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Improving Science Inquiry with Elementary Students of Diverse Backgrounds

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Abstract: This study examined the impact of an inquiry-based instructional intervention on (a) children's ability to conduct science inquiry overall and to use specific skills in inquiry, and (b) narrowing the gaps in children's ability among demographic subgroups of students. The intervention consisted of instructional units, teacher workshops, and classroom practices. The study involved 25 third- and fourth-grade students from six elementary schools representing diverse linguistic and cultural groups. Quantitative results demonstrated that the intervention enhanced the inquiry ability of all students regardless of grade, achievement, gender, ethnicity, socioeconomic status (SES), home language, and English proficiency. Particularly, low-achieving, low-SES, and English for Speakers of Other Languages (ESOL) exited students made impressive gains. The study adds to the existing literature on designing learning environments that foster science inquiry of all elementary students. © 2005 Wiley Periodicals, Inc. J Res Sci Teach 42: 337–357, 2005

At the opening of the previous century, theorist Franklin Bobbitt (1926) described the importance of training students not only to reproduce facts but, more importantly, to develop the power to think in relation to the world's activities. Given the technological and mass media culture that has developed since Bobbitt asserted the importance of preparing students to become critical thinkers, his comments are even more relevant today than when he made them almost a century ago. Today's complex society requires members to analyze and respond to issues and a constantly expanding knowledge base. To achieve this goal, classrooms must be transformed from environments that encourage students to go beyond memorizing facts into taking the initiative and responsibility for their own learning (Alberts, 2000; Gibson & Chase, 2002). Inquiry-based

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learning provides students with opportunities to reflect on, question, and analyze the enormous amount of digital, print, and media information that characterizes our complex technological society.

In recent years, science inquiry has been the focus of researchers and K–12 practitioners. According to the *National Science Education Standards* (hereafter referred to as *the Standards*) (National Research Council, 2000), an inquiry-based learning environment encourages opportunities for children to learn science, learn to do science, and learn about science (p. xv). Science inquiry encourages the development of problem solving, communication, and thinking skills as students pose questions about the natural world and then seek evidence to answer their questions. Particularly, efforts have been focused on improving inquiry skills for students from nonmainstream backgrounds who have traditionally been underserved in the education system (Fradd & Lee, 1999; Lee, 2002; Rosebery, Warren, & Conant, 1992; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001). The ability to question, hypothesize, design investigations, and develop conclusions based on evidence gives all students the problem-solving, communication, and thinking skills that they will need to take their place in the 21st century world (National Research Council, 2000).

This study is part of a large-scale instructional intervention aimed at promoting achievement and equity in science and literacy for linguistically and culturally diverse elementary students. A specific focus of the intervention was on science inquiry. The larger research emphasized the integration of inquiry-based science and English language and literacy instruction while considering students' home languages and cultures. Since previous research indicates the cultural values and practices of nonmainstream cultures may be discontinuous with those of Western modern science (for review, see Lee, 2002), this study focused on the impact of the inquiry-based intervention on the ability of nonmainstream students to conduct inquiry. The results indicate the extent to which the inquiry-based intervention achieved its dual goal of promoting students' ability to conduct inquiry while narrowing gaps in the ability among subgroups of students disaggregated according to grade, achievement, gender, ethnicity, socioeconomic status (SES), home language, and English proficiency.

Literature Review

The literature review focuses on two issues related to science inquiry: (a) lack of a commonly accepted definition of science inquiry and (b) instructional interventions to promote science inquiry with elementary students, particularly with linguistically and culturally diverse students.

Definition of Science Inquiry

A critical challenge in the study of science inquiry is the lack of a clear or agreed-upon conception of what science inquiry involves. The *National Science Education Standards* (National Research Council, 1996) provide a definition modeled after the work of scientists:

> Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (p. 23)

Numerous definitions can be found in the education literature. Flick (2002) provided a three-part definition that includes the process of how modern science is conducted, an approach for teaching science, and knowledge about the nature of science. Other definitions encompass processes, such as using investigative skills; actively seeking answers to questions about specific science concepts; and developing students' ability to engage, explore, consolidate, and assess information (Barman, 2002; Lederman, 2002; Yore, 1984). Inquiry is agreed upon as *student centered* or *open* when students generate a question and carry out an investigation, *teacher guided* when the teacher selects the question and both students and teacher decide how to design and carry out an investigation, and *teacher centered* or *explicit* when the teacher selects the question and carries out an investigation through direct instruction or modeling (National Research Council, 2000). Additionally, students engaged in *simple inquiry* engage in processes such as observing, comparing, contrasting, and hypothesizing. Students engaged in *full inquiry* use these skills in the context of well-structured, science-subject-matter knowledge and the ability to reason and apply scientific understanding to a variety of problems (National Research Council, 2000).

Settlage (2003) suggested that the commonly held framework of science inquiry has remained essentially the same from the middle of the previous century until today: Inquiry begins with a question based on observation, which ultimately leads to a conclusion based on evidence. However, Keys and Bryan (2001) challenged the notion that there is a simple, preconceived framework of inquiry waiting to be discovered by students. Based on a constructivist view of inquiry, Keys and Bryan proposed that inquiry is individually constructed by each student based on his or her interaction with the physical world and abstract ideas. Rather than a lock-step trip through the various components of the inquiry process, Keys and Bryan assumed that students construct their own knowledge about science, about how scientists work, and about the inquiry process as they interact with their peers, their teacher, and the classroom context.

The variety of definitions of science inquiry in the research community, coupled with multiple interpretations of inquiry by teachers and students, presents difficulties in conducting research and interpreting results. Thus, comparing results of studies on inquiry-based learning requires explanations of the type of inquiry employed in each study.

Promoting Science Inquiry with Elementary Students from Diverse Backgrounds

A reason frequently cited for the failure of educators to effectively implement inquiry-based instruction is the lack of empirical studies examining how best to teach the process of inquiry (Evans, 2003; Settlage, 2003). Comparisons of the limited studies that have been conducted are confounded by a variety of inquiry teaching variables including (a) course objectives, (b) the length of courses or units, (c) the focus of the activities, (d) type and amount of teacher direction, and (e) assessment choices. Variations due to classroom, teacher, student, and curriculum variables make comparisons of empirical studies a formidable task (Evans, 2003).

