Promoting Science Literacy with English Language Learners Through Instructional Materials Development: A Case Study

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Abstract

In spite of reform efforts, opportunities for all students to learn science remain illusive. Recent studies indicate that science curricula do not meet students' learning needs. Research-based curricula focusing on science inquiry with English language learners (ELLs) have yet to be developed. To encourage development of appropriate science materials, this paper discusses the learning needs of specific groups of ELLs and their teachers. First, we describe our research with groups of fourth-grade ELLs and their teachers, including perspectives of inquiry with teachers who shared their students' languages and cultures and features of materials developed to integrate science and literacy instruction. Next, we present student achievement results using the materials. Finally, we discuss the importance of materials enabling all students to learn science through inquiry.

Introduction

Reform emphasizing high academic standards and equity for all students has been under way for more than a decade (American Association for the Advancement of Science [AAAS], 1989, 1993). "Science for all" is a key principle guiding standards development to ensure all students access to science (National Research Council [NRC], 1996). Students' engagement in science inquiry is central in learning science (NRC, 2000). According to the *National Science Education Standards* (NRC, 1996), "scientific inquiry is at the heart of science and science learning" (p. 15) and "inquiry into authentic questions generated from student experiences is the central strategy for teaching science" (p. 31). Inquiry is a:

> Multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known, planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. (NRC, 1996, p. 23)

In making science accessible for all students, the National Science Foundation, or NSF (1998), emphasizes "culturally and gender relevant curriculum materials" that recognize "cultural perspectives and contributions so that, through example and instruction, the contributions of all groups to science will be understood and valued" (p. 29). In spite of efforts to increase students' opportunities to learn science, the promise of "science for all" remains illusive. The gap in science achievement between mainstream and non-English language background (NELB) students continues, particularly for those learning English as a new language (English Language Learners, or ELLs) (National Center for Educational Statistics [NCES], 1997a; Rodríguez, 1997). Research-based curricula focusing on science inquiry with diverse learners have yet to be developed (Lynch, 2000).

Even though the *Standards* indicate the need for literacy in "writing, labeling drawings, completing concept maps, developing spreadsheets, and designing computer graphics" (p. 144), they do not explicitly address the relationship of literacy and science learning (Yore, Holliday, & Alverman, 1994). The growing national focus on literacy (Reading Excellence Act, 1998) makes integrating literacy and science an innovation addressing widely established priorities. For ELLs, such a relationship is central to learning science. In addition to lacking a focus on literacy development, most science materials do not seriously consider issues of equity or the instructional needs of ELLs (Lee, 1999; Lynch, 2000). Students identified as "English proficient" may still be acquiring the discourse and interaction patterns of their mainstream English-proficient peers. For this reason, we use a broad definition of ELLs that includes students from non-English language backgrounds whose communication differs from the mainstream (Waggoner, 1993).

In addressing learner needs, little is known about the impact of teachers' perspectives of inquiry on students' engagement in science (Fradd & Lee, 1999; Gee, 1997). A majority of teachers working with ELLs believe they are not adequately prepared to meet their students' learning needs, particularly in academically demanding subjects, such as science and literacy (NCES, 1999b). Although recent studies indicate that teachers' culturally-based perspectives of science influence their instructional approaches (McGinnis, Kramer, Watanabe, 1998; McGinnis & Simmons, 1998), little research exists on the instructional approaches of teachers from non-English language backgrounds. Teachers can bring important insights for promoting academic learning (Au & Kawakimi, 1994; Cochran-Smith & Lytle, 1999; Trueba & Wright, 1992), even when their perspectives differ from those of the mainstream (Delgado-Gaitan, 1993). Such differences suggest areas for expanding the current knowledge base to include ELLs in learning science.

Although little research exists on science curriculum at the elementary level, a recent evaluation of middle school science curricula found most materials covered too many subjects, included irrelevant classroom activities, and failed to develop important concepts (Bradley, 1999). In contrast, effective materials provided students with a sense of purpose about science, engaged them with relevant scientific phenomena, promoted the use of scientific ideas and terms, and encouraged students to examine their own understandings of science. In addition, effective instruction progressed in a sequential manner, using lessons as building blocks to integrate and expand on developing concepts. This evaluation found only one instructional unit that contained these features (Bradley, 1999).

In encouraging the development of instructional materials for ELLs, this paper highlights teachers' perspectives of science inquiry as we discuss materials development in three research projects. First, we describe the research with groups of ELLs and their teachers, including perspectives of inquiry with teachers who shared their students' languages and cultures and features of materials developed to integrate science and literacy instruction. Next, we present student achievement results using the materials. Finally, we discuss the importance of materials in promoting science through inquiry.

