DOCUMENT RESUME

ED 352 263 SE 053 334

AUTHOR	Rosebery, Ann S.; And Others
TITLE	Appropriating Scientific Discourse: Findings From Language Minority Classrooms. Research Report: 3. [Revised.]
INSTITUTION	National Center for Research on Cultural Diversity and Second Language Learning, Santa Cruz, CA.
SPONS AGENCY	Office of Bilingual Education and Minority Languages Affairs (ED), Washington, DC.
PUB DATE	92
CONTRACT	300-87-0131; R117G10022
NOTE	31p.; A version of this paper is also published in The Journal of the Learning Sciences, Vol. 1, No. 2, 1992. pp. 61-94.
AVAILABLE FROM	National Center for Research on Cultural Diversity and Second Language Learning, 399 Kerr Hall, University of California, Santa Cruz, CA 95064.
PUB TYPE	Reports - Research/Technical (143)
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	Bilingual Education; Bilingual Students; *Cultural Influences; Educational Change; High Schools; High School Students; Incentives; Inquiry; Integrated Curriculum; Junior High Schools; Junior High School Students; Middle Schools; *Minority Groups; Science Education; Science Experiments; *Scientific Methodology; Social Influences; *Thinking Skills; *Transfer of Training
IDENTIFIERS	Cheche Konnen Middle School Students; *Collaborative Inquiry; *Science Process Skills

ABSTRACT

This paper reports a study of the effects of a collaborative inquiry approach to science on language minority students' (middle and high school) learning. This approach emphasizes involving the students, most of whom have had very little schooling, in "doing science" in ways that scientists practice. This study addresses the question: To what extent do students appropriate collaborative scientific inquiry? The authors focus the analysis on changes in students' conceptual knowledge and use of hypotheses, experiments, and explanations to organize their reasoning in the context of two think-aloud problems. The findings indicate that at the beginning of the school year the students' reasoning was non-analytic and bound to personal experience. By contrast, at the end of the school year they reasoned in terms of a larger explanatory system; used hypotheses to organize and give directions to their reasoning; and demonstrated an awareness of the function of experimentation in producing evidence to evaluate hypotheses. (Author/PR)

RESEARCH REPORT: 3

APPROPRIATING SCIENTIFIC DISCOURSE: FINDINGS FROM LANGUAGE MINORITY CLASSROOMS

ANN S. ROSEBERY
BETH WARREN
FAITH R. CONANT

APPROPRIATING SCIENTIFIC DISCOURSE:

FINDINGS FROM LANGUAGE MINORITY CLASSROOMS

ANN S. ROSEBERY
BETH WARREN
FAITH R. CONANT

TECHNICAL EDUCATION RESEARCH CENTER

NATIONAL CENTER FOR RESEARCH ON CULTURAL DIVERSITY AND
SECOND LANGUAGE LEARNING

1992

This report was prepared with funding from the Office of Educational Research and Improvement (OERI) of the U.S. Department of Education, under Cooperative Agreement No. R117G10022. The findings and opinions expressed here are those of the author(s), and do not necessarily reflect the positions or policies of OERI.

NATIONAL CENTER FOR RESEARCH ON CULTURAL DIVERSITY AND SECOND LANGUAGE LEARNING

The National Center for Research on Cultural Diversity and Second Language Learning is funded by the Office of Educational Research and Improvement of the U.S. Department of Education to conduct research on the education of language minority students in the United States. The Center is operated by the University of California, Santa Cruz, through the University of California's statewide Linguistic Minority Research Project, in collaboration with a number of other institutions nationwide.

The Center is committed to promoting the intellectual development, literacy, and thoughtful citizenship of language minority students, and to increasing appreciation of the cultural and linguistic diversity of the American people. Center researchers from a variety of disciplines are conducting studies across the country with participants from a wide range of language minority groups in pre-kindergarten through grade 12 classrooms. Research projects deal with the relationship between first and second language learning; the relationship between cultural and linguistic factors in the achievement of literacy; teaching strategies to help children from diverse linguistic and cultural backgrounds gain access to content material; alternate models of assessment for language minority students; various instructional models for language minority children; and the effect of modifications in the social organization of schools on the academic performance of students from diverse backgrounds.

Dissemination is a key feature of Center activities. Information on Center research is published in two series of reports. *Research Reports* describe ongoing research, or present the results of completed research projects. They are written primarily for researchers studying various aspects of the education of language minority students. *Educational Practice Reports* discuss research findings and their practical application in classroom settings. They are designed primarily for teachers, administrators, and policy makers responsible for the education of students from diverse linguistic and cultural backgrounds.