Although asking appropriate questions for investigation is a vital step in the inquiry process, locating a starting point for critical thought is often the most difficult step for students (Royce & Holzer, 2003). Success at increasing students' ability to ask questions is made more difficult if students do not already possess personal experience or prior knowledge of the topic to be studied. For these students, the purpose of inquiring may simply be to gather more information; thus, a descriptive rather than an experimental investigation may initially serve their purposes just as well (Keys & Bryan, 2001). Additionally, when a student fails to conduct inquiry in the way the teacher or the researcher anticipates, it may be that they do not have the same idea or purpose of inquiry.

Admittedly, there are challenges in defining science inquiry, determining how students construct an understanding of science, and developing effective instructional approaches to enhance the inquiry ability; however, an emerging knowledge base indicates how to design learning environments which foster science inquiry. In an attempt to inform the debate on the ability of elementary students to conduct inquiry according to the tradition of Piaget's stage theory (see the exchange between Kuhn, 1997, and Metz, 1995, 1997), this new body of research builds on the concept of learning environments as essential ‘‘engines’’ and teachers as using ‘‘design tools’’ to foster inquiry. While the focus of the debate is on fostering children’s ability to conduct inquiry, the design researchers and the research programs lack a consensus definition of what constitutes science inquiry and how to design learning environments. Several models of this research illustrate the continued dilemma in the search for a common understanding of inquiry and the best methods with which to develop this ability in elementary-age children.

For example, Brown and Campione (Brown, 1992, 1994; Brown & Campione, 1996) focused on activity structures in a collaborative learning community. They emphasized socially distributed expertise among groups and individuals using a variety of design features, including reciprocal teaching groups, the jigsaw method, and individual children ‘‘majoring’’ in particular areas of their choice and serving as experts. Metz (2000) thought of science as method or research designs. She proposed the spheres of knowledge most fundamental to inquiry as (a) domain-specific knowledge; (b) knowledge of the enterprise of empirical inquiry including theory–evidence differentiation, controlled experiments, and scientific argumentation; (c) domain-specific methodologies or problem-solving strategies; (d) data representation and analysis; and (e) relevant tools. In yet another focus, Lehrer and Schauble (2000) conceived of science as a modeling enterprise that is grounded on an epistemological understanding of science. Children behave as scientists, constructing and revising models of natural phenomena through which they can develop model-based reasoning using experimentation (Lehrer, Schauble, & Petrosino, 2001) or design (Lehrer & Schauble, 1998).

In recent years, research has focused on understanding and promoting science inquiry with students from diverse languages and cultures. This research points to the need for teachers to incorporate linguistic and cultural funds of knowledge that students of diverse backgrounds bring to the classroom (Moll, 1992) and the extent to which students’ everyday knowledge and language intersect with scientific practices; however, researchers and research programs have differing views of the manner in which these two areas intersect and their implications for instructional approaches (for review, see Lee, 2002). For example, using science standards documents (National Research Council, 1996, 2000) as the guidelines for science inquiry, Fradd & Lee (1999; (Lee, 2002, 2003) examined students’ cultural values and practices relative to those of Western modern science. Their research indicates areas where these two sets of values and practices are discontinuous as well as continuous. The areas of discontinuity necessitate transitions, or border crossings, between the students’ home culture and the culture of science. As students attempt these transitions, teachers initially provide extensive guidance. As students learn to take initiative and conduct inquiry on their own, teachers gradually withdraw assistance.

Going beyond the view of science as presented in the standards documents (National Research Council, 1996, 2000), Rosebery et al. (1992) and Warren et al. (2001) used the model of everyday practices of scientists in their attempts to promote children’s sense making in science. This research emphasizes that everyday experiences and ways of knowing and talking with students, including students from nonmainstream backgrounds, are continuous with those of science. Therefore, teachers provide opportunities for students to explore their ideas and investigate questions following the model of science as practiced in the scientific community. Additionally, teachers identify intersections between the students’ everyday knowledge and scientific practices, and use these intersections as the basis for instructional practices.

Purpose and Research Questions

The existing literature points to an array of issues related to science inquiry, including the difficulty in arriving at an agreed-upon definition, the question of elementary students’ ability to conduct science inquiry, and how to design instructional approaches appropriate for elementary students. These issues become more complex when students from diverse languages and cultures are involved. Extending the debate in the literature, this study proposes a conception of science inquiry and an instructional intervention to promote such inquiry with elementary students from diverse languages and cultures (described later). Within this conceptualization and implementation of the instructional intervention, this study examined how elementary students from diverse languages and cultures designed an inquiry process to answer a predetermined question. The inquiry task took place in elicitation settings conducted with individual students. The study examined two research questions:

1. What is the impact of the instructional intervention on students' ability to conduct science inquiry overall and to use inquiry skills of questioning, planning, implementing, concluding, and reporting?
2. What is the impact of the instructional intervention on narrowing gaps in the ability to conduct inquiry among demographic subgroups of students with respect to grade, achievement, gender, ethnicity, SES, home language, and English proficiency?

Instructional Intervention: Conceptualization and Implementation

The larger research included three intervention domains: (a) inquiry-based science instruction, (b) integration of English language and literacy as a part of science instruction, and (c) incorporation of students' home language and culture in science instruction (for details, see Lee, 2002, 2003, 2004; Lee & Fradd, 1998). This study focuses specifically on science inquiry with third- and fourth-grade students from linguistically and culturally diverse backgrounds. The conceptual framework for this study is described in terms of inquiry-based teaching and learning emphasized in the instructional units, teacher workshops, and classroom practices (for details, see Fradd, Lee, Sutman, & Saxton, 2002; Lee, Hart, Cuevas, & Enders, 2004).

Instructional Units

The intervention focuses on two units each for Grades 3 (Measurement and Matter) and 4 (The Water Cycle and Weather). These topics follow the sequence of instruction from basic skills and concepts (measurement, matter) to variable global systems (the water cycle, weather). Except for the Water Cycle unit (which is shorter than the others), each unit is designed for 2 to 3 months of implementation, assuming 2 hr of instruction per week. The units were developed by science educators, scientists, and consultants representing the students' languages and cultures in collaboration with the teachers who reviewed and refined these units through their classroom implementation.