Evolution of Science Materials for ELLs

Breaking the cycle of low academic performance so that all students can participate in science requires consideration of the students, their teachers, and the resources and support both require to successfully engage in science. In this section we discuss the evolution of materials in three research projects funded by the National Science Foundation from 1992 through 2000: (a) a Small Grant for Exploratory Research (SGER); (b) the 'Promise' Project; and (c) the 'Science for All' Project. Although materials development was not a focus, the projects' implementation necessitated that materials be developed.

The SGER Project

The SGER research examined the interrelationship of language, science, and cognitive strategies, as students engaged in science activities in controlled settings outside the classroom. Dyads of fourth-grade students composed of the following three ethnolinguistic groups: bilingual Hispanic and Haitian, and mainstream U.S. English. Bilingual teachers were matched with student dyads of the same language and gender (e.g., a Hispanic female teacher with two Hispanic girls). We observed similarities and differences in students' language development, science knowledge, and cognitive strategy use (Fradd & Lee, 1995; Lee & Fradd, 1996a, 1996b; Lee, Fradd, & Sutman, 1995). Analysis of interactions revealed patterns unique to each group and highlighted the importance of cultural congruence (Au & Kawakimi, 1994; Trueba & Wright, 1992), where ethnolinguistically congruent communication between teachers and students facilitated engagement (Lee & Fradd, 1996a, 1996b). Materials development included hands-on activities, elicitation protocols for determining students' perceptions and knowledge of science, and scoring rubrics for oral and written language samples.

The Promise Project

Based on SGER findings, the Promise Project promoted science learning with fourth-grade students and teachers from the same three ethnolinguistic groups. We developed two instructional units, "The Water Cycle" and "Weather," and assessment instruments for the units (Lee & Fradd, 1999a, 1999b). The units consisted of 10 and 15 lessons, respectively, requiring approximately 2–3 hours of hands-on activities and discussion per lesson. To support student learning, we also developed Hyperstudio computer simulations paralleling hands-on activities (Bush, Fradd, & Lee, 1997a, 1997b).

Throughout the three-year research period we worked in four inner-city schools with "focus" teachers who shared their students' languages and cultures. We incorporated insights from these teachers to promote culturally congruent instruction. During the third year (Y3), we included all fourth-grade teachers in the four schools. Our awareness of the strengths and limitations of cultural congruence led us to conceptualize instructional congruence as a process for integrating the nature of science with students' language and cultural experiences (Lee & Fradd, 2001; Lee & Fradd, 1998; Fradd & Lee, 2001). In addition to examining changes in teachers' practices, we considered their insights of science inquiry in developing an explicit-to-exploratory inquiry continuum (Fradd & Lee, 1999). Initially, teachers insisted on explicit instruction to promote student engagement. Because we were building on the strengths of teachers and students with shared languages and cultures, we did not direct the teachers in how to teach. We did encourage them to consider activities that gradually transitioned toward exploration as students gained experience in inquiry.

Concerns teachers expressed in implementing science inquiry highlight discrepancies between their views and expectations for standards-based instruction (AAAS, 1989, 1993; NRC, 1996). Analysis of teacher interviews from two Hispanic-dominant schools are presented here in three themes: (a) teachers as nurturers and caregivers; (b) teachers as representatives and advocates of their students; and (c) teachers as learners with their students. The first two themes reflect established perspectives, whereas the third reveals on-going change as teachers gained knowledge and skill in promoting science inquiry with their students.

Teachers as nurturers and caregivers

Initially, the teachers viewed inquiry as an "all or none" pedagogy where, according to several teachers, "students muck around until they figure science out on their own." Although their opposition derived from a misunderstanding of inquiry (NRC, 2000), this discrepancy influenced the teachers' approach to science instruction. The teachers maintained structured classrooms and were aware of difficulties that could arise if students were given tasks about which they had limited understanding, and over which teachers exercised limited control. Because the teachers wanted their students to achieve, they sought approaches that ensured success as defined by district and state tests (Fradd & Lee, 2001).

The teachers' positive affect created warm, friendly classroom environments where students were comfortable trying new activities. These environments were places where engaging in inquiry gradually became a natural way of interacting for all students (Pearce, 1998). An example of classroom organization illustrates how teachers promoted student participation. At the beginning of class, the teachers made certain everyone had instructional materials and supplies as they ensured no one was left out. To foster collaboration and comprehension, teachers often encouraged more proficient students to work with those beginning to learn English. As students interacted in small groups, teachers orchestrated the classes to support full student participation, frequently scanning the room to assist students experiencing difficulty. At the beginning and conclusion of each lesson, teachers engaged students in reviewing content, linking concepts, and summarizing big ideas. In these and many other ways, the teachers acted as nurturers and caregivers concerned with their students' well-being and academic achievement.

