Science Instruction for All

Yu-Min Ku and Marco Bravo
University of California, Berkeley
and
Eugene E. García
Arizona State University

Draft, Not for Citation (11/1/03)

This work is supported by the National Science Foundation, US Department of Education, and National Institute of Health (Grant No. REC-0089231). Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the position, policy, or endorsement of the funding agencies.

Abstract

This study examines the impact of an instructional intervention designed and implemented to promote achievement of science and literacy among culturally and linguistically diverse students. A total of 374 third and fourth grade students from four urban schools received a years worth of thematic science instruction. The study focuses on two science units at both grades where science and literacy assessments were administered at the onset and end of the intervention. The results indicate participating students, regardless of language and cultural background, experienced significant growth in their science achievement and understandings of scientific writing as they experienced academically challenging yet culturally relevant literacy and science instruction.

Science Instruction for All

The population of the United States is more ethnically and racially diverse than ever, a fact that is particularly evident among young and school-age children. This presents today's elementary schools, including teachers, administrators, and policy makers, with an enormous challenge: promoting educational equity in the classroom and educating all students, regardless of background, to achieve high academic standards. Many students from culturally and linguistically diverse backgrounds in the U.S. have had unsuccessful schooling experiences. Their strengths and needs may not be recognized adequately in mainstream classrooms. This is particularly the case in mathematics and science.

To meet these challenges, we have been building responsive learning communities. This new pedagogy argues for the respect and integration of students' values, beliefs, histories, and experiences, and recognizes the active role that students must play in the learning process (Garcia, 2001). It is therefore a *responsive pedagogy*, one that encompasses practical, contextual, and empirical knowledge and a world view that education evolves through meaningful interactions among teachers, students, and other school community members. This responsive set of strategies expands students' knowledge beyond their own immediate experiences while using those experiences as a sound foundation for appropriating new knowledge. In this paper we explore the efforts in building science and math instructional environments and their related results as we utilize the tenants of our approach.

The Importance of Language and Culture in Learning and Teaching

Successful communication with students is essential to effective teaching. From a constructivist perspective, learning occurs when the students build understanding by integrating prior knowledge with new information. Theoretically, teaching and learning environments that serve students well recognize that students have been constructing knowledge and are continuing to do so, both in and out of school. In the case of students from diverse cultural and linguistic backgrounds, this means building a learning environment that incorporates already constructed knowledge, including their first languages and cultural values, in home and community environments (Garcia, 1999; Tharp & Gallimore, 1988).

How do we as educators begin to understand such a complex set of interactions? The term *constructivist* is an apt one. The constructivist perspective is rooted in the notion that for humans, knowing is a result of continual building and rebuilding. We come to understand a new concept by applying knowledge of previous concepts to the new information we are given. For example, in order to teach negative numbers, a math teacher can use the analogy of digging a hole—the more dirt you take out of the hole, the greater the hole becomes; the more one subtracts from a negative number, the greater the negative number becomes. But, a math teacher cannot use this example with children who have no experience digging holes. It won't work. This theory of how the mind works implies that continual revisions or *renovations*, as an architect might say are to be expected. Therefore, when we organize teaching and learning environments, we must recognize the relevance to our goals of students' previous educational environments.

Embedded in a constructivist approach is the understanding that language, culture, and the values that accompany them are constructed in both home and community environments. This approach acknowledges that children come to school with constructed knowledge about many things and points out that children's development and learning are best understood as the interactions of past and present linguistic, socio-cultural, and cognitive constructions. Development and learning are enhanced when they occur in contexts that are socio-culturally, linguistically, and cognitively meaningful for the learner. These meaningful contexts bridge previous constructions to present constructions.

Meaningful contexts for learning have been notoriously inaccessible to children from culturally and linguistically diverse backgrounds, often contributing to their educational vulnerability. The monolithic culture transmitted by U.S. schools in their forms of pedagogy, curricula, instruction, classroom configuration, and language dramatizes the lack of fit between these students and the school experience. The culture of U.S. schools is reflected in such practices as:

- The systematic exclusion of the histories, languages, experiences, and values of students from diverse linguistic and cultural backgrounds from classroom curricula and activities.
- *Tracking*, which limits access to academic courses and justifies learning environments

that do not foster students' academic development, socialization, or perception of themselves as competent learners and language users.
- A lack of opportunities to engage in developmentally and culturally appropriate learning in ways other than by teacher-led instruction.

Although the cultural norms and language experiences that diverse students bring to the class may differ from those of the mainstream, research indicates that teachers who consider students' home language and cultural experiences:

- provide students with important cognitive and social foundations for learning English;
- produce a positive academic difference (August & Garica, 1988); and
- promote students' participation and positive interpersonal relations in the classroom (Au & Kawakimi, 1994; Trueba & Wright, 1992).

In addition, when teachers treat students' cultural and linguistic knowledge as a resource rather than as a deficit, students are more able to access the school curriculum (Cummins, 2000; Valenzuela, 1999). The more comprehensive the use of their home languages, the greater the potential will be for students from diverse linguistic and cultural backgrounds to be academically successful (Miramontes, Nadeau, & Commins, 1997).

To provide effective instruction for students from diverse backgrounds, teachers can use students' home languages as appropriate to enhance their comprehension of instruction, and encourage students to use their home languages for effective communication (Lee & Fradd, 1998). To establish an instructional environment that builds on students' resources and strengths in classroom instruction, teachers need to incorporate students' cultural experiences at home and in the community. Also, teachers need to use cultural artifacts and community resources, culturally relevant examples and analogies drawn from students' lives, and consider instructional topics from the perspectives of multiple cultures. In essence, learning is enhanced when it occurs in contexts that are culturally, linguistically, and cognitively meaningful and relevant to the students (Cole, 1996; Diaz, Moll, & Mehan, 1986; Heath, 1986; Moll, 2001; Scribner & Cole, 1981; Wertsch, 1985). It is through their first languages and home cultures that students create frameworks for new understandings.

Science Learning for Students from Diverse Backgrounds

All students bring to the science classroom ways of looking at the world that are formed by their environments (Driver, Asoko, Leac, Mortimer, & Scott, 1994). Students from diverse cultural and linguistic backgrounds have acquired everyday knowledge and primary discourses in their homes and communities, while learning science disciplines and discourse in school. To provide effective science instruction, teachers face the challenges to ensure that diverse students, who may have acquired diverse world views and come with varied experiences, have access to and opportunities for acquiring the nature of science disciplines as practiced in the science community and schools.

Science, as generally taught in school, has been defined in terms of Western tradition (American Association for the Advancement of Science [AAAS], 1989, 1993; National Research Council [NRC], 1996) and tends to be regarded as culture free and not as a socially and culturally constructed discipline (Banks, 1993; Peterson & Barnes, 1996). The assumption being that all students would learn science when provided with opportunity. However, critics from diverse disciplines have raised epistemological and pedagogical concerns about the nature of science, learning, and teaching as traditionally defined in the science community and science taught in school. In addition, large-scale standardized test scores in science clearly indicate significant achievement gaps among ethnolinguistic groups. A small body of research currently exists on promoting science learning and achievement with students from culturally and linguistically diverse backgrounds; more is needed if the goal of science for all emphasized in current science education reform is to become a reality.

According to science education standards documents (AAAS, 1989, 1993; NRC, 1996), science learning involves a two-part process: (a) “to acquire both scientific knowledge of the world” and (b) “scientific habits of mind ” (AAAS, 1989, p. 190). The development of scientific knowledge involves *knowing* science (i.e., scientific understanding), *doing* science (i.e., scientific inquiry), and *talking* science (i.e., scientific discourse). The cultivation of scientific habits of mind includes scientific values and attitudes, as well as a scientific world view. Because the science practices in U.S. school contexts reflect the thinking of Western society, the norms and values of science are most familiar to students from mainstream middle-class backgrounds (Eisenhart, Finkel, & Marion, 1996; Lee & Fradd, 1998).