Based on the definition of science inquiry in the standards documents (National Research Council, 1996, 2000), science inquiry occurs when students generate questions, plan procedures, design and carry out investigations, analyze data, draw conclusions, and report findings. Inquiry is not a linear or discrete process; rather, aspects of inquiry interact in complex ways.

The development of the instructional units was guided by two conceptual notions to promote science inquiry (Fradd & Lee, 1999; Fradd et al., 2002; Lee, 2002, 2003). The first involves *the inquiry framework* (see Figure 1). *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'" (National Research Council, 1996, p. 144). Although some advocates of more open-ended, student-centered inquiry would argue against a framework for organizing and

Inquiry Framework	
1. Questioning	**State the problem** • What do I want to find out? (written in the form of a question) **Make a hypothesis** • What do I think will happen?
2. Planning	**Make a plan by asking these questions (think, talk, write)** a. What **materials** will I need? b. What **procedures** or steps will I take to collect information? c. How will I observe and record **results**?
3. Implementing	**Gather the materials** • What materials do I need to implement my plan? **Follow the procedures** • What steps do I need to take to implement my plan? **Observe and record the results** • What happens after I implement my plan? • What do I observe? • How do I display my results? (using a graph, chart, table)
4. Concluding	**Draw a conclusion** • What did I find out? • Was my hypothesis supported by evidence?
5. Reporting	**Share my results (informal)** • What do I want to tell others about the activity? **Produce a report (formal)** • Record what I did so others can learn. • Consider different ways to express my information.

Figure 1. Inquiry framework.

planning inquiry (e.g., see the discussion earlier about Brown, Metz, Lehrer & Schauble, Rosebery & Warren), we found it an important initial step for teachers and students. The purpose of the inquiry framework was to make the inquiry process explicit for students from backgrounds where science inquiry may not be encouraged or for those with limited experience of school science. While making the inquiry process explicit, the framework also allows openness to foster student initiative and responsibility among students for their own learning. It is noted that the icons in the framework serve as points of reference for assisting students in thinking about and organizing their own inquiry. The icons also encourage the use of graphic representations in communicating science, especially for English language learners (ELLs) and students with limited literacy development.

The inquiry framework, however, presents limitations. It defines science inquiry primarily as hypothesis-driven investigations, but it is not comprehensive of other forms of inquiry used in the scientific community. Additionally, although it incorporates linguistic and cultural experiences of nonmainstream students into science and brings them to the norms and practices of science, it does not bring science to the experiences of nonmainstream students in a way to help them critically analyze scientific practices and the role in social, political, and economic power dynamics (Calabrese Barton, 1998a, 1998b).

Second, the units were developed to promote student initiative and responsibility in conducting inquiry, as teachers gradually reduce their level of guidance. According to *the Standards* (National Research Council, 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 units are designed to move progressively along the *teacher-explicit to student-initiated continuum* to promote science inquiry. Student initiative and exploration is encouraged by providing more structure to earlier lessons within each unit while later lessons are more open-ended. The level of complexity of science concepts and the degree of inquiry required from students also increase as students move through the units.

Within the context of science inquiry, science booklets for students emphasize key science concepts and ideas. Following inquiry activities, each lesson provides science background information that explains the question under investigation and related natural phenomena. The units also highlight common misconceptions and potential learning difficulties. Accompanying teachers’ guides provide content-specific teaching strategies for each lesson. They offer suggestions on how teachers may provide different levels of guidance and scaffolding depending on students’ prior experience with different science topics and the demands of specific academic tasks. Teachers’ guides also provide extensive science-background information and detailed explanations for the questions posed in the student booklets, with particular emphasis on students’ common misconceptions and learning difficulties.

Teacher Workshops

Over the course of the year, teachers attended four full-day workshops on regular school days. The workshops were designed and conducted by project personnel with expertise in science, literacy, English for Speakers of Other Languages (ESOL), and linguistic and cultural issues in education. Teachers were actively involved as they shared questions, suggestions, and examples of their own practices and beliefs. Teachers also shared their thoughts about similarities and differences in teaching and learning environments among the schools. Several teachers who had participated in our previous research (and who continued to participate in the current research) demonstrated how to implement the instructional units.

The first workshop focused on inquiry-based science instruction (for additional information, see Lee et al., 2004). The workshop was organized around the two conceptual notions for inquiry-based intervention (discussed earlier). In the beginning of the workshop, project personnel and teachers as a whole group discussed what science inquiry involves (National Research Council, 1996, 2000) and the various components of the inquiry framework (see Figure 1).

Considering that the teachers worked with students from diverse languages, cultures, and SES backgrounds, no single approach to inquiry would apply to this wide range of classroom settings. The *inquiry matrix* served as the guide to implement science inquiry along the teacher-explicit to student-initiated continuum (see Figure 2). Grounded in the inquiry framework, this matrix focuses on inquiry in five areas: questioning, planning, implementing, concluding, and reporting (horizontal). Science inquiry occurs at multiple levels (vertical), ranging from where a teacher guides the students through the entire process (top row) to where students conduct inquiry on their own (bottom row). Inquiry is not an ‘‘all or none’’ pedagogy, but requires levels of guidance along the teacher-explicit to student-initiated inquiry continuum.

Project personnel and teachers discussed the notion of the teacher-explicit to student-initiated continuum in providing instructional scaffolding to promote science inquiry for students from backgrounds where questioning and inquiry may not be encouraged or for those with limited science experience. The aim is to encourage students to question and explore in science class without devaluing the norms and practices of their home communities. Effective inquiry instruction requires a balance of teacher guidance and student initiative, as teachers make the

Inquiry	Questioning	Planning	Implementing	Concluding	Reporting
0	*Teacher*	*Teacher*	*Teacher*	*Teacher*	*Teacher*
1					
2					
3					
4					
5	*Students*	*Students*	*Students*	*Students*	*Students*

Figure 2. Inquiry matrix: Teacher-explicit to student-initiated inquiry continuum.

decisions about when and how to foster student responsibility depending on students' prior experience with inquiry and the difficulty of inquiry tasks. Through gradual progression along the continuum, teachers move away from teacher-explicit instruction and encourage students to take the initiative and assume responsibility for their own learning. The inquiry matrix provides a graphic representation of how teachers can make instructional decisions most appropriate for their students, inquiry tasks, and other factors in given circumstances.