Although nurturing was an important aspect of the instructional process, for students with little literacy development, the teachers' approach sometimes limited learning opportunities. In spite of the specially developed instructional units to reduce language demands, rather than viewing written texts as opportunities to promote literacy, teachers frequently read materials out loud and then explained them to the students. When asked about their roles in teaching science, one teacher summarized her concern for students' affective needs: "These children are young—babies. We have to take care of them, make sure they feel good about themselves before we ask them to do things that frustrate them." Another commented: "Our students have many frustrations just learning English. You can't expect them to jump into inquiry on their own until they're ready."

As instruction progressed, the teachers became enthusiastic about their students' engagement with the hands-on activities. The teachers also valued the integrated manner in which each lesson incorporated knowledge from previous lessons. One teacher summarized her view of science instruction as a positive, nurturing experience: "I never used to like science, or want to teach it. When I see the students enjoying science, I actually look forward to teaching it. I realize what we are doing is good for them. They love science. That makes me feel great."

Teachers as advocates and representatives of students' cultures

Although they were unfamiliar with the concept of cultural congruence (Au & Kawakimi, 1994; Trueba & Wright, 1992), the Promise teachers and students demonstrated the congruent discourse and interaction patterns observed in the SGER study. The teachers usually understood their students, interpreted what the students meant, and knew how to support on-going communication.[1] Frequently the teachers and students interacted in long, meaningful conversations (Tharp & Gallimore, 1988). Often, they used humor to emphasize points and remind students of important ideas (Westby, Dezale, Fradd, & Lee, 1999). Sometimes, rather than encouraging students to provide their own ideas, the teachers told them what to do. Instead of eliciting students' explanations, the teachers answered their own questions. When probed about their actions, teachers emphasized the need to build students' knowledge of science.

Initially, the teachers presented a view of "letting children be children," rather than encouraging them to act like adults or "little scientists." Because they associated science with an adult world where people acted as individual agents and children were not adults, the teachers did not view inquiry as a child-oriented pedagogy. For these teachers, collaboration through sharing and working as a group was more important than independent performance. As one teacher explained:

Remember, many of us come from backgrounds where science was not taught. In our children's homes inquiry may not be an acceptable way of learning because families don't want children asking questions, debating, or challenging authority. Children are expected to learn by watching.

As teachers reflected on the inquiry process, they grappled with discrepancies between their understanding of the *Standards* and their instructional approaches. They noted, for example, students' reluctance to ask questions as a culturally-oriented deference to authority. In reconciling these discrepancies, a teacher reasoned:

Our students see us as their parents. They want us to tell them what to do. If we don't, they think we don't like them. If I tell them to go find out by themselves, they become frustrated. They need to be shown. That's my responsibility. But if I tell them what to do, then they are not really doing inquiry, are they?

One of the most powerful examples of teachers' commitment to full student participation occurred through construction of discourse to which students contributed. Frequently, teachers would conclude a lesson summary by initially asking questions that could be answered with single words and short phrases. Next, they would elicit more elaborated sentences linking student responses. These elaborations evoked brief paragraphs from some of the students. The paragraphs evolved into summaries by multiple students. For beginning ELLs, such activities provided opportunities to contribute to valued interactions. These communication events afforded students at all proficiency levels models of academic discourse in which everyone listened, comprehended, and learned. For more advanced ELLs these were occasions to extend and integrate science knowledge. Through these and many other ways, the teachers revealed themselves as advocates and representatives of their students' languages and cultures.

Teachers as learners with their students

The teachers engaged in inquiry as learners and explorers with their students. Over time, the teachers became aware of changes in their own thinking. Some talked about the importance of preparing students to be on par with age peers and embraced inquiry as a means to enhance learning opportunities. One teacher noted:

I have never worked with any other group of students. These are the only students I know. Until I started working with you, I had not been aware that I was acting in a particular way. I only did what I thought was right for my students. It's important that they fit into the larger society, to be successful academically and socially. I will do whatever I can to ensure their success.

