.g., Biancarosa & Snow, 2004; International Reading Association & National Middle School Association, 2001) called for continued reading instruction beyond the elementary grades, suggesting that adolescents need support when interacting with the dense, complex texts in secondary content areas. Leading science educators (e.g., Norris & Phillips, 2003; Wellington & Osborne, 2001; Yore et al., 2004) have likewise emphasized the need to bridge the gap between literacy practices and the teaching and learning of science in school classrooms. They argued that in embracing inquiry as the cornerstone of science, school science education programs should also include as their goals the development of students' ability to access, comprehend, and produce science texts. These scholars believed that such reading–science integration is needed in order for students to truly develop as scientifically literate citizens. While encouraging science educators to use documented language and literacy practices in the service of science teaching and learning, Hand et al. (2003) also acknowledged that "[s]uccessful implementation of these instructional practices will require support for both teachers and students to buy into this different way of doing business" (p. 614). They further called on the science education research community to "verify the robustness of these approaches in the context of inquiry science and typical classrooms" and to "convince teachers of science that these approaches are authentic science and effective ways of achieving science literacy" (Hand et al., p. 614). The present study answers this call by examining the impact of an inquiry-based science curriculum that infused explicit reading strategy instruction and quality science trade books on middle school students' science literacy development.

Theoretical Perspectives

Science is a discipline that involves "both *material* and *semiotic* practices" (Halliday, 1998, p. 228). On one hand, science is an organized human activity that seeks knowledge about the natural world in a systematic way. It requires the use of scientific methods for observing, identifying, describing, and experimentally investigating the natural phenomenon. On the other hand, science is also a form of discourse that involves the use of language, particularly written language. Scientists use language in conducting scientific inquiries and in constructing theoretical explanations of the natural phenomenon. They also use language to communicate scientific knowledge, principles, procedures, and reasoning to others. For these reasons, science has been characterized as "a unique mix of inquiry and argument" (Yore et al., 2004, p. 347).

Given the nature and character of science, it is not surprising that much of the recent scholarship on science education has emphasized the centrality of both inquiry and reading

---

Address correspondence to Zhihui Fang, School of Teaching and Learning, 2423 Norman Hall, University of Florida, Gainesville, FL 32611-7048, USA. (E-mail: zfang@coe.ufl.edu)

to the development of science literacy. For example, the National Research Council (1996, 2000) outlined a vision of science education that makes inquiry the cornerstone of the science curriculum. An inquiry-based curriculum recognizes science as a process for producing knowledge that depends on careful observations and grounded interpretation. It emphasizes the development of skills in acquiring science knowledge, using high-level reasoning, applying existing understanding of scientific ideas, and communicating scientific information. Similar to scientists who develop their knowledge and understanding as they seek answers to questions about the natural world, students in an inquiry-based curriculum actively and collaboratively engage in the sciencing cycle of recognizing a problem, proposing a hypothesis, designing an experiment, collecting data, analyzing data, and drawing a conclusion.

Meanwhile, recognizing that "without text and without reading, the social practices that make science possible could not be engaged" (Hand et al., 2003, p. 612), science educators have in recent years expanded their conception of science literacy as knowledge of the big ideas in science to also include the general reading ability. For example, Norris and Phillips (2003) defined science literacy from both the fundamental and the derived senses. The fundamental sense of science literacy refers to "the concepts, skills, understandings, and values generalizable to all reading" and the derived sense of science literacy refers to "knowledge of the substantive content of science" (Norris & Phillips, p. 235). In this new conception, reading is inextricably tied to the very nature and fabric of science. It is seen as a powerful vehicle for engaging students' minds, fostering the construction of conceptual understanding, supporting inquiry, and cultivating scientific habits of mind (Wellington & Osborne, 2001; Yore, 2004). Without the ability to read, students are severely limited in the depth and breadth of scientific knowledge they can attain and hence in their development of the derived sense of science literacy.

Review of Related Research

We review three areas of research that inform the design and implementation of the present study: reading in the secondary content area of science, contributions of reading instruction to science learning, and science teachers' attitudes toward and knowledge about reading.

Reading in the Secondary Content Area of Science

Students do not learn to read once and for all in the elementary school. They need to continue to develop their reading ability in order to deal with the more specialized and complex texts of secondary content areas. For example, Fang (2005) demonstrated that middle school science texts are challenging for students because they typically deal with topics that are far removed from students' everyday life experiences and often use language that is simultaneously technical, dense, abstract, and hierarchically structured. According to Berman and Biancarosa (2005), although most adolescent learners can read simple, everyday texts, many "frequently cannot understand specialized or more advanced texts" and "are unprepared to meet the higher literacy demands of today's colleges and workplaces" (p. 6). It is clear that adolescents need support in developing advanced literacy.

The idea of teaching reading in content areas like science is not new (Artley, 1944), and recent attempts to operationalize the idea have focused on two key components: teaching reading comprehension strategies and building domain knowledge (and related vocabulary) through infusion of trade books. One way to help students cope with the more demanding texts of secondary science is to teach them strategies for processing the complex language of science and for monitoring comprehension. An extensive body of reading research has suggested that explicit instruction in reading strategies—such as predicting, questioning, thinking aloud, summarizing, note taking, and recognizing text structure—can improve students' comprehension of content area texts (Alvermann & Moore, 1991; National Reading Panel, 2000). Research also shows that many middle school students have misconceptions of science reading and lack effective strategies for coping with science texts (Craig & Yore, 1995). In reflecting on the adolescence research literature and his own experience studying reading instruction in middle and high schools, Pressley (2004) reported that "there is no evidence of a single student attacking a text on a first reading using the complex repertoire of strategies that are used by skilled readers" (p. 420). Taken together, the existent research suggests that adolescent learners need—and can benefit from—explicit instruction in reading strategies.

Another way to improve students' science reading is to build their background knowledge about science. Hirsch (2006) suggested that a learner's knowledge in a content area has a great impact on the development of his or her reading competence in that content area. That is, the development of science-related reading skills and strategies, reading motivation, and reading comprehension demands a large amount of background knowledge in science. On one hand, if students can relate to the text in some way, they are more likely to want to read it (Tobias, 1994). On the other hand, content areas provide authentic learning contexts in which students can practice and hone their reading skills and strategies. They also provide much of the basis for comprehending, learning, and remembering the ideas in the text (Anderson, 2004). In short, developing a rich store of domain knowledge and related vocabulary about science is key to successful comprehension of science texts. An effective avenue to increase students' domain knowledge and related vocabulary about science is to expose them to lots of science books. However, adolescents engage in very little reading of texts in school (Wade & Moje, 2000). Clearly, adolescents need—and can benefit from—wide reading of science books.