Teachers worked on the unit lessons in small groups where the focus of discussion was on implementing more inquiry-based, open-ended, and student-centered activities. Then, each group demonstrated a lesson and shared ideas with the larger group. Several teachers who had previously taught the unit lessons made suggestions for implementation of particular lessons and activities, highlighted key science concepts and knowledge, and identified students' common misconceptions and learning difficulties.

Project personnel guided the teachers in structuring science lessons around inquiry activities. Given a "practice" science-inquiry task, small groups of teachers came up with a variety of experimental designs, different procedures for gathering data, multiple ways of displaying the data, and conclusions based on hypothetical evidence. Each group presented their work to the larger group and discussed a variety of approaches to promote inquiry.

The second workshop focused on how to incorporate English language and literacy in science instruction (for details, see Hart & Lee, 2003). The third workshop investigated how to incorporate students' home languages and cultures in science instruction (Lee, Luykx, Buxton, & Shaver, under review). The final workshop centered on teachers' feedback about the intervention. At these workshops, science inquiry was a major theme throughout the activities and the discussion.

Classroom Instruction

The third-grade students participated in the research for the first time during the 2001–2002 school year. Except for those students who transferred, the fourth-grade students continued their participation for the second year. While they were in third grade during the previous year, most completed the Measurement unit; however, due to the late start of the research, they did not study the Matter unit that emphasized the inquiry framework. Instruction took place about 2 hr per week. All teachers were provided with complete sets of materials, including teachers' guides, student booklets, science supplies, and trade books related to the science topics in the units. Most teachers completed instruction of their respective units by the end of the school year.

Method

Research Context

The study was conducted in a large, urban school district in the southeastern United States with a high proportion of students from diverse languages and cultures. During the 2001–2002 school year, the ethnic makeup of the student population in the school district was 57% Hispanic, 30% Black (including 7.4% Haitian according to the district data on students' home language), 11% White Non-Hispanic, and 2% Asian and Native American. Note that the school district groups Haitian and other Caribbean students together with African American students under the single category of "Black." The information given here about African American and Haitian students refers to those participating in the study and was gleaned from the student rosters provided by the teachers. Within the school district, 70% of the elementary students participated in free or reduced lunch programs, and 25% were designated as limited English proficient (LEP). "LEP" is the term used by the state to designate ELLs who are in ESOL programs. These terms are used interchangeably in this article.

The six elementary schools participating in this research mirrored the demographics of the school district with respect to students' ethnic and linguistic backgrounds, SES, and English proficiency, among other factors. Demographic information is presented in Table 1.

Participants

This study involved students from each of the seven teachers who were selected for their effectiveness in teaching science and literacy while considering their students' linguistic and cultural experiences. During the previous year (2000–2001), all participating teachers were observed. Based on the criteria of effective science instruction for diverse student groups in the research, seven teachers who demonstrated effectiveness and commitment in the classroom and

Table 1
School demographics

School	% Ethnicity	% LEP	% Low SES
A	41 Haitian 28 African American 25 Hispanic	46	95
B	37 Haitian 53 African American	26	99
C	92 Hispanic	47	85
D	87 Hispanic	19	44
E	55% White 25% Hispanic 16% African American	10	19
F	32% White 33% Hispanic 34% Black	1	16

LEP = language/English proficiency, SES = socioeconomic status.

leadership at the grade and school level were selected. These teachers represented both third and fourth grades from all six participating schools. All were female. Their teaching experience ranged from 7 to 34 years. Of the four teachers who were bilingual Spanish speakers, three taught at two schools with predominantly Hispanic student populations, and one taught at a school with monolingual English-speaking students of Anglo, African American, or Hispanic descent. Of the three remaining teachers who were Anglo, two taught at two schools with predominantly Haitian and African American student populations, and one taught at a school with monolingual English-speaking students of Anglo, African American, or Hispanic descent.

Four students from each of the seven classrooms, for a total of 28 students, were selected by their teachers to represent different achievement levels (high and low) and gender groups. Teachers selected a boy and a girl considered high achievers based on their overall assessments of students' academic performance in the context of classroom lessons and assignments. A low-achieving boy and girl were selected in the same manner. Since the students came from all six schools, they also represented different ethnicities, SES levels, home languages, and English proficiencies. The number of students for each of the demographic subgroups is presented in Table 2.

Instrument

An elicitation protocol was developed asking students to design an investigation in solving a problem regarding the effect of surface areas on the rate of evaporation (see Appendix A). The problem involved a story about a child named Marie who was trying to determine if the size of the opening of a container would affect how quickly water evaporated from the container. This problem is an extension of an inquiry task about the effect of heating on the rate of evaporation in the Matter unit (the second unit at the third-grade level).

After presenting the problem, the protocol guided elicitors to ask students a series of questions reflecting the skills in the inquiry framework (see Figure 1). Students were asked to formulate a

Table 2
Gaps among demographic subgroups

Subgroups (*n*)		Pre		Post		Gain
		M	*SD*	*M*	*SD*	
Grade	Third (10)	7.70	3.47	11.90	1.19	4.20
	Fourth (15)	8.27	2.22	12.33	1.11	4.06
Achievement	High (11)	10.09	1.58	12.82	.75	2.73
	Low (14)	6.43	2.34	11.64	1.15	5.21
Gender	Male (12)	7.92	3.03	12.50	1.31	4.58
	Female (13)	8.15	2.54	11.85	.90	3.70
Ethnicity[a]	African American (5)	7.20	3.27	12.20	.84	5.00
	Hispanic (16)	8.25	2.70	12.19	1.22	3.94
SES	Middle (8)	9.75	1.83	12.38	.92	2.63
	Low (17)	7.24	2.75	12.06	1.25	4.82
Home Language[b]	English (8)	7.75	2.82	12.00	.93	4.25
	Spanish (12)	7.58	2.68	12.17	1.34	4.59
English Proficiency	ESOL exited (13)	7.38	2.60	12.15	1.41	4.77
	Non-ESOL (12)	8.75	2.80	12.17	.84	3.42

[a]This category also includes Anglo (1) and Haitian (3) students, [b]This category also includes Haitian Creole speaking (3) and English-Spanish-speaking (2) students.

question statement to reflect the problem that Marie was trying to solve, formulate a hypothesis, design an investigation, make a list of the materials she would need to carry out the investigation, describe how she would record results, and explain how she would draw a conclusion. Finally, the protocol asked students if they saw any relationship between the problem in the story and what is happening with the water in oceans, lakes, and rivers. The protocol provided probes for each of these questions.