The teachers' willingness to grow became apparent in their interactions with the research and in the journals some kept to reflect on their instruction. The following quotation from a teacher's journal illustrates important insights:

> In the lesson on humidity, I wanted to really promote inquiry while making certain that the students understood the lesson. We went over what humidity is, that it's water vapor in the air. We discussed the humidity measurements in the newspaper. Then, we went outside to measure humidity at different places. Students observed that it was more humid under the trees in the shade than in the sun. For some students, this was very confusing. Their train of thought went something like this, "Since humidity is water vapor in the air and water vapor is caused by evaporation, which is caused by heat, then there should be more humidity where it is hotter, like where direct sun hits, not where there is little direct sun, as in the shade." I asked the students how we could get more information about this discrepancy. We decided to measure the humidity every day for five days at the same locations to see if there was really a pattern of humidity difference. There was! Now we have to figure out why.

Teachers also sought ways to integrate science with literacy in constructing new knowledge. Here, a teacher linked inquiry with students' insights gained on a field trip and through the literature they were reading. In addition to illustrating the teacher's commitment to meaning-making, the example highlights an effort to integrate literacy and inquiry:

> In language arts, we are reading *The Missing Gator of Gumbo Limbo*.[2] After reading a chapter, we got in a discussion about the canopy in the hammocks (which they know about from a field trip we went on to the Everglades). They were able to relate the canopy effect [of the trees] to the pattern we saw of more humidity in the shade. I think this is as close as I've gotten to inquiry. It is very time consuming. As a teacher, I was not in control. The questions kept coming at me and sometimes I wasn't sure of the answers. I had to build a different way of interacting with the students. I wanted them to see that I was learning with them. I didn't know the answers either. This is a hard thing for teachers to do. It's easier to control the questions if we know the answers. I realized the students were much more involved in science this way. This interaction increased their natural curiosity. Mine too!

The teachers recognized the importance of building their own knowledge of science and inquiry. Here, a teacher reflects on the importance of a knowledge base for guiding student learning while maintaining the delicate balance between student initiative and teacher direction:

> For the past week students were using all the weather instruments we have introduced. Their goal for the week was to predict the weather for next week. During the week I observed the students talking more scientifically. I was very impressed with their ability to use the appropriate terminology. I tried to avoid any direct instruction and let them come to me with their questions. I noticed the students' excitement in doing weather reports. I observed the different kinds of charts they made to collect the weather information and report it. I really could see why people are so hyped about inquiry. The students' excitement of having ownership was reason to allow them more control. They were really into it.
>
> However, when they got to actually making their own weather reports, I found the students' performance disappointing. They showed little ability to make predictions. They could report what happened, but they couldn't relate it to what might happen next. I think I was wrong in emphasizing prediction as strongly as I did with the weather measurement. I also think I should have done more direct teaching. I believe that students at this stage in their learning need a lot more help. They may like to do inquiry, but I keep coming back to the same question: Are they really learning anything, or are they just fooling around? I could have really helped them understand, know how to

> organize their work, and relate what they were doing to the tasks they were expected to do. I think these students just haven't had enough experiences with science, with collecting information and making predictions, to be able to do inquiry the way the standards indicate they should. Looking back, I think I should have been more directly involved in leading them through the activities, rather than letting them take the lead in doing it on their own.

Encouraging teachers to provide culturally and linguistically appropriate instruction offered extended opportunities for observing how materials might be enhanced to support student engagement. Through these observations we also recognized the important role instructional materials played in science achievement. As we contemplated discrepancies between the Promise materials and teachers' instructional approaches with the *Standards*, we recognized the need for additional modifications. We sought to address tensions between culturally congruent instruction and instruction aligned with the *Standards*. Some areas, such as students' knowledge of science, could be enhanced by integrating science and literacy instruction, whereas others, such as fostering worldviews congruent with open inquiry, would require extended engagement with science. These insights led to the development of "Science for All," the third research project.

The Science for All Project

Science for All (SFA) promoted science inquiry with all fourth-grade students in seven inner-city and suburban elementary schools, 30 teachers, and approximately 900 students a year for three years. The SFA teachers included many from the Promise Project who continued promoting science inquiry with their students. All materials were reviewed and revised by the teachers in collaboration with scientists, science educators, and consultants representing the students' languages and cultures (Lee & Fradd, 1999a, 1999b). We developed Macromedia computer simulations of selected hands-on activities (Oliver, Fradd, & Lee, 1999a, 1999b).