Recognizing the potential contributions of strategic knowledge and domain knowledge to successful reading comprehension, researchers have conducted empirical studies investigating the effects of infusing explicit reading strategy instruction and science trade books on students' science literacy development. We subsequently review this research base.

Reading Instruction and Science Learning

There has been a considerable amount of research on the effect of reading instruction on science learning. Much of this research, however, focuses on the effect of teaching a single reading strategy, such as recognizing text structure (Spiegel & Barufaldi, 1994) or using graphic organizer (Griffin, Simmons, & Kameenui, 1991), on students' comprehension and recall of the science content in the text. Only a few studies have examined the impact of systematically infusing reading instruction with science on students' learning outcomes. The reading infusion in these studies typically featured comprehension strategy instruction and the use of science trade books. For example, Romance and Vitale (1992) studied the effectiveness of a curriculum-integration model for Grade 4 in which the time available for science instruction was expanded to 2 hr each day. Instead of the traditional separation of reading and language arts instruction (90 min) and science instruction (30 min), the integrated model used in-depth science instruction that taught science, reading, and language arts objectives in an integrated fashion for 2 hr per day. Such in-depth science instruction featured hands-on activities, explicit strategy lessons (e.g., cause–effect relationship, main idea, questioning), and extensive reading of science texts (e.g., trade books, textbooks, other print materials). The researchers found that when compared to their demographically similar peers, the students in the integration model displayed significantly greater achievement in science and reading.

Similar to Romance and Vitale's (1992) study, Guthrie et al. (1998) designed a year-long integration of reading and language arts and science instruction, known as Concept-Oriented Reading Instruction (CORI). The reading strategies taught in the CORI model included activating background knowledge, questioning, searching for information, summarizing, and organizing graphically. The researchers compared third- and fifth-grade students who received CORI to similar students who received traditionally organized instruction aimed toward the same objectives. The study found that the children who received CORI were more likely to learn and use strategies for gaining knowledge from multiple texts than the students in the traditional instruction program that included a basal reader supplemented by children's literature. CORI also had a positive, indirect effect on conceptual knowledge mediated by strategy use. It increased the students' ability to use a range of strategies, and the students who were more adept at using these strategies gained more conceptual knowledge during the performance assessment than the students who were less proficient in the strategies.

Highlighting the role of trade books in the literacy and science curriculum, Morrow, Pressley, Smith, and Smith (1997) studied the impact of a literature-based program integrated into literacy and science instruction on the third-grade students' achievement, use of literature, and attitudes toward the literacy and science program. Standardized and informal written and oral tests were used to determine growth in literacy and science. The researchers found that the children in the literature–science integration group scored significantly better on all literacy measures (e.g., standardized tests, retelling) and two science measures (i.e., science facts and vocabulary) than did the children in the literature-only and the control groups.

Gaskins et al. (1994) examined whether an integrated science and reading and writing program in the middle school facilitated the development of higher order reading and thinking processes in the students who, on average, read two years below grade level. They integrated the teaching of science, reading, and writing processes in a conceptually based, problem-centered unit on simple machine. This 10-week unit featured text reading, experiments, demonstrations, collaboration, and written explanations. The students were explicitly taught reading, writing, and thinking strategies in the curriculum, including what strategy to use, why the strategy is beneficial, when to use the strategy, and how to implement the strategy. They were assessed at the beginning and the end of the unit through the authentic, performance-based task of solving a real-life problem (e.g., removing and transporting a heavy builder, lifting and opening a heavy crate) and explaining in scientific terms the principles behind their solution. The researchers found that the students improved significantly in the processes of stating the problem, selecting resources relevant to the problem, expressing a conceptual solution to the problem, and demonstrating their conceptual understanding in a new application, but not in the visual solution or the written procedural solution to the problem. The study did not, however, address whether student learning was directly attributable to the curriculum or whether the students would have performed better under another instructional setting.

The research studies reviewed previously support the theoretical argument that combining reading and science is beneficial, suggesting that if students are provided time to read science texts and taught how to use reading strategies, they not only become more proficient readers, but also learn science content more effectively. In other words, combining reading and science instruction has the potential to improve science reading comprehension and science content learning, helping promote the development of science literacy. There are several limitations to these studies, however. First, with the exception of Gaskins et al. (1994), the studies all took place in the elementary setting. We have relatively little information about ways to infuse reading into secondary science and the impact of such systematic infusion on student learning. Second, these studies involve integrating science into the reading class, where the architect of classroom instruction is the reading teacher, who typically has specialized training in reading and provides instruction to the same group of students for almost the entire school day. This is different from integrating reading into the science class, where the architect of classroom instruction is the science teacher, who typically has little formal training in teaching reading and provides only one period of instruction to the same group of students in a school day.

According to Eccles et al. (1993), middle schools "are typically larger, less personal, and more formal than elementary schools" and middle school teachers "are often subject-matter specialists and typically instruct a much larger number of students than do elementary teachers in self-contained classrooms" (p. 558). In part because of these changes in the school structure and academic environment, middle school students tend to be much more disengaged from reading and learning than do elementary students (Guthrie & Davis, 2003). These factors make the integration of reading into secondary content areas much more challenging. Thus, it is important to know the extent to which reading can be infused into the middle grades and if such integration produces outcomes comparable to the studies conducted in the elementary school. We addressed this need by examining the effectiveness of an integrated reading–science middle school curriculum that featured the infusion of quality science trade books and explicit reading strategy instruction.