How might science learning be different with diverse groups of students? During the construction of scientific understanding, students from diverse backgrounds may have relevant prior knowledge and experiences in aspects of formal science instruction that will require a bridge to the classroom context. That bridge allows them to integrate what they already know with what they are expected to learn (Garcia, 1999). For example, a Hispanic teacher described how she used students’ home language and culture in science instruction:

> One example is taking temperature. I know now that I have to talk about the different measurements that you can get with the thermometer. Many students know that 38° means a fever, but some of them know it as around 100°. They don’t use terms like Celsius or Fahrenheit. They bring in these different experiences that we need to recognize. Another example is all of the foods we cook at home. Cooking is important in feeding a family, and they relate to that well. Hispanics do a lot of cooking in our homes. All the foods we cook at home require a lot of boiling, and they see the evaporation. So when they have lessons that involve boiling and evaporating, they have something to build on to learn science. When we do the activity on boiling, we talk about boiling *frijoles* (beans) and *arroz* (rice), things they relate to. When we measure the temperature of boiling water, we do it in both Celsius and Fahrenheit. Then they realize there are two systems of measuring the temperature. It is like speaking two languages, like being bilingual.

Scientific inquiry, the most emphasized component of science learning in the National Science Education Standards (NRC, 1996)—the approaches for enabling students to become independent learners as they acquire knowledge by reflecting, predicting, inferring, and hypothesizing—may pose challenges for many students from different cultural and language backgrounds (Casteel & Isom, 1994; Westby, 1995). Limited English language proficiency and diverse cultural perspectives should not prevent diverse students from engaging in meaningful science inquiry or from participating in formal and informal classroom participation. Learning science is dependent on students’ ability to comprehend and communicate concepts and understandings (Fradd & Lee, 1998). To promote science learning and achievement for culturally and linguistically diverse students, educators need to develop a pedagogy merging subject-specific and diverse-oriented approaches (Lee, 2002).

Goals of the Present Study

The objective of this paper is to examine the impact of the instructional intervention on science achievement of students who participated in the Science Instruction for All (SIFA) project during the 2001-2002 and 2002-2003 school years. The SIFA project is funded by the National Science Foundation and collaborates with the University of Miami. The project is a multi-year, multi-school effort to implement an instructional intervention geared to promote achievement and equity in science and literacy for linguistically and culturally diverse as well as mainstream students. This intervention, in the form of a thematic science curriculum, uses household materials for conducting scientific inquiry activities and is a medium for examining language, literacy, and collaborative interactions in the classroom. The research framework's foci are on responsive instructional engagement that encourages students to construct and reconstruct meaning and to seek reinterpretations and augmentations to past knowledge regarding literacy and science within compatible and nurturing schooling contexts. Diversity is perceived and acted on as a resource for teaching and learning instead of a problem.

To evaluate the impact of the intervention, the study utilized a pre-post design to compare students' performance in science and literacy assessments over the course of the intervention. Science assessments were developed to evaluate students' understanding of key scientific concepts and science inquiry, the focus of the instructional units, whereas one strand of the literacy assessment involved the evaluation of students' knowledge and understanding of processes associated with science inquiry and general mechanics of language use including organization, style/voice, and accuracy in grammar. By comparing students' achievement before and after receiving the instructional intervention, the study addresses the following research questions:

1. Do students experience achievement gain after receiving the instructional intervention?
2. Does students' performance differ among demographic subgroups in terms of ethnicity and home language background?
3. How does students' performance compare to national and international samples on test items selected from National Assessment of Educational Progress (NAEP) and the Third International Mathematics and Science Study (TIMSS)?
4. Do fourth grade students experience achievement gains in literacy and science when presented with authentic science writing tasks?
5. Do fourth grade students reach grade level standards in expository writing and science inquiry after experiencing each of two thematic science units?

Methods

Research Setting and Participants

The study is conducted in an urban school district located in a large metropolitan city in the San Francisco Bay area. The district enrolls approximately 58,000 students annually, of which 31% are Chinese, 21% Latino, 15% African American, and 10% White (not Hispanic). District-wide, 56% of elementary students are in free or reduced lunch programs, and 29% are designated as limited English proficient (LEP), primarily speaking Spanish and Chinese in the home.

During the academic years 2001-2002 and 2002-2003, four elementary schools, representing different linguistic and cultural groups of students, participated in the project. Two of the participating schools have bilingual programs in which students receive content instruction in both English and designated languages. Table 1 summarized the key features of the participating schools. A total of seven 3rd-grade teachers, 216 third grade students, six 4th-grade teachers and about 158 fourth grade students were involved in the project. Teacher participation was voluntary.

Table 1
Key Features of Schools

School	Bilingual Program	Ethnicity (Major groups)	SES (free & reduced lunch)	Limited English Proficient (LEP)
1	Bilingual Spanish & bilingual Chinese	40% Latino 25% African American 23% Chinese	88%	41%
2		27% Chinese 20% White 16% African American 14% Latino	26%	21%
3		25% White 25% Latino 16% African American 11% Chinese	22%	6%
4	Bilingual Spanish & bilingual Chinese	67% Latino 19% Chinese	85%	72%

Instructional Intervention

The instructional intervention focused on two thematic science units for 3rd grade (*Measurement* and *Matter*) and two units for 4th-grade students (the *Water Cycle* and *Weather*). Before implementing each science unit, the 3rd and 4th grade teachers met with the University of California-Berkeley research team to discuss the overall goals of the project, review the instructional materials, and receive training on how to implement the units.

The implementation of the science unit took place, on average, two to three hours a week for the majority of classrooms. Project personnel visited each classroom once a week to provide instructional support. All teachers were provided with complete sets of materials, including teachers' guides, copies of student books, and science supplies. All participating 3rd and 4th grade teachers completely implemented their respective units.

Research Instruments and Data Collection

To examine the impact of the intervention on student achievement, three types of assessments were designed to assess students' knowledge of science and literacy: Unit Test, NAEP/TIMSS, and Authentic Science Inquiry Literacy Assessment System (ASILAS). Table 2 illustrates the data sources and analysis.

Table 2
Data Sources and Data Analysis

Assessment type	Unit of analysis	Data analysis to display..
UNIT TEST	Science Concepts Science Inquiry	• achievement growth in unit concepts (pre/post) • if achievement gap narrow
NAEP/TIMMS	Science Concepts	• achievement growth in relation to national and international norms • achievement gap between demographic subgroups
ASILAS	Science Inquiry Science Writing	• understanding and application of science inquiry • development of Expository Writing

Unit Test. The Unit Test was designed to assess students' knowledge of science directly tied to the instructional units. The test is specifically designed to measure (a) key science concepts and big ideas of patterns, systems, and models of the unit and (b) science inquiry, using structured inquiry tasks in which students used the data provided to construct graphs and draw conclusions, and open-ended inquiry tasks in which students generate questions, hypotheses, and planned investigations and procedures. For each grade level, there were two science unit tests, and each unit test was administered before and after the implementation of that particular unit. Generally, there were about three months between the pretest and posttest.

NAEP/TIMSS. The NAEP/TIMSS test consisted of public-release items from the NAEP and the TIMSS. In particular, NAEP items were taken from the release pool from the1996 and 2000 4th-grade science subject tests, TIMSS items were chosen from 3rd, 4th, 7th, and 8th grades for math (measurement) as well as science assessment release pool items. The NAEP/TIMSS test contained mostly multiple-choice items and a few short answer and extended response items. For each grade level, there was a NAEP/TIMSS test that measured the key concepts in both instructional units and was administered at the onset and the end of both units. Usually, there were seven months between the pretest and posttest of the NAEP/TIMSS tests.

Both the Unit Test and NAEP/TIMSS assessments were developed and based on previous research conducted at the University of Miami (Lee, 2002), and refined with 3rd and 4th-grade students in the SIFA project's collaborative effort with the research team at the Miami site.

ASILAS. To assure more authentic assessment tasks were included in measuring student achievement, a partnership between classroom teachers and researchers from the SIFA research group led to a co-constructed assessment, the ASILAS, which lend itself to authentically gauge students' science inquiry and literacy development not in isolation of each other, but at their intersection.