According to the *Standards* (NRC, 1996), "Students will engage in selected aspects of inquiry as they learn the scientific way of knowing the natural world, but they also should develop the capacity to conduct complete inquiries" (p. 23). The document also states, "Although the *Standards* emphasize inquiry, this should not be interpreted as recommending a single approach to science teaching. Teachers should use different strategies to develop the knowledge, understandings, and abilities described in the content standards" (NRC, 1996, p. 23). In SFA, we promoted inquiry through a continuum of experiences beginning with scaffolded explicit instruction and moving to student-initiated inquiry. Revisions of the previously developed units offered greater support for literacy instruction, including the use of English to Speakers of Other Languages (ESOL) strategies to promote comprehension and participation. Since this research involved teachers who shared students' languages and cultures, and teachers who did not, the focus was on enabling *all teachers* to meet students' learning needs. Specific features of the units are discussed next.

The inquiry continuum

If learning to engage in inquiry is seen as occurring along a continuum, without intervention, students accustomed to being told and shown may remain at the explicit end of the continuum. A combination of teacher and materials support can facilitate students' progression along the continuum toward more open-ended inquiry.

<u>An initial continuum matrix</u>: Although our initial conceptualization of the 'Science Inquiry Matrix' (Figure 1a) (Sutman et al., 1997) was more theoretical than practical, it provided a starting point for discussing and observing the inquiry process. Our first matrix focused on inquiry in six areas: questioning, planning, implementing, concluding, reporting, and applying (horizontal) in eight stages, 0 to 7 (vertical). This initial matrix served the important purpose of enabling teachers to recognize how inquiry could occur in stages and encouraged them to consider inquiry as a process requiring levels of guidance, rather than an "all or none" pedagogy (NRC, 2000). Through this realization, teachers began to evaluate their own efforts in engaging students in inquiry.

Figure 1a. Initial science inquiry matrix indicating levels of student engagement

Inquiry Levels	Questioning	Planning	Implementing	Concluding		Reporting	Applying
			Carry out plan Record	Analyze data	Draw conclusion		
0	Teacher	Teacher	Teacher	Teacher	Teacher	Teacher	Teacher
1	Teacher	Teacher	Teacher	Teacher	Teacher	Teacher	Students
2	Teacher	Teacher	Teacher	Teacher	Teacher	Students	Students
3	Teacher	Teacher	Teacher	Teacher	Students	Students	Students
4	Teacher	Teacher	Teacher	Students	Students	Students	Students
5	Teacher	Teacher	Students	Students	Students	Students	Students
6	Teacher	Students	Students	Students	Students	Students	Students
7	Students	Students	Students	Students	Students	Students	Students

The revised matrix: Classroom observations revealed that some areas of inquiry, such as implementing activities and reporting results, more easily involved students. Others, such as questioning and applying findings, required more experience. For students socialized not to ask questions, posing questions for inquiry presented a challenge (McKinley, Waiti, & Bell, 1992; Ogunniyi, 1988; Prophet & Rowell, 1993). As the teachers began to promote more open inquiry, we encouraged them to create a continuum reflecting the reality of their practice. The revised version (Figure 1b) illustrates how multiple components of inquiry, such as implementing, recording, and reporting, could be integrated simultaneously. Other components, such as planning and drawing conclusions, might be more appropriately carried out through a combination of teacher-guided instruction and student initiative. Learning to do inquiry became a balance of teacher guidance and student initiative with teachers making the decisions about when and how to foster student responsibility.

Figure 1b. Modified science inquiry matrix showing transition toward open inquiry

Inquiry Levels	Questioning	Planning	Implementing	Concluding		Reporting	Applying
			Carry out plan Record	Analyze data	Draw conclusion		
0	Teacher	Teacher	Teacher	Teacher	Teacher	Teacher	Teacher
1	Teacher	Teacher	Students/ Teacher	Teacher	Teacher	Students	Teacher
2	Teacher	Teacher	Students	Students/ Teacher	Students/ Teacher	Students	Teacher
3	Teacher	Students/ Teacher	Students	Students	Students	Students	Students
4	Students/ Teacher	Students	Students	Students	Students	Students	Students
5	Students	Students	Students	Students	Students	Students	Students

Scaffolding to promote inquiry

The *Standards* are clear that supporting students' progress in learning to engage in inquiry is important but "should not be interpreted as advocating a 'scientific method'" (NRC, 1996, p. 144). Although some advocates of more open inquiry would argue against a framework for organizing and planning inquiry, we found it an important initial step for teachers and students. Like the continuum described above, the Science Inquiry Planning Framework evolved in stages and underwent several modifications.

The initial planning framework: The purpose of the planning framework was to make the inquiry process comprehensible, as scaffolding to be reduced, as the students internalized the process and accepted responsibility for their own learning. Classroom observations of teachers and students using the initial framework (Table 1a) revealed the literacy requirements for initial version were too complex for ELLs.