Science Teachers and Reading Instruction

Despite its potential benefits, integrating reading into secondary content areas such as science has been difficult and met with limited success. In a seminal review, O'Brien, Stewart, and Moje (1995) presented several reasons as to why this is the case from the perspectives of curriculum, pedagogy, and school culture. First, reading and literacy instruction confronts deeply embedded values, beliefs, and practices held by secondary teachers, students, and other members of the school culture. For a long time, secondary science is perceived as a hands-on subject that has little to do with reading, and reading was by and large a neglected activity in the science classroom (Wellington & Osborne, 2001). The facts that secondary students are generally less motivated to read/learn (Biancarosa & Snow, 2004) and that science is a highly specialized discipline with unique discursive conventions, values, and worldviews (Halliday & Martin, 1993; Martin & Veel, 1998) make the integration of reading especially challenging. To exacerbate the situation, present science methods textbooks for secondary preservice teachers often show a lack of explicit encouragement for—and provide little assistance to teachers in—reading instruction (Draper, 2002). Second, the infusion of reading in science is likely to mean that reading competes with science for the limited time and resources in the science classroom. The idea of allocating time for reading instruction may not sit well with some science teachers, who sometimes fail to see the usefulness of reading instruction for meeting their instructional goals (e.g., hands-on activities, content coverage). Third, the overall school climate and reward structure tied to professional development can impact science teachers' enthusiasm for integrating reading into their subject. The compartmentalization of curriculum subjects (50 min per subject per day) in the secondary school reflects and reinforces the division of curricular content areas, further inhibiting the infusion of reading instruction.

Research has suggested that although many science teachers are not philosophically opposed to the idea of integrating reading instruction in science, they often lack knowledge, resources, and support to make the integration happen. In a pioneering study, Yore (1991) conducted a survey of 215 Canadian secondary science teachers' beliefs about and attitudes toward science reading and science textbooks. Yore reported that the science teachers appeared to value science reading and science reading instruction and were willing to accept responsibility for it; however, they lacked substantive backgrounds in science reading and held fragmented beliefs about the cognitive and metacogntive reading skills needed to learn effectively from science texts.

Building on Yore's work, DiGisi and Willett (1995) surveyed 149 U.S. high school biology teachers' instructional use of reading and textbooks. They found that even though these teachers believed that reading is an important means of learning science in addition to inquiry-based activities, they were unsure about how to incorporate active reading comprehension instruction into their science curriculum. Further, despite the popularity of concept mapping, reading aloud, and teaching text structure, these activities were not used in the science classroom. Instead, the teachers reported that their common practices involving reading included the preteaching of vocabulary, asking questions while students were reading, assigning worksheets after reading, writing answers to questions after reading, and quizzing students after reading. They did not actually teach the metacognitive strategies needed to enable students to monitor their reading comprehension or the active cognitive strategies necessary to construct meaning from texts.

In summary, although secondary science teachers generally believe in the importance of reading to science, they often report difficulties incorporating reading into the science lesson. The consequence of this failure to infuse reading in science is that many adolescents do not read much in the science classroom and have difficulties understanding what they read in the school.

Present Study

It is clear from this review of related research that secondary science teachers face considerable challenges in integrating reading into their classrooms and that they need much support in this endeavor. Cognizant of the many obstacles facing science teachers, we, a team of university-based reading educators, recently worked with 2 sixth-grade science teachers to infuse reading into their inquiry-based science curriculum. One of the teachers was a veteran science teacher with over 20 years of teaching experience in science and mathematics. Prior to participating in the project, she believed that "reading the textbook was what happened in boring science classes" and that "depending on the textbook was for unmotivated, lazy teachers." The other teacher was a first-year science teacher. The emphasis on hands-on, inquiry-based activities in her collegiate science education program had led her to believe that "teaching using the text was not ideal." As a result, she "used the text very little and even tried to avoid it."

Because of the historically documented difficulty with integrating reading into secondary content areas (O'Brien et al., 1995), we decided to moderate the amount of reading infusion by conducting one reading strategy lesson per week for about 15–20 min and instituting a home reading program through which students could select quality science trade books to read at home. We believed that such a modest level of reading infusion stood a better chance of success because it minimized science teachers' concerns about the instructional time and their knowledge of reading.

Further, because preparing secondary content teachers to become competent in reading instruction is a long-term process (Brown, Pressley, van Meter, & Schuder, 2004), we felt that from a practical standpoint, we could not wait until they became experts in teaching reading to start the research project. Rather, in consideration of the two teachers' beliefs about and prior experience with content area reading instruction, we adopted what Singer and Bean (1988) called an evolutionary model of training content area teachers to teach reading. In this model, a small number of science teachers (two in our case) who had little experience teaching reading in science worked collaboratively with the university-based reading educators to plan and implement the infusion of reading strategy instruction and quality science trade books into the science curriculum. Mindful of Guskey's (1986) principles for effective staff development, we worked *with*, rather than worked *on*, these teachers to bring about the reading integration in science. Specifically, in the initial phase of the project, we assumed the primary responsibilities in designing and implementing reading infusion in consultation with the two teachers. As the year progressed, the teachers gradually took on a more active role, coplanning and coteaching reading lessons with the reading educators. By the end of the year, the teachers planned and implemented their own reading lessons with little outside support. This model of collaboration had a more realistic chance of success because it allowed us to support teacher learning and practice in a way that was neither intimidating nor overwhelming.

This study was designed to explore the impact of the yearlong collaboration between us and the two science teachers on the sixth-grade students' science learning. It examined the extent to which the inquiry-based science plus reading (ISR) curriculum differed from the inquiry-based science only (IS) curriculum in influencing students' learning outcomes in science literacy. Two research questions were addressed in the study:

Research Question 1: What was the relative efficacy of the ISR curriculum in developing students' fundamental sense of science literacy when compared to the IS curriculum?

Research Question 2: What was the relative efficacy of the ISR curriculum in developing students' derived sense of science literacy when compared to the IS curriculum?

Method

Participants

The present study took place in a public middle school (Grades 6–8) located near a major research university in the United States. The school had a student population of approximately 900 students (51% boys, 49% girls; 51% White, 34% Black, 9% Hispanic, 4% Asian, 2% other), divided about equally among the three grade levels. Roughly half of the students in the school were considered low socioeconomic and qualified for free or reduced school lunch. At the time of this study, the school was ranked one of the lower performing middle schools in the district. Its students scored below the district average in every grade on a statewide high-stakes reading assessment. All sixth-grade students were invited to participate in the study.

Design and Treatment

There were 10 regular science classes in the Grade 6, taught by the 2 science teachers mentioned previously, each with 5 classes. Three classes per teacher (6 classes total, with 140 consenting students) were then randomly assigned to be the experimental group. The remaining 2 classes per teacher (4 classes total, with 93 consenting students) were designated as the comparison group. The comparison group used an inquiry-based curriculum previously developed by the 2 science teachers. The experimental group used a similar curriculum, but with the following two components of reading infused into it: (a) explicit instruction of reading strategies for an average of 15–20 min per week and (b) access to a home reading program that encouraged students to read and respond to one quality science trade book per week.