Data Collection and Analysis

Elicitation sessions were conducted individually with the same third- and fourth-grade students at the start and the end of the school year. The elicitations were performed by five research-team members who worked with each of the seven teachers. All five elicitors were Anglo, with two being fluent in English and Spanish and two having a working knowledge of Spanish. Each elicitation took about 20 to 40 min. All sessions were audiotaped, videotaped, and transcribed.

Student responses during elicitation sessions were coded using scoring rubrics (see Appendix B) that were designed on the basis of student responses in our previous research (Fradd et al., 2002). Overall, the four-level scoring rubrics assessed the conceptual accuracy and completeness of responses, with a score of 0 used to indicate irrelevant or no response. The total score for each elicitation was obtained by summing the number of points obtained on each item, for the maximum score of 16 points. One rater, who had extensive knowledge and experience of coding student responses on various assessments throughout her participation in the research for several years, completed all the coding.

Three of the 28 students in the sample missed either pre- or post-elicitation and thus were not included in the analysis. To determine the impact of the instructional intervention on students' ability to conduct inquiry and use the specific skills of the inquiry framework, paired samples *t* tests were conducted with the responses of the 25 students who completed both pre- and post-elicitations. Paired samples *t* tests were used as an analysis tool for a repeated measures design with the intervention. Given the multiple *t*-test measures, family-wise error value to evaluate the results of statistical analysis was considered. The significance level was set at $\alpha < .01$ using a Bonferroni correction to approximate $\alpha < .05$ level (i.e., .05 divided by eight significance tests) and a critical value of $t(24) = 2.80$. As a measure of effect size, Cohen's *d* was computed. A small sample size did not allow tests of statistical significance for comparisons among demographic subgroups. Instead, gain scores between the pre- and post-elicitations for the subgroups were obtained to examine the impact of the intervention on narrowing or widening the gaps among the demographic subgroups.

Results

Ability to Conduct Science Inquiry

Significance tests of mean scores between the pre- and post-elicitations indicate statistically significant increases in students' ability to conduct inquiry in general and to employ each of the specific skills of the inquiry framework. The results are presented in Table 3.

The sample, as a whole, experienced statistically significant positive change in inquiry ability, $t(24) = 9.19, p < .000$. This change represents a large effect size using Cohen's *d*. The mean scores for the entire sample ($n = 25$) increased from 8.04 ($SD = 2.73$) during the preintervention elicitations to 12.16 ($SD = 1.14$) during the postintervention elicitations.

Table 3
Ability to conduct science inquiry (n = 25)

Skills in Inquiry Framework		Maximum Points	Pre *M*	Pre *SD*	Post *M*	Post *SD*	*t*	*p*	Cohen's *d* (effect size)	d^a (magnitude)
Questioning	Problem statement	2	1.40	.65	1.72	.46	2.55	.018	.49	small
	Hypothesis	2	2.00	.00	2.00	.00				
Implementation	Procedures	3	1.36	.76	2.72	.46	8.39	.000*	1.79	large
	Materials	2	1.16	.69	1.64	.57	2.75	.011	.70	medium
	Recording	3	.72	.68	1.28	.54	3.41	.002*	.82	large
Concluding		2	.74	.86	2.00	.00	6.70	.000*	1.47	large
Applying		2	.80	.41	.84	.37	.37	.714	.10	small
Overall		16	8.04	2.73	12.16	1.14	9.19	.000*	1.51	large

*All t values greater than 2.80 were deemed significant at $\alpha < .01$ to consider family-wise error value for multiple t-test measures.
[a] $d > .20$ is "small" effect size; $d > .50$ is "medium," and $d > .80$ is "large."

Students' ability to formulate a problem statement did not improve significantly, $t(24) = 2.55$, $p < .018$. The increase of the pre-elicitation mean of 1.40 ($SD = .65$) to the post-elicitation mean of 1.72 ($SD = .46$) represents a small effect size (Cohen's *d* magnitude). For example, during the pre-elicitation session, a student (African American, male, high achieving) stated the problem as: "If the water is going to dry out. She won't want the water to dry out because she knows fishes need to be in water." In the post-elicitation session, this student believed the problem was: "Which one will evaporate faster, the one that has the big opening or the small?"

Even after probing, some students still could not state the problem in the story, particularly during pre-elicitations. Because students had to understand the question to continue with the inquiry task, the elicitors helped them pose a question or, in some cases, provided them with the question. Once all students understood the question by themselves or with the elicitors' help, all could formulate a hypothesis relevant to the question. Thus, all students received a perfect score of 2 during both pre- and post-elicitations.

Students' ability to develop procedures for solving the problem improved significantly, $t(24) = 8.39$, $p < .000$. The post-elicitation mean of 2.72 ($SD = .46$) represents a large effect when compared with the pre-elicitation mean of 1.36 ($SD = .76$). For example, the pre-elicitation response of a student (African American, female, low achieving) demonstrates almost no understanding of how to find out which container would hold water longer. When asked "Do you think you could set up an experiment to get the answer? What would you do?" by the elicitor, the student's response was simply: "Put water in each one and see if it would dry up." The post-elicitation response reveals consideration of the need to control variables that could confound the results as well as an understanding of exactly what information the experiment should provide. The student said: "She could put water in here and put water in here before she go, set it outside, and see which one evaporated faster." Then, the student poured the same amount of water in the two containers. In response to the elicitor's query "Why are you putting the same amount in both containers?" the student responded: "Because if it is not the same amount, then they aren't gonna know, if it's not the same amount, one of them would evaporate faster than the other." Several moments later in the exchange, the elicitor asked "Would you put both containers in the same place?" The student responded "Um, because if I don't put it in the same place, then we are not gonna prove. I'm gonna sit one right here and the other one we might not see. One might evaporate faster in one place and one might evaporate slower in another place." Her response indicates a consideration of control of confounding variables (i.e., the same amount of water and the same place for the two containers), step-by-step planning, and an understanding of how her plan would result in an answer to the problem.