Two ASILAS writing tasks accompanied each unit taught at the 4th grade. One of the units comprised of instruction surrounding Water Cycle while the other dealt with the theme Weather. Each of these units were embedded with literacy activities including reading material and opportunities for students to write expository texts. The ASILAS were administered in conjunction with the investigations that students were already a part of in the unit. They were purposely administered in a pre-post manner. This paper will share the findings from 40 4th-grade students' writing, which rendered a total of 160 writing samples.

Because the assessment had an explicit goal of creating assessment conditions that required students to think and write authentically like scientists, the ASILAS included a student investigation, group work where a lab book was utilized to record findings, opportunities to share their results and finally an independent writing task. The following, Figure 1, more vividly represents the cyclical nature of the ASILAS administration.

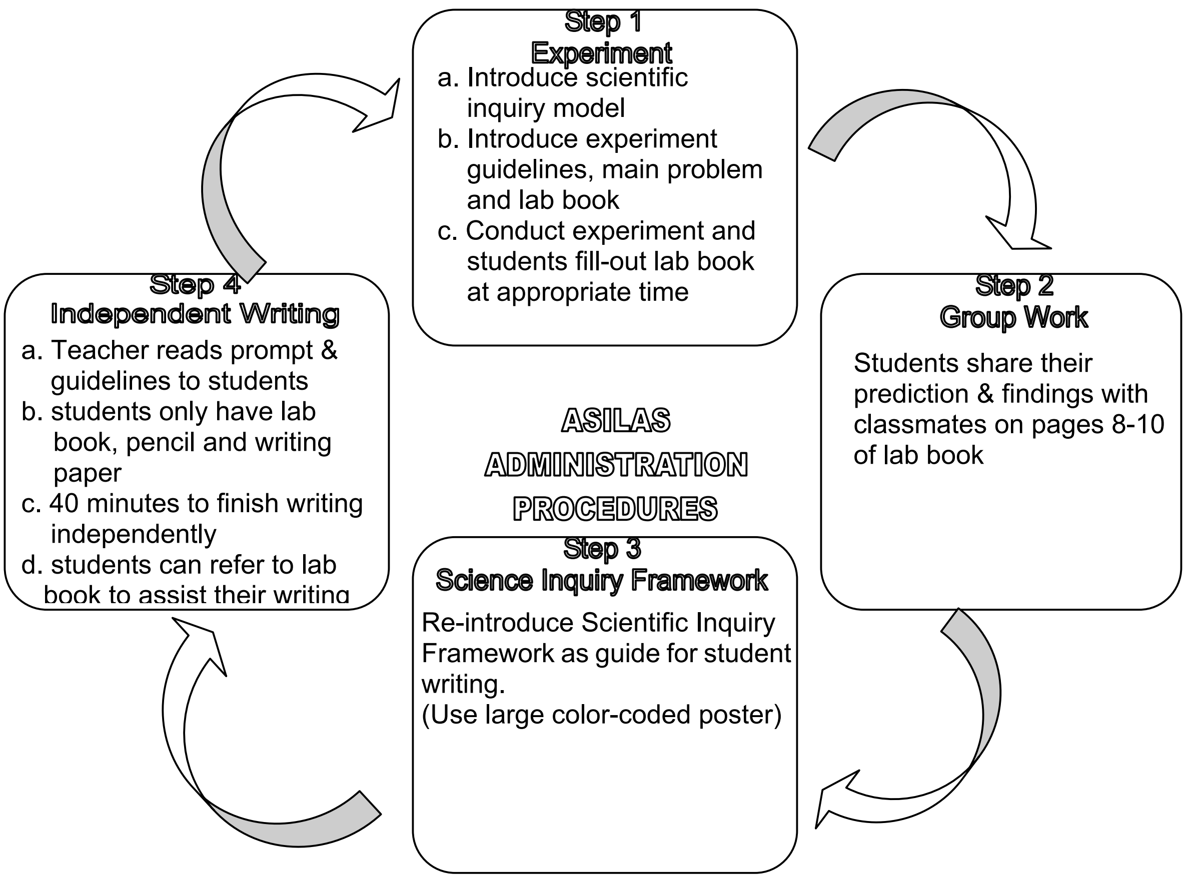


Figure 1
The Nature of the ASILAS Administration

Results and Discussion

The results of student assessment include the data analysis and results of students' performance on three science measures (i.e., concepts, inquiry, NAEP/TIMSS) and ASILAS.

Science achievement: overall results. The analyses of the test score change on three science achievement measures (i.e., concepts, inquiry, NAEP/TIMSS) by 3rd and 4th grade students are presented in Table 3. Significance tests of mean scores between pretests and posttests indicate significant increase on all science achievement measures. The results indicate both 3rd and 4th grade students gained significant amount of knowledge about these two science units after participating in academically challenging and culturally relevant curriculum. Furthermore, analysis yielded stronger effect sizes (Cohen's *d*) for science concept measures than inquiry or the NAEP/TIMESS measures with both 3rd and 4th-grade students. Figures 2 and 3 depict the mean percentage correct in pretests and posttests on three science achievement measures for 3rd and 4th grade students, respectively.

In comparing the overall results of 3rd and 4th-grade students' science achievement, it was interesting to find that the gain on the posttests for 3rd grade students (average 28.17% gain) was higher than the gain on the posttests for 4th-grade students (average 18.94% gain). A plausible reason for the differences in their achievement growth could be that the instructional units for 4th-grade students were relatively more complex and difficult than those for 3rd-grade students. The instructional units for 3rd grade (Measurement and Matter) involved mostly basic skills and concepts while the instructional units for 4th grade (The Water Cycle and Weather) contained major global systems.

Figure 2

Mean Percentage Correct in Pretests and Posttests on 3 Science Achievement Measures

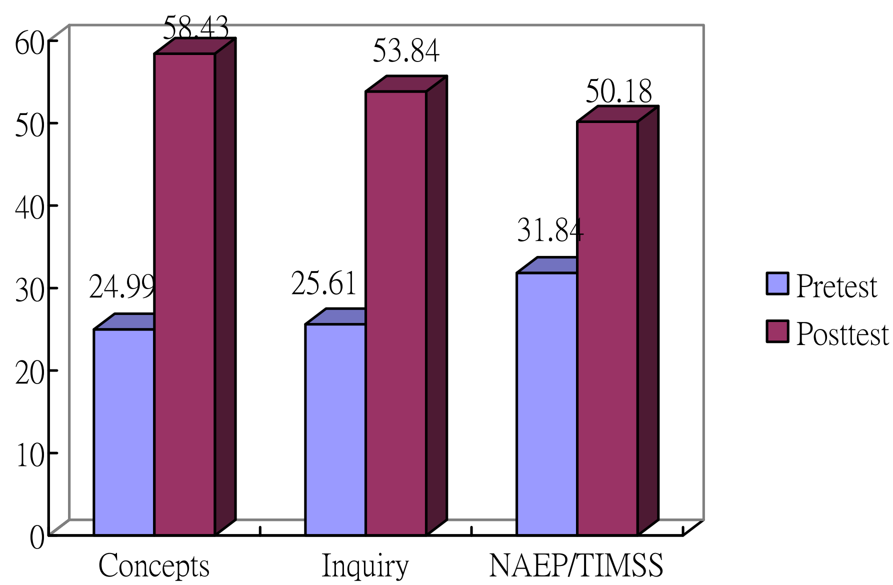


Figure 3

Mean Percentage Correct in Pretests and Posttests on Three Science Achievement Measures: Grade 4