Inquiry-Based Science Only (IS) Curriculum

All sixth-grade students were served in their regular science class for 50 min per day. The scope and sequence of the science curriculum were based on the sixth-grade science textbook adopted by the school district, *Science Voyages: Exploring the Life, Earth, and Physical Sciences* (Glencoe, 2000). The two science teachers, in collaboration with a team of university-based scientists and science educators had, during the previous year, developed an inquiry-based curriculum based on the framework outlined in the *National Science*

Education Standards (National Research Council, 1996). The curriculum aimed at helping students develop an interest in science, enhance their understanding of science as a human endeavor, and acquire scientific knowledge and thinking skills. It engaged students in making observations; posing questions; predicting; planning investigations; using tools to gather, analyze, and interpret data; proposing answers and explanations; and communicating results. It offered unique opportunities to support students' learning of science. Although there were occasional reading assignments in the curriculum, most involved silent reading of short textbook excerpts or directions in activity worksheets in the classroom. There was no reading instruction.

The inquiry-based science curriculum consisted of six units related to the main textbook: introduction to science, waves, motion and force, matter, earth and space science, and life science. Its scope and sequence were directly correlated to the selected science benchmarks from the state standards. The yearlong curriculum was divided into four 9-week quarters, each focusing on a different aspect of the nature of science: (a) observing and generating problems and conducting background research and planning, (b) conducting experiments to find viable responses to the problems raised in the first quarter, (c) exploring scientists and science-related careers, and (d) exploring science-related issues through projects. Each quarter included a range of teacher-directed inquiry activities and field trips, requiring students to explore relevant scientific phenomena, create reports, and present findings using appropriate media. These experiences paralleled the development of a culminating science project to be presented at the end-of-year school science fair. The students in the comparison group received instruction using this curriculum only.

Inquiry-Based Science Plus Reading (ISR) Curriculum

The students in the experimental group used a similar inquiry-based science curriculum, but with the following two components of reading infused into it.

Reading strategy instruction. Middle school students need explicit strategy instruction to help them cope with the often dense and complex texts in science (Craig & Yore, 1995; Fang, 2005). One reading strategy lesson was taught to the experimental group for 15–20 min every Thursday for 22 weeks between October and April. Each strategy was taught on a 1–2 week cycle, depending on student and curricular needs. The reading strategies taught included predicting, thick and thin questioning, concept mapping, morphemic analysis, recognizing genre features, paraphrasing, note taking, and think-pair-share. These strategies were selected from a list of 20 or so strategies that we had compiled prior to the intervention based on our review of related research literature on strategy instruction (e.g., Alvermann & Moore, 1991; National Reading Panel, 2000) and on the language demands of science reading (e.g., Fang; Halliday & Martin, 1993; Lemke, 1990). They were chosen based on the following three criteria suggested by Yore (2004, p. 88): be important to science literacy, have the potential to improve learning from text, and can respond to explicit instruction.

Each week, the science teachers and the reading educators worked together to select one reading strategy from the identified list of strategies based on the science topic or concept to be covered and the science texts to be read. They designed the lesson plan together and then cotaught the lesson. Initially, the reading educators assumed the primary responsibility in lesson planning and delivery, but as the teachers gained more confidence and expertise in reading instruction during the year, they gradually took on a more active role, and by the fourth quarter of the year they were able to assume the major responsibility in lesson planning and delivery. To support the teachers' integration efforts, we conducted three professional development workshops during the school year in which the teachers read and discussed the ideas in several significant texts on reading–science integration (e.g., Harvey, 2002; Saul, 2004; Wellington & Osborne, 2001). We also held monthly meetings and weekly debriefing sessions, which provided the project team members opportunities to share observations, voice concerns, tweak the implementation, and further develop personal bonds. We felt that this collaborative model featuring a gradual release of scaffolds is needed based on our own experience working with content area teachers and in light of Hand et al.'s (2003) call to support science teachers in their efforts to infuse reading.

Using an explain–model–guide–apply (EMGA) instructional model, each lesson included a quick review of the previous week's strategy, an explanation of the target strategy for the week, the teacher's modeling of the use of the strategy, and brief guided and independent practices in applying the strategy. The students were reminded throughout the week to use the target strategy when reading the science textbook and related trade books. We also conducted two review lessons during the year, one at the end of the fall semester when we asked the students to select a strategy from the list taught for use with a text excerpt from a science trade book, and the other at the end of the spring semester when we invited all students to comment on their favorite strategy (strategies).

Home science reading program. Besides explicit reading strategy instruction, the experimental group was also provided access to a home science reading program (HSRP). The HSRP is important not only for building students' science content and vocabulary knowledge, but also for practicing the reading strategies they had been taught.

The home science reading program was organized in the fall semester and started in January. The students in the experimental group were required to check out one science trade book every Thursday and share the book with a family member. They completed a Reading Response Sheet (RRS) for each book on which they recorded the title and author of the book, amount of time spent reading the book, with whom they shared the book, one big idea they learned from the book, one thing they wondered about after reading the book, and how much they enjoyed the book by rating the book on a 5-point Likert-type scale of 1 (*not at all*) to 5 (*very much*). On the following Thursday, the students engaged in a short, teacher-guided discussion about their book responses and then checked out a new book.

We knew that for the HSRP to work the books we sent home had to contain accurate science content and be engagingly written and illustrated. Thus, we decided to select the award-winning literature for our project. We started with the Outstanding Science Trade Books for Students K–12 (http://www.nsta.org), published by the National Science Teachers Association in cooperation with the Children's Book Council, selecting all of the books from the intermediate level (Grades 6–8) and a few from the elementary level (Grades 3–5) since the inception of the award in 1973. We also selected the science winners and runners-up of the Orbis Pictus Award for Outstanding Nonfiction for Children (http://www.ncte.org/elem/awards/orbispictus), sponsored by the National Council of Teachers of English. In addition, we selected the winners of the Robert F. Sibert Information Book Award (http://www.ala.org), established in 2001 by the Association for Library Services to Children. We intentionally chose books with a wide range of reading levels and science topics. Eventually, we put together a total of 196 books for use in the HSRP collection. These books covered a wide range of topics relevant to the science curriculum. They were made available to the students in six book bins, one for each participating class. We made sure that each bin had a similar proportion of books that were balanced in the topical areas of science, in reading difficulty, and in the nonfiction subgenres. The bins were rotated midway through the semester.