After developing procedures, students were asked to make a list of materials needed to carry out their investigation. Containers, water, and measuring cups were placed on a table in front of the students at both pre- and post-elicitation sessions. Although students' ability to describe how they would use those materials to conduct their investigation was not statistically significant, $t(24) = 2.75, p < .011$, the p value is extremely close to .01 and is clearly approaching significance. The increase from the pre-elicitation mean of 1.16 ($SD = .69$) to the post-elicitation mean of 1.64 ($SD = .57$) represents a medium effect size. For example, in the pre-elicitation session, a student (Haitian, male, high achieving) provided an explanation lacking in detail when asked to describe the materials he would need for his investigation and how he would use them. "I need the water, so I could see how much water would be left, if it is the same amount of size. . . and I need different sizes, so I could, so I could, to see the water evaporate, to see how much, how much more does this have than that." By the post-elicitation session, the student described in detail the materials he would need and how he would use them, "Water, a tank with a graduate, so I can measure the water in it, a graduated cylinder or a measuring cup . . . pour the water into the containers so they have the same amount of water in them and put them in the same place." This response also indicates control of confounding variables, i.e., amount of water and place for the containers.

After listing materials and procedures, students were asked how they would record the results of their investigation. The statistically significant result for students' ability to adequately describe how they would record the results increased from the mean of .72 ($SD = .68$) in the pre-elicitations to 1.28 ($SD = .54$) in the post-elicitations, $t(24) = 3.41, p < .002$. This increase represents a large effect size. For example, the responses of a student (African American, male, low achieving) represent this positive change. At the start of the intervention, the elicitor asked the student: "What kind of things do you think you would want to write down?" The student gave a convoluted and uncertain response:

> How high like. . .how low the water was in, how much water, and how little this one was. . .because if like, if somebody were to ask you, did you do it, you could show them. And if you didn't write it down, they might think you didn't do it and you'd have to do it all over.

By the post-elicitation, the focus of the response had changed from proving he had actually done the investigation to recording results to show continuity in the investigation:

> I would record the information that it was on the 400 ml and then how low it got or how high it got. . .the number it started with and the number it ended with. . .because if you got like, if you don't put them down, you won't know which one did you start with. You might forget which one you start with, and then when you come back, you don't know which one you ended with.

The positive increase in students' ability to formulate a conclusion, from the pre-elicitation mean of .74 ($SD = .86$) to the post-elicitation mean of 2.00 ($SD = .00$), was statistically significant, $t(24) = 6.99$, $p < .000$. This increase represents a large effect size. The responses of a student (African American, male, low achieving) represent this significant increase in his ability to answer the problem based on the results of the investigation. In the pre-elicitation session, the student replied "I don't know" in response to the question "What information would you look at to see which is the best container for the fish?" The post-elicitation response was concise and to the point: "Because the one that didn't evaporate faster, that's the one I would pick."

Finally, students were asked to apply the investigation examining the concept of the effect of surface area on the rate of evaporation to the evaporation that is occurring from the oceans, rivers, and lakes. There was a negligible (.04 point) increase in students' ability to apply the results of their investigation in the pre-elicitation sessions (*M* = .80, *SD* = .41) and the post-elicitation sessions (*M* = .84, *SD* = .37). Although this did not represent a statistically significant difference in terms of students' understanding of the effect of surface area on the rate of evaporation, most students provided more comprehensive and accurate explanations about evaporation or the water cycle. For example, one student's (Haitian, female, high achieving) explanation moved froma very general response, ''They are the same because the water in the oceans dries when the sun comes out and the water in the container does too,'' to a more specific response, ''It [the water] evaporates and it goes up into the sky, condenses and forms a cloud and water droplets, and it goes back into the ocean. In the container you can control it but in nature you can't.'' The student gave a more complete explanation of the water cycle, expressed her ideas using appropriate science vocabulary (e.g., *evaporates* rather than *dries up*, *condenses*), and described the difference between a controlled experiment and a naturally occurring phenomenon.

Gaps among Demographic Subgroups

The study examined the impact of the inquiry-based intervention on narrowing the gaps in students' ability in conducting inquiry among demographic subgroups in terms of grade, achievement, gender, ethnicity, SES, home language, and English proficiency. Because of a small sample size, tests of statistical significance were not conducted. The results of means, *SD*s, and gain scores for the subgroups are presented in Table 2. The fourth-grade students' ability to conduct inquiry started (*M* = 8.27, *SD* = 3.47) slightly higher than that of the third graders (*M* = 7.70, *SD* = 2.22). Similarly, the fourth graders (*M* = 12.33, *SD* = 1.11) ended slightly higher than the third graders (*M* = 11.90, *SD* = 1.19). Gains for the two grade levels were comparable, with 4.20 for the third graders and 4.06 for the fourth graders.

Gains for the low-achieving students were dramatic. In pre-elicitation sessions, they started well below the high achievers, with a mean of 6.43 (*SD* = 2.34) for the low-achieving group compared to 10.09 (*SD* = 1.58) for the high-achieving group. The post-elicitation mean for low achievers increased to 11.64 (*SD* = 1.51) compared to 12.82 (*SD* = .75) for the high-achieving group. This represents an increase of 5.21 points for the low-achieving students compared to 2.73 points for the high-achieving students.

At the start of participation in inquiry-based instruction, the ability of male and female students to conduct inquiry was almost on par. The mean for females in the pre-elicitations was 8.15 (*SD* = 2.54) compared to 7.92 (*SD* = 3.03) for the males. After participation in inquiry-based instruction, the resulting mean for females was 11.85 (*SD* = .899), an increase of 3.70 points. The post-elicitation mean for males increased to 12.50 (*SD* = 1.31), an increase of 4.58 points.

Both African American and Hispanic students increased significantly in their ability to conduct inquiry. Although the African American students' mean of 7.20 (*SD* = 3.27) was below that of Hispanic students (*M* = 8.25, *SD* = 2.70) on pre-elicitation responses, the mean of African American students' post-elicitation responses (*M* = 12.20, *SD* = .84) was comparable to that of Hispanic students (*M* = 12.19, *SD* = 1.22). This represents an increase of 5.0 points for African American students compared to 3.94 points for Hispanic students. Due to the small number of students in the Haitian (3) and Anglo (1) groups, the results are not reported.