Table 1a

Science Inquiry Planning Framework

1. Pose a question
   (a) What do you want to know?
2. Make a plan to answer the question
   (a) Decide what you want to do to find out the answer to the question.
   (b) Decide what materials you need.
   (c) Decide how to record the information.
   (d) Decide how to analyze the information.
   (e) Decide how to report the findings.
3. Carry out the plan
   (a) Make sure you have the materials.
   (b) Make sure you know and follow the procedures of your plan.
4. Record and analyze the information
   (a) Make sure that your recordings are accurate.
   (b) Decide what the information means.
5. Report and share the findings
   (a) Consider multiple representations to report your information, such as graphs, tables, drawings, diagrams, oral presentation, and written work.
   (b) Answer your question.
   (c) Draw conclusions about your inquiry activity.
   (d) Compare your findings with others.
6. Further considerations
   (a) After completing the inquiry activity, learn about the science content related to the activity.
7. Extension activity
   (a) After answering the question in each activity, propose other questions that you want to know more about.
   (b) Make a plan and carry out the plan to find an answer to your question.

The modified planning framework: Students' drawings and use of iconic representations provided insights for modifying the planning framework. In the revised version (Table 1b), icons serve as points of reference, assisting students in thinking about and organizing their own inquiry. The icons also encourage the use of graphic representations in communicating science.

Table 1b

Science Inquiry Planning Framework.

Language Function Icons		Science Inquiry Planning Framework
1.	Questioning	(a) Pose a question What do you want to know? (b) Make a hypothesis What do you think the answer to your question is? Can you explain your thinking?
2.	Planning	(a) Make a plan by answering these questions (think, talk, write) What steps or procedures will you take to collect the information? What materials will you need? How will you record the information? How will you analyze the information? How will you report the findings?
3.	Implementing	(a) Follow your plan Gather the materials. Carry out your plan. Observe the results. Record the information accurately.
4.	Concluding	(a) Classify, interpret, and analyze the data Decide what the information means. (b) Draw a conclusion Is what happened what you expected? Was your hypothesis correct?
5.	Reporting	(a) Share your results (informal) What do you want to tell others about the activity? (b) Produce a report (formal) Record what you did so others can learn. Consider different ways to express your information.

Literacy and language development through science

In addition to enabling students to represent their ideas in multiple ways, literacy promotes strategic competence in using language to inquire, problem-solve, and extend communication beyond the immediate environment (Calfee, 1994; Westby et al., 1999). Becoming literate necessitates a discourse shift from communicating at a personal, concrete level to using a variety of representational forms to express both concrete and abstract understandings (Scallon & Scallon, 1981). Although literacy is central to science learning, the power of this relationship does not appear in most science instruction (Yore et al., 1994). Unless instruction includes an explicit focus on literacy development, ELLs are often excluded (Westby et al., 1999). In this section we discuss innovations to materials required to foster literacy for science inquiry.

Language functions: With regard to literacy development, language functions refer to the ways that language is used to achieve a variety of outcomes (Tough, 1986). Similarly, in science instruction language functions can be equated with science process skills (Casteel & Isom, 1994). The headings on the "Science Inquiry Planning Framework" exemplify some of these functions used in inquiry (Table 2b). Because language is used differently in diverse cultures, some ELLs may not have developed the skills or cultural knowledge to use the variety of language functions required to communicate in science inquiry. In the SFA materials, each lesson emphasized a specific language function, such as describing, reporting, or explaining, and provided corresponding developmental activities to promote practice in meaningful contexts.

Vocabulary development: As students' knowledge of science increased, their vocabulary became more precise and specific. In discussing the lesson features that contributed to effective instruction, teachers were clear about the importance of identifying the vocabulary to be used. Teachers found that students required explicit instruction in combination with contextualized vocabulary use to integrate new terminology into their communication (García, 1994; Gersten & Baker, 2000). The SFA vocabulary did not occur as long lists of scientific terms, but as key words to facilitate comprehension. In addition to vocabulary in English, the teachers requested comparable terms in Haitian Creole and Spanish.

Multiple representational formats: A focus on the use of multiple representational formats became an important feature. Providing ELLs with opportunities to communicate science through drawings, charts, tables, graphs, and computer-developed simulations reduced the language load required to participate. The use of icons, graphics, and drawings promoted a focus on communication for understanding, rather than to convey correct answers (DiSessa, Hammer, Sherin, & Kolpakowski, 1991).