Measurement Instruments

Several instruments were used to measure the impact of the project on the students' science literacy. Adopting Norris and Phillips' (2003) new conception of science literacy, we measured the students' science literacy development in both the fundamental and the derived senses. To assess the students' fundamental sense of science literacy (i.e., general reading ability), we used the Gates-MacGinitie Reading Tests (GMRT; MacGinite, MacGinite, Maria, & Dreyer, 2002), a standardized test of general reading ability widely used in the schools across the United States. The GMRT for Grade 6 (Level 6) consists of vocabulary and comprehension subtests, both presented in a multiple-choice format. The vocabulary subtest is a test of word knowledge. The comprehension subtest measures students' ability to read and understand prose passages and verses. The test–retest reliability coefficients for the GMRT is in the .90s. The correlations between the GMRT and the Iowa Tests of Basic Skills range between .67 and .84 for vocabulary and between .53 and .83 for comprehension (Harp, 2000). The test was administered at the beginning (September) and end (May) of the project.

To assess the students' derived sense of science literacy (i.e., their knowledge about science content) we used a curriculum-referenced science test (CRST). The CRST was developed at the beginning of the school year by the two science teachers in collaboration with the university researchers based on a commercial test bank of multiple-choice items made available by the publisher of the science textbook adopted for Grade 6 (Glencoe, 2000). The test bank (with answer keys) was originally designed to help sixth-grade science teachers review the state standards while reinforcing the science concepts taught in the class. Half of the items in the test bank assessed science skills directly, using the science concepts incorporated on a chapter-by-chapter basis from the *Science Voyages* textbook. Approximately one quarter of the items tested mathematics skills using the science content, and another quarter tested reading skills using the science content. The CRST consisted of 25 multiple-choice items that correlated with the scope and sequence of the science curriculum, covering the nature of science (1 item), physical science (11 items), life science (10 items), and earth and space science (3 items).

We decided to use the CRST, instead of other standardized science tests, so as to ensure that the test measured the content and knowledge that was covered in the science curriculum. Another reason for our choice of the content-and-knowledge-based test is that this form of assessment dominates present high-stakes tests. The CRST's item difficulty index was around .50 and the item discrimination index was close to or within the range of .30–.40. Overall, the Cronbach's alpha for the test was .78. These indices are within the acceptable ranges from a psychometric perspective (Crocker & Algina, 1986; Kaplan & Saccuzzo, 2001). The test was administered at the beginning (September) and the end (May) of the project.

In addition to the CRST, we also collected the students' academic year science grade (AYSG) as another measure of their derived sense of science literacy. The AYSG was computed by averaging the students' science grades (on a 100-point scale) in four quarters of the academic year. The students' quarterly science grades were determined based on weekly quizzes, lab reports, term projects, and other related class assignments. The AYSG can, thus, be considered both knowledge based and performance based. In short, we believed that the use of both CRST and AYSG is in alignment with the science framework used in the National Assessment of Educational Progress (Grigg, Lauko, & Brockway, 2006), enabling us to better capture the students' level of science literacy in its derived sense.

Data Sources and Analysis

The data sources for the study included the pre- and posttest scores for the GMAT and the CRST, as well as the AYSG. To answer the question of whether the students taught with the ISR curriculum outperformed their peers in the IS curriculum with respect to science literacy, we first verified whether the nested structure of the data (i.e., students nested within classes) required the use of a hierarchical linear model (HLM). HLM can be used only if there is a strong cluster effect, which means that a substantial proportion of the variability of the outcome variables is between classes. We assessed the cluster effect by calculating the intraclass correlations, which is the ratio of the between-class variance and the total outcome variance (Raudenbush & Bryk, 2002; Snijders & Bosker, 1999). Because the intraclass correlation for all outcome variables was below 0.06, we concluded that the between-class variability was too small to justify the use of HLM.

Thus, we chose the traditional analysis of covariance (ANCOVA) for data analysis, using the pretest as the covariate and the posttest as the dependent variable. We found that the data in this study satisfied the basic assumptions, such as homogeneity of variances, for ANCOVA. Using ANCOVA has several advantages. First, ANCOVA accounts for possible nonrandom differences between the treatment and comparison groups on the measures of science literacy. Second, ANCOVA can provide an estimate of the effect size (d) for the treatment effect, which is not available in the nonparametric methods (Hollander & Wolfe, 1999). Finally, ANCOVA outperforms Mann-Whitney for most distributions under most circumstances (Vickers, 2005).

An initial analysis using the full ANCOVA model indicated a lack of significant interaction effect ($p > .05$) between the covariate and the between-subjects factor (group) for all dependent variables. Thus, the interaction effect was excluded from the final analysis. For each variable, the cases with missing values were removed prior to the analysis. Removing the cases with missing values is an adequate method to deal with the missing data if the missing values occurred completely at random, which we determined to be the case for our data set.

In the ANCOVA analyses, we used the individual student, rather than the class, as the unit of analysis. The major reason for using the class means instead of the individual student scores as the unit of analysis is that the assumption of independence of observations is violated. If the assumption is not violated, which is the case in the present study based on a calculation of the intraclass correlation coefficients, then the use of the class means as the unit of analysis is not warranted. Even if the assumption were violated, we still would not have used the class means to do the ANCOVA analyses in this study because the sample size (10 classes) was too small, which makes the power of analysis very low (Lederman & Flick, 2005).

Results

The posttest means and standard deviations for all dependent variables are presented in Table 1. To answer the first research question of whether the ISR group outperformed the IS group in the fundamental sense of science literacy, we conducted an ANCOVA analysis, using the GMRT pretest as the covariate and the GMRT posttest as the dependent variable. The results showed that the ISR group significantly outperformed the IS group in the GMRT: for vocabulary, $F(1, 223) = 10.03, p < .01, d = .23$; for comprehension, $F(1, 223) = 6.64, p = .01, d = .22$; and for the total score, $F(1, 223) = 9.98, p < .01, d = .22$.

To answer the second research question of whether the project had an advantageous effect on the students' derived sense of science literacy, we conducted an ANCOVA analysis on the CRST, using the CRST pretest as the covariate and the CRST posttest as the dependent variable. The results showed that the ISR group scored significantly higher than the IS group, $F(1, 210) = 9.61, p < .01, d = .35$. Using the CRST pretest as the covariate, we also conducted an ANCOVA analysis on the students' AYSG and found that the ISR group again significantly outperformed the IS group, $F(1, 210) = 6.78, p = .01, d = .34$.