Like the impressive gains made by low-achieving students, the gains made by low-SES students were noteworthy. Although the mean for middle-SES students was 9.75 (*SD* = 1.83) compared to low-SES students' mean of 7.24 (*SD* = 2.75) on the pre-elicitations, the post-elicitation means were almost equal, 12.38 (*SD* = .916) for middle-SES students and 12.06 (*SD* = 1.25) for low-SES students. The increase was 4.82 points for low-SES students compared to 2.63 points for middle-SES students.

Both native English-speaking and native Spanish-speaking students increased significantly in their ability to conduct inquiry. Both groups performed comparably on the pre-elicitations, with a mean of 7.75 (*SD* = 2.82) points for the English-speaking students and a mean of 7.58 (*SD* = 2.68) points for the Spanish-speaking students. During post-elicitation sessions, both groups again performed comparably, with a mean of 12.00 (*SD* = .93) points for the English-speaking students and a mean of 12.17 (*SD* = 1.34) points for the Spanish-speaking students. Thus, both groups showed comparable gains, with 4.25 points for English-speaking students and 4.59 points for Spanish-speaking students. Due to the small number of students in the Haitian Creole (3) and English/Spanish (2) groups, the results are not reported.

The study involved 13 students who had exited from ESOL programs and 12 students who had never participated in ESOL programs. Non-ESOL students (*M* = 8.75, *SD* = 2.80) began the year with a greater ability to conduct inquiry than ESOL exited students (*M* = 7.38, *SD* = 2.60); however, on the post-elicitations, both groups performed comparably, with a mean of 12.17 (*SD* = .84) points for non-ESOL students and a mean of 12.15 (*SD* = 1.41) points for ESOL exited students. Thus, the gain of 4.77 points made by ESOL exited students was greater than the gain of 3.42 points made by non-ESOL students.

Discussion

There have been concerted efforts in the science education community to provide opportunities for students, particularly those from diverse languages and cultures, to conduct inquiry (Fradd & Lee, 1999, Lee, 2002; Rosebery et al., 1992; Warren et al., 2001). This study contributes to the knowledge base by examining the impact of an inquiry-based intervention on the ability to conduct inquiry by third and fourth graders from diverse backgrounds over the course of a school year.

The results of this study demonstrate that inquiry-based instruction effectively promoted these increases. For the students in the study as a whole, their ability to ask appropriate questions as a starting point for science inquiry increased after the intervention (Royce & Holzer, 2003). Additionally, they were better able to plan procedures for investigation, record results, and draw conclusions. The largest gains were observed for the skills of planning and drawing a conclusion (see Table 3).

The intervention had a positive impact on students' inquiry ability regardless of their grade, achievement, gender, SES, ethnicity, home language, or English proficiency. Comparisons among demographic subgroups indicate that the low achievers and the low-SES students made impressive gains from the pre- to post-elicitations compared to their high-achieving and middle-SES counterparts. Students who had exited from ESOL programs also showed a greater gain than non-ESOL students. There were no noticeable differences in mean scores on the pre- and post-elicitations as well as gain scores between male and female students, indicating that both groups equally benefited from the intervention. The comparable performance between the third and fourth graders both in the beginning and at the end of the intervention is noteworthy. The fourth-grade students had partially participated in the research as third graders during the previous year; however, due to the late start of the research, they had received little exposure to science inquiry within the scope of the intervention. Additionally, the results suggest that they had received little exposure outside the scope of the intervention during the previous year. As a result, the inquiry-based intervention had a similar impact on both the third- and fourth-grade students.

The small numbers of students by ethnicity and home language did not allow systemic examination of group comparisons.

In this study, the intervention was comprised of instructional units, teacher workshops, and classroom instruction. The intervention was guided by two conceptual notions, including the inquiry framework (see Figure 1) and the teacher-explicit to student-initiated inquiry continuum (see Figure 2). This instructional approach benefited all students to improve their inquiry ability, particularly those from low achievement, low SES, and limited English proficiency. The results suggest that such students who often have limited experience with school science may need to become aware of what science inquiry involves. The inquiry framework represents the inquiry process explicitly for them. Additionally, along the teacher-explicit to student-initiated continuum, the students initially require extensive teacher guidance and gradually develop the ability to conduct inquiry on their own. The emerging literature in science education indicates that elementary students, especially those from nonmainstream backgrounds or those with limited science experience, require teacher's explicit instruction and scaffolding to engage in the sense-making process and to gradually develop student-centered inquiry ability (Hogan, Natasi, & Pressley, 2000; Valeras, Becker, Luster, & Wenzel, 2002). More broadly, explicit instruction of both academic content and processes in the context of authentic and meaningful tasks and activities has been advocated with nonmainstream students across subject areas (for review, see Lee, 2002).

There are limitations to this study. One is the lack of a control or comparison group. Another limitation is the small sample size of 25 students who completed both pre- and post-elicitations. The even smaller demographic subgroup sizes rendered statistical analyses of group comparisons unwise. Still another limitation is that analysis of oral performance on inquiry tasks may or may not compare with written performance. While oral performance would be a good measure to explore students' reasoning while engaging in science inquiry, the reality of school science may necessitate their written performance despite the fact that written performance would substantially underestimate the inquiry ability of ELLs and students with limited literacy development. Finally, although teachers participated in professional development with equal opportunities (e.g., the same instructional units, the same sets of supplies and materials, the same teacher workshops), it is conceivable that there were substantial differences in the manner in which individual teachers implemented the intervention.

Further research may remedy the limitations of this study by employing a control or comparison group and by including a large sample size that allows comparisons of demographic subgroups. Further research also may examine some domains of inquiry in which students make large gains and other domains in which students experience difficulties even after the intervention. Additionally, further research may examine the relationships among instructional practices, students' engagement in science inquiry in the context of instruction, and students' ability to conduct inquiry in the context of elicitations. The results of such research will further increase our understanding of the manner in which students carry out science inquiry and the approaches to design effective instructional intervention to enhance their ability to conduct inquiry. Finally, further research may examine the long-term impact of the intervention over the years.

Beyond the scope of the intervention in this study, considerations may be given to other forms of science inquiry used in the scientific community as well as hypothesis-driven investigation (the focus of the intervention). Additionally, considerations may be given to how to bring science to the experiences of nonmainstream students as well as how to bring these students to the norms and practices of science (the focus of the intervention).