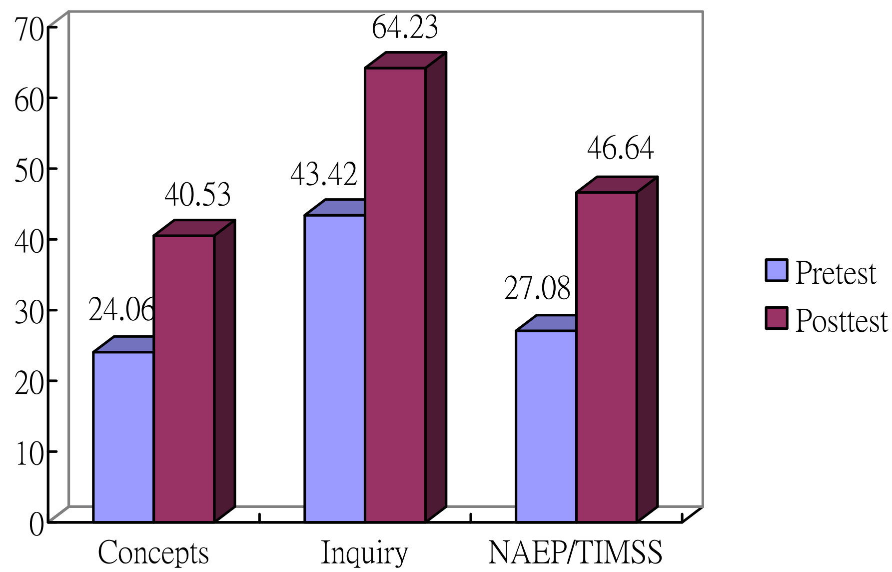


Table 3

Analysis of Test Score Change on Three Science Achievement Measures by Grade Level

Grade	Domain	Pretest	Posttest	*t*	*df*	*d*[a]
3rd	Concepts	24.99 (13.84)	58.43 (17.92)	25.90	136	2.09
	Inquiry	25.61 (22.96)	53.84 (20.19)	14.85	134	1.31
	NAEP/TIMSS	31.84 (15.18)	50.18 (20.13)	10.69	150	1.03
4th	Concepts	24.06 (12.28)	40.53 (16.00)	11.60	75	1.20
	Inquiry	43.42 (29.07)	64.23 (22.10)	8.43	74	0.82
	NAEP/TIMSS	27.08 (18.18)	46.64 (24.60)	8.52	91	0.92

Note. [a] d > .20 is "small", d > .50 = "medium", and d > .80 is a "large" effect size.
Number of students in each analysis is equal to (*df* + 1).

Achievement gaps among 3rd-grade subgroups. To compare the impact of the instruction on different demographic subgroups, several additional analyses of test scores change between pretest and posttest by students' ethnic and linguistic backgrounds were also performed. The results indicated that all third grade students, regardless of their ethnic and linguistic backgrounds, gained significant amount of knowledge about Measurement and Matter after one year of instruction.

To perform group comparisons, a series of multiple regressions were carried out whereby each demographic variable (ethnicity and home language) served as predictor of achievement growth (change) and achievement gaps in pre/post tests. When conducting the analyses on group comparison, the English-speaking group served as the reference group for the home language variable, while the White group served as the reference group for the ethnicity variable. Tables 4, 5, and 6 show the analyses of achievement gaps (*t* test of the pretest scores difference and *t* test of the posttest scores difference) and achievement growth (*t* tests of change scores between pre and post) of subgroups on three science measures (concepts, inquiry, and NAEP/TIMSS).

Table 4
Achievement Gap (Science Concepts) by Demographic Subgroups: Grade 3

	Major Subgroup	Pretest	*t pre difference*	Posttest	*t post difference*	Change	*t change difference*
Ethnicity	White	42.27		72.09		22.62	
	African American	23.92	-4.79*	41.46	-4.93*	24.60	0.36
	Latino	21.79	-5.91*	52.35	-3.50*	33.93	2.34*
	Asian	26.64	-4.54*	64.57	-1.33	37.55	3.11*
Language	English	30.70		53.96		26.42	
	Spanish	21.15	-3.70*	52.24	-0.45	35.84	3.01*
	Chinese	26.30	-1.80	64.24	2.85*	37.88	3.95*

Note. * $p < .05$.

Table 5
Achievement Gap (Science Inquiry) by Demographic Subgroups: Grade 3

	Major Subgroup	Pretest	*t pre difference*	Posttest	*t post difference*	Change	*t change difference*
Ethnicity	White	47.69		62.99		5.19	
	African American	16.45	-4.91*	36.02	-4.01*	25.75	2.61*
	Latino	20.83	-4.67*	53.00	-1.63	32.23	3.85*
	Asian	28.82	-3.30*	59.17	-0.63	28.94	3.42*
Language	English	29.67		48.61		19.76	
	Spanish	18.69	-2.55*	54.14	1.31	37.23	3.59*
	Chinese	26.72	-0.73	59.38	2.72*	31.67	2.66*

Note. * $p < .05$.

Table 6

Achievement Gap (NAEP/TIMSS) by Demographic Subgroups: Grade 3

	Major Subgroup	Pretest	*t pre difference*	Posttest	*t post difference*	Change	*t change difference*
Ethnicity	White	41.45		63.64		23.08	
	African American	22.09	-4.41*	42.81	-2.87*	17.73	-0.71
	Latino	24.85	-4.53*	46.50	-2.57*	19.93	-0.46
	Asian	35.81	-1.53	54.28	-1.42	18.34	-0.70
Language	English	31.42		50.14		18.00	
	Spanish	23.69	-2.90*	46.37	-0.87	20.14	0.46
	Chinese	36.03	1.80	54.46	1.10	18.15	0.04

Note. * $p < .05$.

Based on the analyses presented in Table 4, 5, and 6, four finings can be summarized in terms of the impact of the instructional intervention on closing the achievement gaps among 3rd-grade subgroups. First, achievement gaps often existed between White students and African-American and Latino students at the time of the pretest and posttest; however, the gaps narrowed at the end of the school year because of significant achievement growths. Second, achievements gaps between White students and Asian students at the beginning of the year had noticeably narrowed after the instruction intervention. Third, in all science measures, the gaps between the Spanish group and the English group at pretest had dramatically narrowed by the end of the school year. Finally, Chinese bilingual students attained the highest posttest scores among the three major language groups.

It is not unexpected to find White students outperforming the other three ethnic subgroups at pretest because the majority of White students in the project were from School 3 where they had access to additional educational resources. However, through the instructional intervention that emphasized on incorporating students' cultural experience into instruction and bridging students' prior knowledge to the science contents, the learning of culturally diverse students started to improve and the achievement gaps gradually narrowed or closed after the intervention.

The intervention also had a positive impact on the science learning of students who speak Spanish or Chinese at home. Many of the participating teachers promoted students' participation by encouraging students to use their first language while conducting science inquiry within small groups. The linguistic scaffolding between students may play an important role in closing of the achievement gaps between the English group and the Spanish group.

<u>Achievement gaps among 4th-grade subgroups.</u> The results for 4th-grade students indicated that almost all students, regardless of their ethnic and linguistic backgrounds, gained significant amount of knowledge about the Water Cycle and Weather units on the three science achievement measures after one year of instruction. Some noticeable exceptions included African-American, Latino, and the Spanish bilingual group who did not show significant gain on the NAEP/TIMSS test.

To perform group comparisons, a series of multiple regressions similar to those carried out for the 3rd-grade data were calculated. Tables 7, 8, and 9 show the analysis of achievement gaps (*t* test of the pretest scores difference and *t* test of the posttest scores difference) and achievement growth (*t* tests of change scores between pre and post) of subgroups on three science measures (concepts, inquiry, and NAEP/TIMSS).

Table 7

Achievement Gap (Science Concepts) by Demographic Subgroups: Grade 4

	Major Subgroup	Pretest	*t pre difference*	Posttest	*t post difference*	Change	*t change difference*
Ethnicity	White	28.00		45.71		22.86	
	African American	19.05	-2.69*	28.57	-3.30*	11.65	-2.02*
	Latino	17.39	-3.25*	33.97	-2.28*	17.52	-0.98
	Asian	30.13	0.74	47.35	0.35	18.48	-0.89
Language	English	26.61		38.60		16.09	
	Spanish	17.29	-2.93*	33.78	-1.13	16.53	0.11
	Chinese	29.57	0.98	43.76	1.26	15.80	-0.08

Note. * $p < .05$.