For more information about individual research projects, or to have your name added to the mailing list, please contact:

Eugene Garcia and Barry McLaughlin, Co-Directors
National Center for Research on Cultural Diversity
and Second Language Learning
399 Kerr Hall
University of California
Santa Cruz, CA 95064

COLLABORATING INSTITUTIONS

University of California
Santa Cruz

University of California
Berkeley

University of California
Irvine

University of California
Los Angeles

University of California
San Diego

University of California
Santa Barbara

University of Arizona
Tucson

University of Oklahoma
Norman

University of Southern California
Los Angeles

Center for Applied Linguistics
Washington, DC

Technical Education Research Center
Cambridge, MA

AUTHOR NOTES

We gratefully acknowledge the teachers and students with whom we have collaborated during the last three years. Through their creativity and dedication, they have made an invaluable contribution to the Cheche Konnen project.

The work reported in this paper was supported under the Innovative Approaches Research Project, Contract No. 300-87-0131, from the U.S. Department of Education, Office of Bilingual Education and Minority Languages Affairs (OBEMLA). Preparation of the paper was also supported by the National Center for Research on Cultural Diversity and Second Language Learning, under the Educational Research and Development Center Program (Cooperative Agreement No. R117G10022), administered by the Office of Educational Research and Improvement (OERI), U.S. Department of Education. The views expressed here do not necessarily reflect the position or policies of OBEMLA or OERI.

A version of this paper is also published in *The Journal of the Learning Sciences,* Volume 1, Number 2, 1992, pp. 61-94.

APPROPRIATING SCIENTIFIC DISCOURSE:

FINDINGS FROM LANGUAGE MINORITY CLASSROOMS

ABSTRACT

This paper reports a study of the effects of a collaborative inquiry approach to science on language minority students' (middle and high school) learning. This approach emphasizes involving the students, most of whom have never studied science before and some of whom have had very little schooling of any kind, in "doing science" in ways that practicing scientists do. This study addresses the question: To what extent do students appropriate scientific ways of knowing and reasoning as a result of their participation in collaborative scientific inquiry? We focus our analysis on changes in students' conceptual knowledge and use of hypotheses, experiments, and explanations to organize their reasoning in the context of two think-aloud problems. The findings indicate that at the beginning of the school year the students' reasoning was non-analytic and bound to personal experience. By contrast, at the end of the school year they reasoned in terms of a larger explanatory system, used hypotheses to organize and give direction to their reasoning, and demonstrated an awareness of the function of experimentation in producing evidence to evaluate hypotheses.

What does it mean to learn science in language minority classrooms? This question is more complex than it seems because it brings into focus a tension between content area learning and English language development that plagues educational programs for language minority students. Typically, learning science in language minority classrooms (when it is taught at all) means learning English in the context of science content. Students may memorize the definition of the word *hypothesis* but never experience what it means to formulate or evaluate one. The emphasis is squarely on learning English vocabulary and grammar, with science as one means to that end. In undertaking the *Cheche Konnen* (which means *search for knowledge* in Haitian Creole) project three years ago, we sought to develop an approach to "doing science" in language minority classrooms that would provide an alternative to conventional practice. Science, we thought, needed to be valued not just as a means for teaching English but as a way of knowing and thinking in its own right. In this light, language—both first and second languages—becomes a means for constructing scientific meaning.

We were concerned, too, by the fact that science is often absent altogether from bilingual and English as a second language programs. One reason for this seems to be an assumption in the educational system about what language minority students can achieve and how they should learn. Language minority students are typically identified in terms of what they don't know (e.g., English). This "identity," as Moll (in press) argues, is reflected not only in the forms and foci of instruction found in language minority classrooms ("intellectually limited, with an emphasis on low-level literacy and computational skills") but in the very types of questions and issues that guide bilingual education research and policy (paraphrasing Moll, how to determine language dominance; how long to use the first language; when to mainstream students to English-only instruction; and what kinds of language tests to use in program evaluation).

The Cheche Konnen project attempts to address these concerns. In Cheche Konnen, students plan and carry out investigations into phenomena in the natural world (e.g., water quality, weather, human physiology, and sound). The basic idea is to involve the students, most of whom have never studied science before and some of whom have had very little schooling of any kind, in doing science in ways that practicing scientists do. They pose their own questions; plan and implement research to explore their questions; build and revise theories; collect, analyze, and interpret data; and draw conclusions and make decisions based on their research (Rosebery, Warren, & Conant, 1989; Warren, Rosebery, & Conant, 1989).

In this paper, we report a study of the effects of doing science on language minority students' learning. We address the question: "To what extent do the students appropriate scientific ways of knowing and reasoning?" Our analysis focuses on changes—from the beginning of the school year to the end—in students' conceptual knowledge and use of hypotheses, experiments, and explanations to organize their reasoning.