This study, as well as areas of future research described earlier, may result in valuable information about how to design learning environments that foster science inquiry of all elementary students, including those from diverse languages and cultures. It is our hope that as these students acquire the tools and the habits of inquiry, they will recognize that they are prepared to meet the challenges of the 21st century.

Notes

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Appendix A

Science Inquiry: Student Investigation of Evaporation

Opening: Explain to the student that he/she is not expected to know all about the activities he/she is about to do. The purpose of talking with students is to find out what they know. They should understand that what they tell us will be helpful in planning the science lessons for their class.

Tell the student, ‘‘We are going to do a science activity today. I am going to ask you some questions. I would not expect you to know all of them. I want you to tell us as much as possible about these activities. You can ask questions about what we are doing.’’

Present a copy of the inquiry reading passage and materials to the student.

Reading passage: Marie is a girl who has a pet fish. She knows that fish need to live in water, and she also knows that water left in an open container will dry up, or evaporate. Marie has to go away for a few days and leave her fish at home. She wants to make sure that all her fish’s water will not evaporate while she is gone. She has two containers that hold the same amount of water but have openings of different sizes. She wonders whether the size of the opening would affect the evaporation of the water in the containers. She wants to find this out, so she can decide which container would be best for her fish while she is gone.

1. Pose a question—What does Marie want to find out?

Note. To continue with the inquiry task, students need to understand the question. Therefore, if a student does not ask an appropriate question, help the student pose a question:

a. ‘‘How does the size of the opening of the container affect evaporation?’’ or
b. ‘‘In which container will the water dry up more slowly?’’

2. Make a hypothesis—What do you think the answer to the question might be?
    - PROBE: Why do you think this is the answer?
3. How could Marie find out? How could she set up an experiment to get the answer?
    - PROBE: Explain why each step is important in answering your question.

Note 1. Explain to the child that we won’t have time to do the whole experiment, but ask him/her to show how it could be set up.

Note 2. ‘‘The same amount of water’’ in the two containers is different from ‘‘the same height (level) of water’’ in the two containers. See if the student’s description of his/her action matches what he/she is actually doing.

4. What materials will you need to do the experiment?
   - PROBE: Explain why you need each material.
5. How will you record your results?
   - PROBE: What information do you think is important to record?
   - PROBE: Why is that information important?
6. How will you make your conclusion about the answer to your question?
   - PROBE: What information would be important for you to consider when you make your conclusion?
   - PROBE: How do you reach the conclusion about which container is best for the fish?
7. I’m wondering if what happens to the water in the containers is related to what is happening with the water in the oceans, lakes, and rivers. What do you think?
   - PROBE: How do you think it is related?
   - PROBE: How do you think it is different from what happens with the oceans, lakes, and rivers?
   - PROBE: If the student says ‘‘water dries up from the river,’’ probe the response by asking ‘‘where does the water go?’’ Find out whether the student means that the river runs out of water, or the water evaporates from the river.
8. Do you have any other questions you would like to ask about this activity? Do you have any other questions about evaporation?

Appendix B

Scoring Rubric for Elicitation Responses

2 points 1. Pose a question – ‘‘What does Marie want to find out?’’

2: an adequate question that relates directly to the activity, such as ‘‘How does the size of the opening of the container affect evaporation?’’ or ‘‘Which container holds the water longer for the fish?’’

1: a tangential question that refers to the elements of the activity without directly addressing the issue of evaporation or the size of the openings of the containers, such as ‘‘Which container holds more water?’’ or ‘‘Which container will make the better home for the fish?’’

0: irrelevant, ‘‘I don’t know,’’ or no response.

2 points 2. Make a hypothesis – What do you think the answer to the question might be?’’

2: an adequate hypothesis that relates directly to the question, such as ‘‘How does the size of the opening of the container affect evaporation?’’ or ‘‘Which container holds the water longer for the fish?’’

1: a hypothesis that is tangential or does not relate directly to the activity.

0: irrelevant, ‘‘I don’t know,’’ or no response.

3 points 3. How could Marie find out? How could she set up an experiment to get the answer?

Put equal amounts of water in each container. Place the containers in the same place. Wait for a certain amount of time (may vary). Measure how much water is gone from each container.

3: a complete description listing the steps or procedures required to answer the question, presented in the form of a sequential list or paragraph.

2: a list of some but not all of the steps or procedures, OR an incomplete or nonsequential description of the procedures showing an understanding of the task (''I will put water in the containers and put them outside and see what happens.'')

1: a rudimentary listing of some of the steps or procedures with little evidence of understanding of the task (''I will put water and wait.'')

0: irrelevant, ''I don't know,'' or no response.

2 points 4. What materials will you need to follow your plan?

Materials you will need to carry out your plan
May include: two containers, water, a clock or watch, a notepad for recording results

2: a complete description listing at least 3 relevant materials required to answer the question.

1: an answer consisting of two relevant materials (i.e., water and containers).

0: No or irrelevant response.

3 points 5. How will you record your results?

3: response includes the explanation of the use of a table, chart, or graph for displaying information about the amount of water in the two containers over time.

2: response refers to recording or noting the amount of water across time but does not refer to a table, chart, or graph, such as ''I will write down how much water was left in the containers'' or ''I will write down how much water was gone the next day.''

1: a rudimentary notion of recording information, such as ''I will write it down'' or ''I will write a paper/report.''

0: irrelevant, ''I don't know,'' or no response.

2 points 6. How will you make your conclusion about the answer to your question?

2: a complete response, stating that the container that Marie should use/the best for the fish will be (a) the container that holds the water longer because (b) the water in that container will have evaporated the slowest/the water will have evaporated in the other container more quickly.

1: tangential response that indicates the loss of water in the container without mentioning evaporation

0: irrelevant, ''I don't know,'' or no response

2 points 7. I'm wondering if what happens to the water in the containers is related to what is happening with the water in the oceans, lakes, and rivers.

What do you think?

2: an accurate response indicating that evaporation occurs a lot in the ocean, lakes, and rivers because larger bodies of water have larger surface areas (or are wider).

1: a response indicating that evaporation occurs in both settings but does not mention the larger surface area.

0: irrelevant, ''I don't know,'' or no response.

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