Table 8

Achievement Gap (Science Inquiry) by Demographic Subgroups: Grade 4

	Major Subgroup	Pretest	*t pre difference*	Posttest	*t post difference*	Change	*t change difference*
Ethnicity	White	48.04		64.35		28.26	
	African American	25.05	-2.83*	38.87	-3.24*	17.39	-1.14
	Latino	33.46	-1.84	59.18	-0.66	27.25	-0.11
	Asian	51.88	0.55	75.53	1.58	19.57	-1.04
Language	English	42.95		58.00		21.39	
	Spanish	29.57	-1.89	59.34	0.20	28.57	1.08
	Chinese	51.42	1.26	71.40	2.12*	17.90	-0.58

Note. * $p < .05$.

Table 9

Achievement Gap (NAEP/TIMSS) by Demographic Subgroups: Grade 4

	Major Subgroup	Pretest	*t pre difference*	Posttest	*t post difference*	Change	*t change difference*
Ethnicity	White	40.69		61.54		27.27	
	African American	15.38	-5.01*	31.55	-3.76*	13.29	-1.69
	Latino	22.40	-3.68*	35.41	-3.35*	9.57	-2.32*
	Asian	30.04	-2.35*	56.06	-0.78	26.77	-0.07
Language	English	25.62		46.17		22.92	
	Spanish	23.27	-0.53	36.87	-1.44	10.61	-2.00*
	Chinese	33.09	1.69	54.55	1.32	22.49	-0.07

Note. * $p < .05$.

Based on the analyses presented in Table 6, 7, and 8, four finings can be summarized in terms of the impact of the instructional intervention on closing the achievement gaps among 4th-grade subgroups. First, achievement gaps often existed between White students and African-American and Latino students, and the gaps widened at the end of the school year, especially on the NAEP/TIMSS measure. Second, Asian students generally performed comparably or higher than White students on the science measures except on NAEP/TIMSS test where a gap was found at pretest but was considerably declined at posttest. Third, the gap between the Spanish bilingual group and the English group narrowed in the science concepts and inquiry measure but the gap widened in the NAEP/TIMSS test. Finally, Chinese bilingual students scored the highest on all the science measures among the three major language groups.

The impact of the intervention on 4th-grade ethnic subgroups was different from the impact on 3rd-grade ethnic subgroups. The fact that the gaps between White students and African-American and Latino students widened at the end of school year, especially on science concept and NAEP/TIMSS measures, might suggest that more culturally relevant and meaningful contexts are needed to enhance the learning of the major science concepts in Water Cycle and Weather unit for culturally diverse students.

Similar to the findings for 3rd-grade students, a strong positive impact was also found among Spanish group, especially on science inquiry measure where the performance of Spanish group was lower than English group at pretest (29.57% correct vs. 42.95% correct) but slightly higher than English group at posttest. It is also noteworthy that Chinese group at both 3rd and 4th-grade outperformed English and Spanish groups in the posttests of all three science measures. Further investigation is needed to examine to the linguistic scaffolding that enhanced linguistically diverse students' understanding of science concept and inquiry through teacher-student and student-student interactions.

<u>Performance on NAEP/TIMSS compared to national and international samples.</u> Tables 10 and 11 list the percentage correct for 3rd and 4th-grade participating students' performance on NAEP/TIMSS items, compared to national and international samples. Participating 3rd-grade students in the SIFA project generally performed lower than 3rd or 4th-grade national and international samples in the pretest. However, on many of the items, they outperformed their counterparts, and on a few items, they even performed comparably or higher than 7th or 8th-grade national and international samples in the posttest.

The comparison for the 4th graders showed that the participating 4th grade students in the SIFA project also generally scored lower than 3rd and 4th grade national and international samples in the pretest. However, on most of the items in the posttest, they performed higher than 7th and 8th grade national and international samples.

Table 10
Grade 3 Performance on NAEP/TIMSS Items

		Norm Group Percentage Correct				**SIFA 2001-2003**	
Item	*Source*	*Grade 3*	*Grade 4*	*Grade 7*	*Grade 8*	*Pretest*	*Posttest*
1	TIMSS			24	29	10	27
2	NAEP		35		49	23	37
3	TIMSS			76	81	61	74
4	NAEP		27		63	23	45
5	NAEP		77			68	87
6	TIMSS			79	82	53	76
7	TIMSS	69	71			36	44
8	TIMSS	52	62			46	58
9	TIMSS			83	87	31	60
10	NAEP		11		47	9	17
11	TIMSS			33	33	12	21
12	TIMSS	30	38			26	35

Table 11

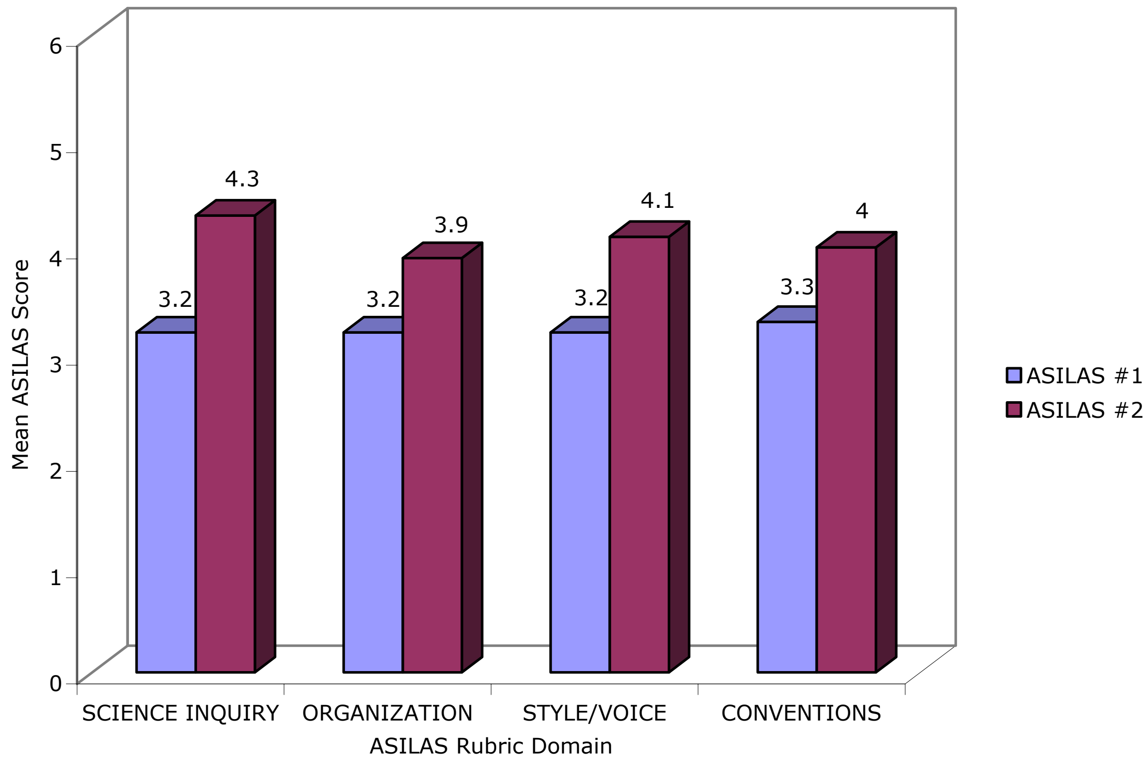
Grade 4 Performance on NAEP/TIMSS Items

		Norm Group Percentage Correct				**SIFA 2002-2003**	
Item	*Source*	*Grade 3*	*Grade 4*	*Grade 7*	*Grade 8*	*Pretest*	*Posttest*
1	TIMSS			38	41	28	46
2	NAEP		56		76	64	77
3	TIMSS			24	29	14	36
4	NAEP		27		63	37	72
5	NAEP		28			33	42
6	TIMSS	31	41			29	49
7	TIMSS			34	34	18	30
8	TIMSS	32	44			9	43

Science Writing. The research team evaluated each of the writing samples by scoring them according to the ASILAS rubric (aligned with state standards for expository writing and science writing), which contained four categories (Science Inquiry, Organization, Style/Voice, and Conventions). The rubric scaled from a score of one to six and clearly marked state standards at scores of two for 3rd grade, four for 4th-grade and six for 5th-grade. In other words, at the end of each grade, students' writing should be performing at these scores to be considered as writing at grade level. A fifth category (Holistic Score) was then derived by obtaining a mean score across the domains, giving equal weight to each of the four domains. Before scoring the writing samples, five team members were involved in a two-day training on the scoring protocol to assure reliability and validity. Members scored ASILAS writing samples only after obtaining a 90% inter-rater reliability score on ten student-writing samples.