Expository and narrative texts: Comprehension and production of narrative and expository texts is an important facet of literacy development in the intermediate grades (Ruddell & Ruddell, 1994; Westby, 1985). The availability of narrative and expository texts afforded opportunities to compare and contrast the features of both genre as students recontextualized their science experiences. Students' stories of their science activities at home and their shared experiences at school provided insights for linking science with real world events. Teachers found that the stories made science meaningful and relevant, and they used expository passages for summarizing, reviewing, and expanding science content.

In summary, despite contextualized learning through hands-on activities, the benefits of science inquiry for ELLs may be limited without a concomitant focus on literacy development. In SFA we integrated science inquiry with literacy development to include: (a) an explicit-to-exploratory continuum for promoting science inquiry, (b) scaffolding to make the inquiry process explicit and accessible, and (c) specific components integrating literacy with science learning. Science provides an important venue for content-based literacy development. Integrating the two areas reduces the competition for instructional time while extending opportunities to promote meaningful engagement and purposeful, authentic communication (NCES, 1997b; NRC, 2000).

Findings: Student Performance Using the Science Materials

Evaluation of the effectiveness of instructional materials can occur through classroom practices and through student outcomes. Students and teachers must be comfortable using the materials, understand their purposes, know how to engage in the activities, and acquire the knowledge and understandings which the materials were designed to develop (AAAS, 1997). Students should also demonstrate higher achievement as a result of using the materials (AAAS, 1993). This section provides a summary overview of student achievement in the Promise Project and Science for All Project.

The Promise Project

The Promise Project focused on promoting students' communication of science knowledge. Assessment included pre/post unit science tests and pre/post elicitations of randomly selected dyads. Paper-and-pencil tests were the major source of group achievement information.

During Year Two (Y2), only the focus teachers used the units, while the non-focus teachers used district-mandated curricula including the same content and objectives. As might be expected, in Y2 there was an achievement difference of 20 points between the students in the focus (M = 47.6) and non-focus (M = 27.7) classrooms. During Y3, when all of the teachers used the Promise Project units, achievement scores in focus (M = 60.0) and non-focus classrooms (M = 57.2) were comparable and exceeded Y2 focus classrooms (M = 47.6) ($p < .001$) (Fradd & Lee, 2001; Fradd, Lee, Cabrera, del Rio, Leth, Morin, Ceballos, Santalla, Cross, & Mathieu, 1997). Science achievement by teacher group (focus and non-focus) during Y2 and Y3 is summarized in Table 2.

Table 2

Hispanic Student Achievement on Two Unit Tests in Classes of Focus and Non-Focus Hispanic Teachers, Years 2 and 3*

Year	Groups	n	Pre		Post		t	p
			M	SD	M	SD		
Y2	Focus	140	20.16	8.89	47.65	12.38	27.33	.000***
	Non-Focus	96	24.48	11.13	27.71	10.06	3.55	.001**
Y3	Focus	120	24.04	10.59	60.00	15.50	28.83	.000***
	Non-Focus	174	24.90	12.20	57.28	14.73	31.09	.000***

*High teacher attrition prevented longitudinal data collection with the three groups. Hispanic is the only group for which three-year data are available.
**$p < .01$
***$p < .001$ Maximum score: Matter, 69; Weather, 63; Combined, 132

The Science for All Project

Classroom observations revealed that when teachers became familiar with the materials, gained knowledge of science content, and recognized the value of the inquiry process, they were better able to promote student engagement in science inquiry. For all three ethnolinguistic groups, achievement data included student performance on pre/post unit science tests, pre/post elicitations of randomly selected dyads, and standardized state tests in reading and writing. Assessment of "concepts" was separated from "inquiry" to more accurately observe changes in student performance.

Although Y3 data are still being analyzed, Y2 student performance reveals significant achievement gains ($p < .001$) in both science concepts and inquiry for all three ethnolinguistic groups. Total scores as well as subset scores for concepts and inquiry indicate comparable growth in both areas. Classroom observations of students' engagement in science inquiry support these findings. Student achievement by ethnolinguistic group is summarized in Table 3.