TABLE 1. Posttest Means and Standard Deviations of Outcome Variables for the Inquiry-Based Science Plus Reading (ISR) and Inquiry-Based Science Only (IS) Groups

	ISR Group		IS Group		Entire Sample	
Criteria	M	*SD*	M	*SD*	M	*SD*
Fundamental sense of science literacy						
Vocabulary	30.60	8.62	26.08	9.75	28.77	9.28
Comprehension	36.00	8.16	31.56	9.72	34.14	9.02
Total score	66.60	15.54	57.64	18.02	62.91	17.00
Derived sense of science literacy						
CRST	13.08	4.54	10.83	4.90	12.16	4.77
AYSG	79.75	11.69	74.88	13.31	77.79	12.57

Note. CRST = curriculum-referenced science test; AYSG = academic year science grade.

To summarize, the results from the present study demonstrated that an inquiry-based science curriculum that infused explicit reading strategy instruction and a home science reading program on a weekly basis was more effective than an inquiry-based science only curriculum in developing the sixth-grade students' science literacy in both the fundamental and the derived senses. We subsequently interpret this finding in light of the relevant research.

Discussion

In the present study, we investigated the potential benefits of integrating reading into the inquiry-based science in the secondary context. We found that the ISR students significantly outperformed their IS peers in the fundamental sense of science literacy. This finding is consistent with similar studies that were conducted in the elementary school context (e.g., Guthrie et al., 1998; Romance & Vitale, 1992). Several factors in the ISR curriculum likely contributed to this positive outcome. We believed that through strategy instruction, the ISR students became more strategic in their reading, enabling them to better cope with the demands of secondary texts. Strategy use is a hallmark of expert reading, and recent reviews of research (e.g., National Reading Panel, 2000) have confirmed that strategy instruction improves students' ability to comprehend texts. Although our strategy lessons were generally less intensive than were those in the studies reviewed by the National Reading Panel, we were able to explain and model each target strategy and provide opportunities for guided and independent practices with the strategy. In addition, the students were reminded throughout the week to apply the strategy within the context of science reading. These instructional features are consistent with the models of effective strategy instruction recommended by experts (e.g., Block & Pressley, 2007). Furthermore, our strategy instruction lasted for two semesters, which is sufficiently long enough for its effect to emerge. According to Brown et al. (2004), for example, the effects of strategy instruction "appeared in the long term; that is, at a minimum, only after a semester to an academic year" (p. 1002).

Simply providing strategy instruction is not sufficient to develop reading competence; students also need to engage in wide reading through which they can apply reading strategies and learn subject content. The present study provided that opportunity by encouraging the students to read and respond to a variety of quality science trade books through the home science reading program. These trade books provided more in-depth treatment of the science topics than did the textbook. They were also written at a wider range of reading levels and in more engaging ways, thus better accommodating the needs of the students with varying reading abilities. Through reading and responding to these books, the students were able to develop greater vocabulary knowledge and content knowledge, which, according to Hirsch (2006), are the two foremost building blocks of reading comprehension.

We also found that the ISR group outperformed the IS group in the derived sense of science literacy. We reasoned that by reading and discussing quality science trade books through the home science reading program, the students expanded and enriched their knowledge of the science content. Science trade books provide rich, interesting information on a great variety of science topics that are often superficially covered in the textbook. The book responses and discussion helped consolidate the students' understanding of text and enhanced their learning of text information. On the other hand, the teaching of reading strategies also enabled students to better comprehend and learn from science texts, therefore effectively increasing their content knowledge about science. Furthermore, explicit instruction of reading strategies likely enhanced the sixth-grade students' awareness of as well as the ability to use the reading processes and skills, such as predicting, inferring, monitoring, making connections, analyzing, drawing conclusions, problem solving, interpreting, and critiquing. These processes and skills are also central to science. Thus, the improvement in the students' general reading ability (i.e., the fundamental sense of science literacy) might have contributed to the improvement in their derived sense of science literacy. As Norris and Phillips (2003) argued, "It is through the resources available in the fundamental sense of [science] literacy that the relevant connections among otherwise isolated pieces of science are made" (p. 235). Finally, it is also possible that the students who became more knowledgeable about the science processes and content developed into more proficient readers, as reading comprehension is highly dependent on background (or domain-specific) knowledge (Hirsch, 2006; O'Reilly & McNamara, 2007). In short, the two senses of science literacy seem inextricably linked, as development in one likely leads to improvement in the other.

The findings of the present study are noteworthy, especially in light of the present push within the science education community to foster the reading–science connection in the secondary school context. With the reconceptualization of science literacy as involving not only knowledge of the scientific processes and content (i.e., the derived sense), but also the ability to read and reason with texts (i.e., the fundamental sense), it is encouraging that even a modest amount of reading infusion made a significant difference in the students' science literacy. Recall that we only included 15–20 min of reading strategy instruction per week for 22 weeks and involved the students in reading and sharing one science trade book per week for about 15 weeks. Such a modest level of infusion may also explain the relatively small effect sizes (*d*) associated with the outcome measures. It is possible that with a heavier dose of reading infusion, the effect size would become larger.

Limitations

The present study was designed to answer Hand et al.'s (2003) recent calls to investigate the robustness and effectiveness of the reading–science integration in helping students learn science. We found that the ISR curriculum was more effective than the IS curriculum in helping the middle school students develop science literacy in the fundamental and the derived senses. This finding should be interpreted with caution in the context of the research study. First, the present study was a quasi-experiment rather than a true experiment. Although classes were randomly assigned to either the experimental or comparison group, there was a lack of randomization at the student level because of its impracticality in the real world. Second, recall that in the present study the reading educators worked collaboratively with the two sixth-grade science teachers to design and deliver the reading infusion within the context of the inquiry-based science. We do not know if similar outcomes could have been guaranteed had we allowed the science teachers to plan and implement the reading infusion entirely on their own from the outset of the project. Nor do we know for sure if the findings from this study are generalizable to other populations (e.g., different grade levels and demographic compositions) or to different pedagogical contexts (e.g., traditional science classrooms).