The ASILAS data collected for the academic year 2002-2003 yielded some interesting results. At the onset of the Water Cycle unit, students in the 4th-grade class experienced difficulties writing an expository text based on their investigations. As Figure 4 illustrates, students were well below grade level when the first ASILAS was administered.

Figure 4
2002-2003 ASILAS Water Cycle Unit Pre/Post Assessment (n=40)



For ASILAS #1, students' writing somewhat addressed the Scientific Inquiry domain of the rubric, which required students to: (a) align their hypothesis with their proposed question, (b) describe the procedures and materials involved in the experiment, and (c) conclude with some results. Initially, students listed only partial procedures and either proposed a question to study or a hypothesis, but not both. The difficulty with the appropriation of such processes by English language learners has been echoed by other researchers as well (Miramontes, Nadeau, & Commins, 1997; Lee, 2000). At the end of the unit and after several practice activities with the Scientific Inquiry model, students managed to better provide descriptions of their materials and procedures, addressed their results in their concluding paragraph, but continued to include either a question or hypothesis in their expository text. Students managed to attain a score of 4.3 on the rubric, a score above the 4th-grade benchmark.

The Organization domain of the rubric involved paragraph structure and overall cohesiveness of the students' text. Though students included a topic and supporting sentences in their paragraphs, the sequence of the paragraphs was often not logical, an elusive trait associated with academic English which requires explicit instruction (Scarcella, 2003). Three months later when the second ASILAS was administered, students' writing matured considerably in this domain. Student writing included transition words that connected introductory, supporting and summarizing paragraphs, yet was marked by a tendency to structure these elements in a narrative fashion. This can be attributed to the fact that minimal instruction during the unit dealt with the structure needed in composing expository texts. Duke (2000) found students in primary grades had little instruction and experience with informational texts in schools, the place where students could gain exposure to both style and structures of expository texts.

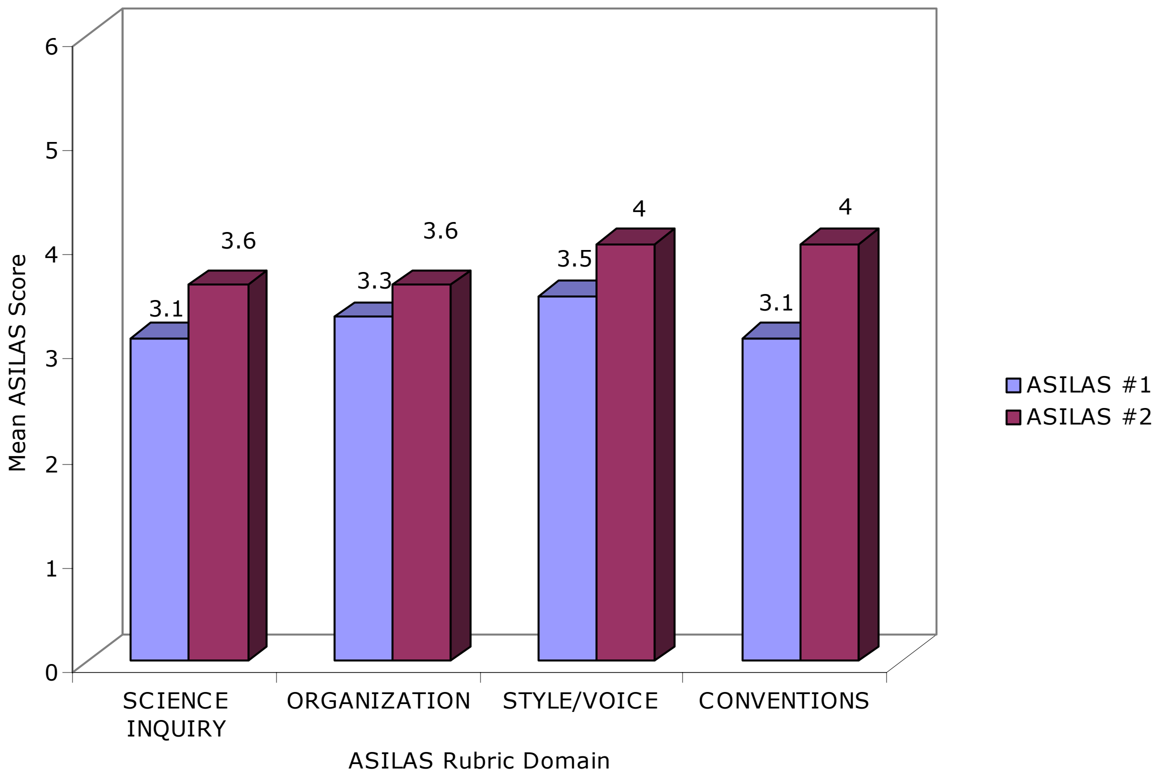
The Style/Voice domain addressed issues of sentence structure and the use of science/ descriptive language. Student understandings about using simple and compound sentences and including such terms as hypothesis, investigate and evidence ripened as students encountered these vocabulary items in texts and were required to utilize them in their investigations during the unit. Yet, the sentences were seldom constructed in the passive voice as is common in many science textbooks (Wong-Fillmore & Snow, 2000). Instead, the past tense and active first person was employed, another characteristic of narrative texts.

A common worry of many classroom teachers teaching writing deals with the last domain of the ASILAS rubric, Conventions (Calkins, 1986). This domain assessed how well students spelled, punctuated, and used correct grammar. While initially students managed to spell all high frequency words (e.g., I, am, have) correctly, almost always used appropriate punctuation and capitalization, and showed some troubles with using the correct pronoun and/or adverbial forms, by the end of the unit they were more capable of spelling correctly irregular words and demonstrated no difficulties with punctuation or capitalization. Troubles with using conjunctions and correct pronoun continued to plague student papers after the second ASILAS administration. Explicitly targeting these language difficulties through teaching them within the context in which they occur has been found to be instructionally fruitful (Garcia, Bravo, Dickey, Chun, & Sun-Irminger, 2002).

A similar blue print in scores was found among student papers when the Weather unit was administered during the second semester of the academic year (see Figure 5).

Figure 5

2002-2003 ASILAS Weather Unit Pre/Post Assessment (N=40)