Table 3

Achievement by Three Student Language Groups on Two Unit Tests, Year 2

Science Areas	Student Groups	Students (classes)	Pre		Post		t	p
			M	SD	M	SD		
Concepts	Hispanic	226 (12)	16.17	8.87	38.18	12.20	31.54	.000***
	Haitian	175 (13)	10.88	7.69	26.70	10.97	22.35	.000***
	English	101 (06)	18.95	8.32	39.11	11.51	22.85	.000***
	All	502* (31)	14.90	8.91	34.41	12.91	42.95	.000***
Inquiry	Hispanic	226 (12)	6.00	5.96	15.18	7.07	20.42	.000***
	Haitian	175 (13)	5.10	5.22	8.54	6.98	7.88	.000***
	English	101 (06)	8.85	7.15	18.20	6.12	15.76	.000***
	All	502* (31)	6.25	6.12	13.49	7.81	23.63	.000***
Total	Hispanic	226 (12)	22.16	13.47	53.36	17.50	31.73	.000***
	Haitian	175 (13)	15.93	11.62	35.33	16.38	21.21	.000***
	English	101 (06)	27.84	14.15	57.31	15.72	25.45	.000***
	All	502* (31)	21.15	13.69	47.93	19.13	41.77	.000***

***$p < .001$ Maximum scores: Concepts, 86; Inquiry, 32; Total, 118

* This number includes students completing the pre- and post-tests for both units and reflects mobility and attrition in the inner-city schools.

Note: Data have also been analyzed through repeated measures ANOVA and the significance in magnitude of gain effects has been substantiated.

Discussion

This paper has described research to include students who have traditionally not achieved well in science (NCES, 1997a, 1999b). Although students learning English as a new language represent a rapidly growing portion of the school-age population (NCES, 1997a, 1999b), few materials address their science learning needs (Lynch, 2000). Research suggests that many teachers require extended assistance with literacy and content area instruction to meet ELLs' learning needs (NCES, 1999a). In spite of inquiry's central role in the *Standards*, little research has been conducted to determine the curricular needs of ELLs with limited science experience. Building on the insights of teachers who shared the languages and cultures of their students, we gained insights for promoting science inquiry with specific groups of ELLs.

The achievement gains through the use of the materials developed in the research projects indicate the important role materials play in making science accessible to all students. In the Promise Project, a focus on science content produced important achievement gains (Table 1). Extending the focus to include science knowledge and inquiry in the Science for All Project enabled us to examine achievement in both areas (Table 2). Student anecdotal data, classroom observations, and teacher and student interviews also contributed to our understanding of ELLs' needs in engaging in science inquiry.

Inquiry is a fluid process that grows in complexity as students and teachers gain science knowledge and inquiry skills. Cultural and linguistic differences can make inquiry challenging in ways that may not be apparent to the mainstream science community (Rodríguez, 1997). Of particular importance is a view of inquiry that acknowledges teachers' and students' evolving skills and abilities in engaging in science inquiry (NRC, 2000). For ELLs with limited experience with science or inquiry, current conceptions of inquiry may also require reconsideration.

In spite of the achievement gains of the students in our research, many questions persist about how to effectively support inquiry with ELLs. Although we observed a movement from teacher-directed toward teacher-facilitated approaches to inquiry as students gained in the knowledge and understandings of science, the transition points and the instructional materials required to move to open inquiry remain to be identified. Teacher insight in identifying these transitions is essential in creating the knowledge base and instructional materials to make inquiry accessible. Enabling teachers to promote open inquiry requires knowledge of science, an understanding of the inquiry process, and an ability to determine students' strengths and learning needs. Incorporation of these components in teacher preparation is essential for enabling ELLs to learn science through inquiry.

Of equal importance in developing instructional materials is the science community's perspective of the instructional innovations required to address students' needs. Collaboration among teachers, researchers, scientists, and publishers is essential in ensuring that the materials meet the needs of students and teachers as well as the expectations of the science community. In creating "culturally and gender relevant curriculum materials" (NSF, 1998, p. 29), consensus is needed about the contents of such materials as well as the ways they might successfully be used.

Developing consensus involves exploration of the commonalties and differences in perceptions of the stakeholders responsible for ensuring inquiry as “the heart of science and science learning” (NRC, 1996, p. 15). In this endeavor, teachers who share the languages and cultures of their students can provide important insights (Cochran-Smith & Lytle, 1999; Delgado-Gaitan, 1993). Toward that outcome, we suggest a research agenda that: (a) considers teachers’ perspectives in promoting science inquiry with students learning English; (b) develops science curricula integrating literacy development with science learning; and (c) seeks innovation to reduce the barriers to the inquiry process. Inherent in this agenda is the goal of making learning science through inquiry a priority for all students and their science teachers.

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Endnotes

1. When we began the Promise Project, bilingual instruction was not an option in the participating schools. Teachers' growing awareness of the importance of students' languages and cultures led them to become advocates of bilingual instruction. Since then, dual language programs have become an integral in one school and are under consideration at the others.

2. George, J. C. (1992). *The missing 'gator of Gumbo Limbo: An ecological mystery.* New York: HarperCollins.