We also wonder about the exact amount of reading infusion that is most appropriate in an inquiry-based secondary science classroom. For example, would a greater amount of reading infusion, such as 30–45 min of reading strategy instruction per week (or 15–20 min twice a week), have produced comparable or better results? Related to this point, Hirsch (2006) argued that spending an excessive amount of time for conscious strategy practices after initial instruction does not necessarily yield better results in reading comprehension and can be a waste of the precious school time. He noted that many of the reading comprehension strategies (e.g., predicting, inferencing, questioning) that are recommended for instruction are the ones students have already been using proficiently since early childhood in listening comprehension during their everyday social interactions with peers and family members. He contended that the surest way to increase students' reading competence is through building their domain knowledge, to be developed by reading content-rich materials. If this is true, then would an increase in exposure to science trade books (e.g., reading two books per week) and in time spent discussing these books in class (e.g., 15–20 min) produce a larger effect size for both measures of science literacy? On the other hand, scholars (e.g., Halliday & Martin, 1993) have argued that learning science is synonymous with learning the technical, dense, abstract, and complex language of science. Thus, we wonder if a greater emphasis on the strategies for unpacking the language of science (see Fang & Schleppegrell, 2010) would have resulted in enhanced science literacy achievement for students.

Finally, we wonder if different patterns of findings could have emerged had we used assessment measures that are different from those employed in the present study. For example, instead of using the paper-and-pencil tasks, other measures, such as the performance-based tasks and interviews used in Gaskins et al.'s (1994) study, could have been employed to assess students' science literacy.

Implications

These limitations suggest that further research on border crossing between reading and science is still needed. Because most of the reading–science integration studies were conducted in the reading classroom at the elementary level, there is a need for more integration studies in the content area classroom at the secondary level, especially in the present high-stakes testing educational climate in which time for instruction is limited and where teacher autonomy is seriously threatened. Future researchers can, for example, vary the amount (i.e., how much), composition (i.e., teaching comprehension strategies, reading and responding to science trade books, teaching strategies for unpacking the language of science, writing, or different combinations of these three), duration (i.e., how long), and intensity (once, twice, or three times per week) of reading infusion in the context of the inquiry-based science. And although we know that strategy instruction alone is not effective without time actually spent in reading books, it may still be important to tease out the relative contributions of each of these two components of reading infusion to students' science literacy development. Taken together, such further research efforts may help us more satisfactorily answer the question of whether and how reading infusion supports science teaching and learning.

ACKNOWLEDGMENTS

The research reported in this article was supported by a Multi-University Reading, Mathematics and Science Initiative (MURMSI) grant funded by the U.S. Department of Education and coordinated through Florida State University's Learning Systems Institute. The views expressed in the article are not necessarily endorsed by the funding agency. The authors are grateful to Linda Lamme and Rose Pringle for their collaboration on the project and to Troy Sadler for reading and reacting to an earlier version of the article. The authors remain, nonetheless, solely responsible for the content of the article.

REFERENCES

Alvermann, D., & Moore, D. (1991). Secondary school reading. In R. Barr, M. Kamil, P. Mosenthal, & P. D. Pearson (Eds.), *Handbook of reading research* (Vol. 2, pp. 951–983). New York: Longman.

Anderson, R. (2004). Role of the reader's schema in comprehension, learning and memory. In R. Ruddell & N. Unrau (Eds.), *Theoretical models and processes of reading* (5th ed., pp. 594–606). Newark, DE: International Reading Association.

Artley, A. S. (1944). A study of certain relationships existing between general reading comprehension and reading comprehension in a specific subject-matter area. *The Journal of Educational Research*, *37*, 464–473.

Berman, I., & Biancarosa, G. (2005). *Reading to achieve: A governor's guide to adolescent literacy*. Washington, DC: National Governors Association Center for Best Practices.

Biancarosa, G., & Snow, C. (2004). *Reading next—A vision for action and research in middle and high school literacy: A report from Carnegie Corporation of New York*. Washington, DC: Alliance for Excellent Education.

Block, C., & Pressley, M. (2007). Best practices in teaching comprehension. In L. Gambrell, L. Morrow, & M. Pressley (Eds.), *Best practices in literacy instruction* (pp. 220–242). New York: Guilford Press.

Brown, R., Pressley, M., van Meter, P., & Schuder, T. (2004). A quasi-experimental validation of transactional strategies instruction with low-achieving second-grade readers. In R. Ruddell & N. Unrau (Eds.), *Theoretical models and processes of reading* (5th ed., pp. 998–1039). Newark, DE: International Reading Association.

Craig, M., & Yore, L. (1995). Middle school students' metacognitive knowledge about science reading and science text: An interview study. *Reading Psychology*, *16*, 169–213.

Crocker, L., & Algina, J. (1986). *Introduction to classical and modern test theory*. New York: Holt.

DiGisi, L., & Willet, J. (1995). What high school biology teachers say about their textbook use: A descriptive study. *Journal of Research in Science Teaching*, *32*, 123–142.

Draper, R. (2002). Every teacher a literacy teacher? An analysis of the literacy-related messages in secondary methods textbooks. *Journal of Literacy Research*, *34*, 357–384.

Eccles, J. S., Wigfield, A., Midgley, C., Reuman, D., MacIver, D., & Feldlaufer, H. (1993). Negative effects of traditional middle schools on students' motivation. *The Elementary School Journal*, *93*, 553–574.

Fang, Z. (2005). Science literacy: A systemic functional linguistics perspective. *Science Education*, *89*, 335–347.

Fang, Z., & Schleppegrell, M. (2010). Disciplinary literacies across content areas: Supporting secondary reading through functional language analysis. *Journal of Adolescent and Adult Literacy*, *53*, 587–597.

Gaskins, I., Guthrie, J., Satlow, E., Ostertag, J., Six, L., Byrne, J., et al. (1994). Integrating instruction of science, reading, and writing: Goals, teacher development, and assessment. *Journal of Research in Science Teaching*, *31*, 1039–1056.

Glencoe. (2000). *Science voyages: Exploring the life, earth, and physical sciences* (Florida ed.). Columbus, OH: Author.

Grigg, W., Lauko, M., & Brockway, D. (2006). *The nation's report card: Science 2005 assessment of student performance in grades 4, 8 and 12 (*NCES *2006466)*. Washington, DC: National Center for Educational Statistics.

Griffin, C., Simmons, D., & Kameenui, E. (1991). Investigating the effectiveness of graphic organizer instruction on the comprehension and recall of science content by students with learning disabilities. *Reading, Writing, and Learning Disabilities*, *7*, 355–376.