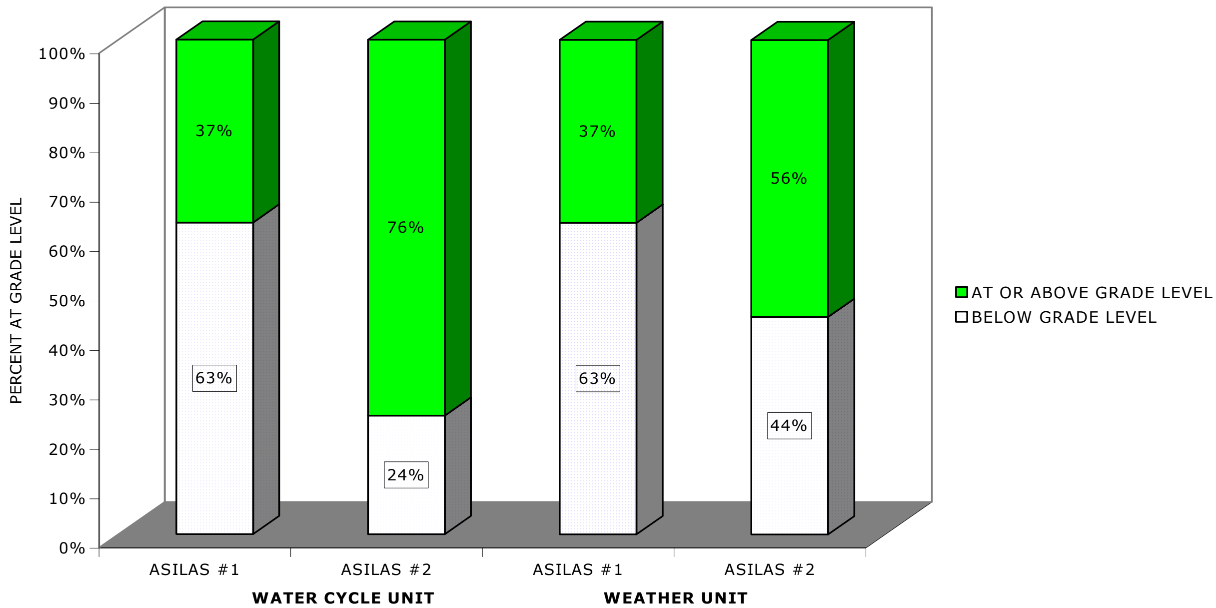
In comparing the initial scores with those in the previous unit, what is initially observable is that students did not sustain their understandings of the elements found in the four domains of the writing rubric as would be expected at the onset of the first ASILAS. Writing trajectories are less often neat and more likely to follow an unpredictable pathway (Moll, Saez, & Dworin, 2001). The long winter break could be responsible for the descent in scores. An alternate plausible purpose for the descent in scores could be that the Weather Unit curriculum was found more demanding than the Water Cycle Unit, making the conceptual understanding of key scientific inquiry knowledge challenging. This latter explanation assumes that students' demonstration of their literacy skills was highly dependent on their understanding of the scientific content material.

Nonetheless, students managed to again demonstrate an increasing understanding of the scientific inquiry framework. Three months after the initial ASILAS was administered, students outlined their experiment nicely, assuring to include a question, hypothesis, procedures, and materials and results. This framework was organized in two paragraphs written in a logical sequence with varied sentence structures and science vocabulary. Spelling, punctuation, and grammar also matured by the end of the unit. Though students did not reach grade level standards in Science Inquiry and Organization, they did so in Style/Voice and Conventions.

To probe the percentage of students that were scoring below, at, or above grade level, a holistic score was calculated through attaining a mean among the Science Inquiry, Organization, Style/Voice, Conventions domains, giving equal weight to each. These scores were then measured up to the 4th-grade benchmark of four. This yielded percentages that represented the proportion of students reaching or falling below grade level expectations for each pair of ASILAS administrations. As is evident by Figure 6, more students were writing and understanding the scientific inquiry process after experiencing the embedded literacy and science curriculum in both the Water Cycle and Weather units than at the onset of the intervention. Hart and Lee (in press) found similar science and literacy gains when instruction in these subject areas was introduced at their intersection.

Figure 6

2002-2003 ASILAS Benchmark Scores



At the onset of the Water Cycle Unit, only about one-third of students were considered to be writing at or above grade level. Two months later, when the second ASILAS was administered, an additional 39% were reaching grade level expectations, taking the total up to the point where more than three fourths of the class were reaching the target.

Though not as dramatic a shift as with the ASILAS in the Water Cycle Unit, a significant number of students managed to reach the benchmark score at the end of the Weather Unit than when the first ASILAS was administered. Initially 63% of students demonstrated such troubles with the four domains of the ASILAS rubric that their student writing samples were considered to be at the 3rd-grade status. Only 37% of student writing samples were deemed to be grade level appropriate. Yet, by the second ASILAS administration, a noticeable shift occurred. An additional 19%, for a total of 56% of students, were writing science texts that accomplished grade level equivalency. A contributing factor to this development was the literacy activities in the service of science concept learning entrenched throughout the science unit that enhanced both literacy and science learning for all students, but particularly the English language learner (ELL) (Garcia & Lee, in press).

Conclusions

The impact of the intervention on student science achievement is evident and prevalent as demonstrated by the results on Unit posttests, NAEP/TIMSS, and the ASILAS assessments. Students, regardless of language and cultural background, often experienced significant growth in learning science concepts and inquiry measured by the unit tests. Comparing the 3rd and 4th grade students' performance on NAEP/TIMSS posttests with other national and international samples, students in our project generally outperformed their counterparts and performed comparably or higher than upper grade students.

Two salient points are noteworthy while comparing the impact of the intervention among demographic subgroups. First, the instruction intervention generally had positive impacts on the Spanish bilingual groups (3rd and 4th grade) by closing the achievement gap between them and native English speaking students in the study, especially regarding science inquiry. This is an important finding because the primary purpose of the SIFA project was to promote achievement and equity in science and literacy, particularly focusing on science inquiry, for culturally and linguistically diverse students. Second, the Chinese bilingual groups outperformed the English and Spanish bilingual groups at both grade levels. To further investigate the differential impacts on the subgroups, careful examination of classroom practices is required.

With reference to literacy, the results from ASILAS clearly demonstrated that students' understandings regarding writing like a scientist matured as they experienced literacy and science instruction at their intersection with a healthy dose of culturally relevant instructional material. When students were asked to exhibit their acquaintance with the scientific inquiry framework, they initially provided partial responses, at times listing incomplete procedures and/or excluding the hypothesis for their experiments. These gaps were filled for many with extensive opportunities during the unit to experience hands-on science where literacy activities such as a lab book scaffolded students' acquisition of science concepts. Conversely, having authentic tasks for reading and writing through out the unit in the service of science also enhanced students abilities to write expository texts.

In both units, students were better able to handle the demands of the writing task and the science concepts that were expected in the writing samples at the conclusion of the units. Students better understood that their writing needed to be organized in a particular manner, had to include descriptive and science related vocabulary terms, needed to have words spelled correctly, and appropriately punctuated and grammatically correct sentences.

These results were also visible when considering the number of students reaching grade level expectations at the onset and conclusion of the units. Three fourths of students were considered to be reaching the benchmark score of four at the end of the Water Cycle Unit compared with the 37% of students who were reaching this goal at the outset. Similarly, approximately an additional 20% of students managed to reach grade level equivalency for a total of 56% at the conclusion of the Weather Unit.

Though students made significant progress, some troubles with writing in an expository genre were uncovered. For the students that experienced the most difficulty in formulating an expository text, a portion of them had a narrative tendency, though the prompt elicited an informational text. This genre confusion was a consistent trend for those students who fell below grade level across the four writing assessments probed. Instead of listing their materials and procedures, some students narrated a story that included materials and procedures, but were only mentioned at times when their narrative required them and rarely included all, as is called by the rubric. Moreover, the organization of the scientific inquiry framework was often not reported in a logical sequence. For example, the question to be investigated that was to drive the experiment, was either left out or placed at the end of their writing.

Implications

To be responsive to the cultural and linguistic diversity of students, it is imperative to probe what students bring to the learning context. For the work conducted by SIFA, the rich data utilized to record students' understandings was only made possible by going to the source, student work. Students' writing samples and experiences with the assessment procedures both drove the inception of the assessment at the onset and informed the direction the assessment took when it was piloted. This process assured students were being assessed only after they experienced optimal conditions to learn key grade-level appropriate science concepts with literacy as tool to write as scientists do.

Responsive Pedagogy and Learning Communities. The implication of this specific research has profound effects for the teaching/learning enterprise related to culturally diverse students (Garcia, 1999). This new pedagogy is one that redefines the classroom as a community of learners in which speakers, readers, and writers come together to define and redefine the meaning of the academic experience. It is therefore a responsive pedagogy, one that encompasses practical, contextual, and empirical knowledge and a world view of education that evolves through meaningful interactions among teachers, students, and other school community members. This responsive set of strategies expands students' knowledge beyond their own immediate experiences while using those experiences as a sound foundation for appropriating new knowledge.

Of course, a teaching and learning community that is responsive to the dynamics of social, cultural, and linguistic diversity within the broader concerns for high academic achievement both requires and emerges from a particular schooling environment. While considerable work has been devoted to restructure schools and change the fundamental relationships that exist among school personnel, students, families, and community members, seldom have these efforts included attention to the unique influences of the linguistic and sociocultural dimensions of these same relationships and structures. The environments that potentially support and nurture the development of responsive learning communities are not unlike those promoted by leading school reform and restructuring advocates; however, we further suggest that the incorporation of social, cultural, and linguistic diversity concerns creates a set of educational principles and dimensions that are more likely to address the challenges faced by schools that must attend to the needs of growing populations of diverse students.

Responsive Learning Communities. The learning environments that we consider essential to the development of a responsive pedagogy are referred to as "effective schooling" (Garcia, 1999). The focus on the social, cultural, and linguistic diversity represented by students in today's public schools further challenges us to consider the theoretical and practical concerns relative to ensuring educational success for diverse students. That is, responsive learning communities must necessarily address issues of diversity in order to maximize their potential and to sustain educational improvement over time (Garcia & Lee, 2003). To further examine this challenge, Table 1 summarizes the conceptual dimensions for high performing responsive learning communities.

Table 1
Conceptual Dimensions of Addressing Cultural and Linguistic Diversity in Responsive Learning Communities in Science

School-wide Practices

- A vision defined by the acceptance and valuing of diversity--Americanization is NOT the goal
- Treatment of classroom practitioners as professionals, colleagues in school development decisions
- Characterized by collaboration, flexibility, enhanced professional development
- Elimination (gradual or immediate) of policies that seek to categorize diverse students thereby rendering their educational experiences as inferior or limiting for further academic learning--
- Reflection of and connection to surrounding community and ways in which that community deals with scientific issues--particularly with the families of the students attending the school

Teacher/Instructional Practices

- Bilingual/bicultural skills and awareness
- High expectations of diverse students
- Treatment of diversity and diverse science knowledge as an asset to the classroom
- Ongoing professional development on issues of cultural and linguistic diversity and practices that are most effective for science instruction
- Basis of curriculum development to address cultural and linguistic diversity:
  1. Attention to and integration of home culture/practices/theories
  2. Focus on maximizing student interactions across categories of English proficiency, academic performance, schooling prior to immigration to US, etc.
  3. Regular and consistent attempts to illicit ideas from students for planning units, themes, activities
  4. Thematic approach to learning activities--with the integration of various skills, events, learning opportunities
  5. Focus on language development through meaningful interactions and communications versus on grammatical skill-building that is removed from its appropriate context

References

American Association for the Advancement of Science. (1989). *Science for all Americans*. New York: Oxford University Press.

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. New York: Oxford University Press.

Au, K. H., & Kawakami, A. J. (1994). Cultural congruence in instruction. In E. R. Hollins, J. E. King, & W. C. Hayman (Eds.), *Teaching diverse populations: Formulating a knowledge base* (pp. 5-24). Albany, NY: State University of New York Press.

August, D., & Garcia, E. (1988). *Language minority education in the U.S.: Research policy and practice.* Springfield, IL: Charles C. Thomas.

August, D., & Hakuta, K. (Eds.). (1997). *Improving schooling for language-minority children: A research agenda.* Washington, DC: National Academy Press.

Banks, J. (1993). Multicultural education: Historical development, dimensions and practice. In L. Darling-Hammond (Ed.), *Review of Research in Education* (Vol. 19) (pp. 3-49). Washington, DC: American Educational Research Association.

Calkins, L. M. (1986). *The art of teaching writing*. Portsmouth, NH: Heinemann.

Casteel, C. P., & Isom, B. A. (1994). Reciprocal processes in science and literacy learning. *The Reading Teacher, 47*, 538-545.

Cole, M. (1996). *Cultural psychology: A once and future discipline.* Cambridge, MA: Belknap Press of Harvard University Press.

Cummins, J. (2000). *Language, power & pedagogy: Bilingual children in the crossfire.* Clevedon: Multilingual Matter LTD.

Diaz, S., Moll, L. C., & Mehan, H. (1986). Sociocultural resources in instruction: A context-specific approach. In Bilingual Education Office (Ed.), *Beyond language: Social and cultural factors in schooling language minority students* (pp. 197-230). Los Angeles: Evaluation, Dissemination, and Assessment Center, California State University.

Driver, R. Asoko, H. Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23,* 261-295.

Duke, N. K. (2000). 3.6 minutes per Day: The scarcity of informational texts in first grade. *Reading Research Quarterly, 35,* 202-224.

Eisenhart, M., Finkel, E., & Marion, S. F. (1996). Creating the conditions for scientific literacy: A re-examination. *American Educational Research Journal, 33,* 261-295.

García, E. E. (1999). *Student cultural diversity: Understanding and meeting the challenge* (2nd ed.). Boston, MA: Houghton Mifflin Company.

Garcia, E. E., Bravo, M., Dickey, L, Chun, K., & Sun-Irminger, X. (2002). Rethinking school reform in the context of cultural and linguistic diversity: Creating a responsive learning community. In Minaya-Rowe, L. (Ed.), *Teacher training and effective pedagogy in the context of ctudent diversity.* Greenwich, CT: Information Age Publishing Company.

García, E. E., & Lee, O. (in press). Science instruction for all: Creating a responsive learning community. In A. S. Rosebery & B. Warren (Eds.), *Language, culture, and science education: Teaching science to students from diverse linguistic and cultural backgrounds.* Washington, DC: The National Science Foundation.

Hart, O., & Lee, O. (in press). Promoting L2 literacy through inquiry-based science. *Bilingual Research Journal.*

Heath, S. B. (1986). Sociocultural contexts of language development. In California Department of Education (Ed.), *Beyond language: Social and cultural factors in schooling language minority students* (pp.143-186). Los Angeles, CA: Evaluation, Dissemination, and Assessment Center, California State University.

Lee, O. (2002). Science inquiry for elementary students from diverse backgrounds. In W. G. Secada (Ed.), *Review of Research in Education*, (Vol. 26) (pp. 23-69). Washington, DC: American Educational Research Association.

Lee, O., & Fradd, S. H. (1998). Science for all, including students from non-English language backgrounds. *Educational Researcher, 27*(3), 12-21.

Miramontes, O., Nadeau, A., & Commins, N. (1997). *Linguistic diversity and effective school reform: A process for decision making.* New York, NY: Teachers College Press.

Moll, L. (2001). *Funds of knowledge: Bilingualism and cultural as specific assets in schooling.* Presented at the Language Minority Research Institute Conference, University of California, Los Angeles.

Moll, L. C., Saez, R., & Dworin, J. (2001). Exploring Biliteracy: Two student case examples of writing as a social practice. *Elementary School Journal, 100,* 435-450.

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

Peterson, P. L., & Barnes, C. (1996). Learning together: The challenge of mathematics, equity, and leadership. *Phi Delta Kappan, 77,* 485-491.

Scarcella, R. (2003). *Academic English: A Conceptual Framework.* University of California Linguistic Minority Research Institute. Technical Report.

Scribner, S., & Cole, M. (1981). *The psychology of literacy.* Cambridge, MA: Harvard University Press.

Tharp, R., & Gallimore, R. (1988). *Rousing minds to life: Teaching, learning, and schooling in social context.* Cambridge, England: Cambridge University Press.

Trueba, H. T., & Wright, P. G. (1992). On ethnographic studies and multicultural education. In M. Saravia-Shore & S. Arvizu (Eds.), *Cross-cultural literacy: Ethnographies of communication in multiethnic classrooms* (pp. 299-338). New York: Garland.

Valenzuela, A. (1999). *Subtractive schooling: US-Mexican youth and the politics of caring.* SUNY.

Wertsch, J. V. (1991). *Vygotsky and the social formation of the mind.* Cambridge, MA: Harvard University Press.

Westby, C. E. (1995). Cultural and literacy: Frameworks for understanding. *Topics in Language Disorders, 16,* 50-66.

Wong Fillmore, L., & Snow, C. (2000). *What teachers need to know about language.* Washington, DC: ERIC Clearinghouse on Languages and Linguistics.