Guskey, T. (1986). Staff development and the process of teacher change. *Educational Researcher*, *15*, 5–12.

Guthrie, J., & Davis, M. (2003). Motivating struggling readers in middle school through an engagement model of classroom practice. *Reading and Writing Quarterly*, *19*, 59–85.

Guthrie, J., Van Meter, P., Hancock, G., McCann, A., Anderson, E., & Alao, S. (1998). Does concept-oriented reading instruction increase strategy use and conceptual learning from text? *Journal of Educational Psychology*, *90*, 261–278.

Halliday, M. A. K. (1998). Things and relations: Regrammaticising experience as technical knowledge. In J. R. Martin & R. Veel (Eds.), *Reading science: Perspectives on discourses of science* (pp. 185–235). London: Routledge.

Halliday, M. A. K., & Martin, J. R. (1993). *Writing science: Literacy and discursive power*. Pittsburgh, PA: University of Pittsburgh Press.

Hand, B., Alvermann, D., Gee, J., Guzzetti, B., Norris, S., Phillips, L., et al. (2003). Guest editorial: Message from the "Island Group": What is literacy in science literacy? *Journal of Research in Science Teaching*, *40*, 607–615.

Harp, B. (2000). *The handbook of literacy assessment and evaluation*. Norwood, MA: Christopher-Gordon.

Harvey, S. (2002). *Non-fiction matters: Reading, writing and research in grades 3–8*. Portland, ME: Stenhouse.

Hirsch, E. D. Jr. (2006). *The knowledge deficit: Closing the shocking education gap for American children*. Boston: Houghton Mifflin.

Hollander, M., & Wolfe, D.A. (1999). *Nonparametric statistical methods*. New York: Wiley.

International Reading Association & National Middle School Association. (2001). *Supporting young adolescents' literacy learning*. Newark, DE: International Reading Association.

Kaplan, R. M., & Saccuzzo, D. P. (2001). *Psychological testing: Principles, applications, and issues* (5th ed.). Stamford, CT: Wadsworth.

Lederman, N. G., & Flick, L. B. (2005). Beware of the unit of analysis: It may be you! *School Science and Mathematics*, *105*, 381–383.

MacGinitie, W. H., MacGinitie, R. K. Maria, K. & Dreyer, L. G. (2002). *Gates-MacGinitie reading tests* (4th ed.). Itasca, IL: Riverside Publishing Company.

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

Martin, J. R., & Veel, R. (1998). *Reading science: Critical and functional perspectives on discourses of science*. New York: Routledge.

Morrow, L., Pressley, M., Smith, J., & Smith, M. (1997). The effect of a literature-based program integrated into literacy and science instruction with children from diverse backgrounds. *Reading Research Quarterly*, *32*, 54–76.

National Reading Panel. (2000). *Teaching children to read: An evidence-based assessment of the scientific research literature on reading and its implications for reading instruction*. Washington, DC: National Institute of Child Health and Human Development.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning*. Washington, DC: National Academy Press.

Norris, S., & Phillips, L. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education*, *87*, 224–240.

O'Brien, D., Stewart, R., & Moje, E. (1995). Why content literacy is difficult to infuse into the secondary school: Complexities of curriculum, pedagogy, and school culture. *Reading Research Quarterly*, *30*, 442–463.

O'Reilly, T., & McNamara, D. (2007). The impact of science knowledge, reading skill, and reading strategy knowledge on more traditional "high stakes" measures of high school students' science achievement. *American Educational Research Journal*, *44*, 161–196.

Pressley, M. (2004). The need for research on secondary literacy instruction. In T. L. Jetton & J. A. Dole (Eds.), *Adolescent literacy research and practice* (pp. 415–432). New York: Guilford.

Raudenbush, S. W., & Bryk, A. (2002). *Hierarchical linear models: Applications and data analysis methods*. Thousand Oaks, CA: Sage.

Romance, N., & Vitale, M. (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 4. *Journal of Research in Science Teaching*, *63*, 201–243.

Saul, E. W. (2004). *Crossing borders in literacy and science instruction: Perspectives on theory into practice*. Newark, DE: International Reading Association.

Singer, H., & Bean, T. (1988). Models for helping teachers to help students learn from text. In S. J. Samuels & P. D. Pearson (Eds.), *Changing school reading programs* (pp. 161–182). Newark, DE: International Reading Association.

Snijders, T., & Bosker, R. (1999). *Multilevel analysis*. London: Sage.

Spiegel, G., & Barufaldi, J. (1994). The effects of a combination of text structure awareness and graphic postorganizers on recall and retention of science knowledge. *Journal of Research in Science Teaching*, *31*, 913–932.

Tobias, S. (1994). Interest, prior knowledge and learning. *Review of Educational Research*, *64*, 37–54.

Vickers, A. J. (2005). Parametric versus non-parametric statistics in the analysis of randomized trials with non-normally distributed data. *BMC Medical Research Methodology*, *5*(35). Retrieved April 15, 2007, from http://www.biomedcentral.com/1471-2288/5/35

Wade, S., & Moje, E. (2000) The role of text in classroom learning. In M. Kamil, P. Mosenthal, P. D. Pearson, & R. Barr (Eds.), *Handbook of reading research* (Vol. 3, pp. 609–627). Mahwah, NJ: Erlbaum.

Wellington, J., & Osborne, J. (2001). *Language and literacy in science education*. Philadelphia: Open University Press.

Yore, L. (1991). Secondary science teachers' attitudes toward and beliefs about science reading and science textbooks. *Journal of Research in Science Teaching*, *28*, 55–72.

Yore, L. (2004). Why do future scientists need to study the language arts? In E. W. Saul (Ed.), *Crossing borders in literacy and science instruction: Perspectives on theory into practice* (pp. 71–94). Newark: DE: International Reading Association.

Yore, L., Hand, B., Goldman, S., Hildebrand, G., Osborne, J., Treagust, D., et al. (2004). New directions in language and science education research. *Reading Research Quarterly*, *39*, 347–352.

AUTHORS NOTE

Zhihui Fang is a Professor of Literacy and Language Education at the University of Florida. His recent research focuses on the use of evidence-based language and literacy practices to support science teaching and learning. He is particularly interested in exploring the connection between language use and disciplinary literacy practices.

Youhua Wei is an associate psychometrician at Educational Testing Service with expertise in statistical analysis and educational measurement.