A COLLABORATIVE INQUIRY APPROACH

In Cheche Konnen, the emphasis on authentic scientific practice is realized as a form of collaborative inquiry. This approach reflects our belief, building on Vygotsky (1978), that robust knowledge and understanding are constructed socially through talk, activity, and interaction around meaningful problems, tasks, and tools. In collaborative inquiry, teachers guide and support students as they explore problems and define questions that are of interest to them. The investigations described in the Method section exemplify this process. In one, the Water Taste Test, students conducted a blind taste test to confirm their belief that one water fountain in the school, the one they always drank from, had "better" water than the other fountains. When the results of their test showed that most of them actually preferred the water from the "worst" fountain in the school, the students were shocked and suspicious of their results. This suspicion motivated them to conduct a second test with a larger sample of students. When their second test confirmed the results of the first, the students wanted to find out *why* one water fountain was preferred over the others. To answer this, they analyzed the school's water fountains for differences along several chemical, biological, and physical dimensions.

The stages of the Water Taste Test clearly show how the results of one inquiry can lead to new questions that in turn spawn further research. The course of the Water Teste Test was not predetermined; rather, it grew directly out of the students' beliefs and questions. This is how inquiry proceeds: The investigation of one question motivates additional explorations, initially unforeseen. For this reason, Cheche Konnen does not follow a set curriculum; investigations evolve through the joint activity of students and teacher.

By pursuing their questions, students work toward goals that are meaningful to them and, often, to the larger community (which can encompass the classroom, the school, or the outside community). In this way, through their own activity, students begin to bridge the gap that separates the school culture from the culture of the home and community (Heath, 1983). In addition, by planning and implementing investigations, students learn how to confront the kinds of ill-defined problems that arise in most real world (scientific and non-scientific) activity. They learn that there are alternative investigative paths to a problem and that many different questions can be pursued at any given point. And, importantly, they learn that there is not necessarily one solution or answer to a given problem.

The value of collaborative inquiry is that it provides direct cognitive and social support for the efforts of individual students (Brown & Palincsar, 1989). Students share the responsibility for thinking and doing, distributing their intellectual activity so that the burden of managing the whole process does not fall to any one individual. The sharing of intellectual responsibility is particularly effective for language minority students because the English language demands of complex tasks (e.g., interviewing a water chemist at the local water treatment plant) can overwhelm them and even mask their true abilities and understanding. In addition, collaborative inquiry creates powerful contexts for constructing scientific meanings, for example, when students use data to debate the explanatory power of rival theories. In challenging one another's thoughts and beliefs, students must be explicit about their meanings; they must negotiate conflicts in belief or evidence; and they must share and synthesize their knowledge in order to achieve a common goal (Barnes & Todd, 1977; Brown & Palincsar, 1989; Hatano, 1981; Inagaki & Hatano, 1983).

Finally, in Cheche Konnen, collaborative inquiry is interdisciplinary. Mathematics and language are essential tools of scientific inquiry. This stands in sharp contrast to traditional schooling in which science is separated from math and the role of language goes unacknowledged. Mathematics mediates students' scientific sense-making primarily through data collection and analysis activities (e.g., measurement, statistics, graphical analysis, and representation). In Cheche Konnen investigations, students use mathematics in diverse ways: for example, to measure water flow; to represent and analyze data (e.g., using bar graphs, boxplots, scatterplots); and to design and develop their own measurement instruments.

Language (talk, reading, and writing) plays an equally crucial mediating role in collaborative inquiry as a system for thinking and talking scientifically and for communicating and sharing ideas. As we will discuss below, we conceptualize science as a discourse in order to emphasize the pluralistic nature of literacy, the fact that over the course of a lifetime, we all acquire many different literacies (e.g., control over the discourses enacted in one's work, recreational activity, church or synagogue; among one's peers in a bar, playground, or baseball diamond; in various educational disciplines such as linguistics, literature, physics, engineering, etc.) (Gee, 1989; The Literacies Institute, 1989; Warren, Rosebery, & Conant, in press). When acquiring new literacies, we do not simply learn the form of a language and then apply that form to generate meanings. Rather, we learn to use language in specific ways and situations to accomplish particular purposes, such as to answer questions in school, to tell stories at the dinner table, to play with peers, and so forth (Cazden, John, & Hymes, 1972; Gee, 1989; Heath, 1983). This is the heart of the perspective on language that underlies the Cheche Konnen approach. Through collaborative scientific inquiry, students expand their linguistic repertoire, in both their first and second languages, to encompass the discourse of science. For example, in Cheche Konnen investigations, students learn the discourse of theorizing as they make sense of data they have collected, and they learn scientific forms of writing as they produce reports of their results.

The importance of an interdisciplinary approach for language minority students cannot be overstated. It involves them directly in the kinds of purposeful, communicative interactions that promote genuine language use. Such interactions are arguably the most productive contexts for language acquisition: for example, talking in the context of doing science and trying to solve a meaningful problem (Trueba, Guthrie, & Au, 1981). The interdisciplinary approach also creates opportunities for students to use the languages of science and mathematics in ways that society at large requires: not just to read textbooks, but to write reports, argue theories, develop evidence, and solve meaningful problems.

A major goal of Cheche Konnen is to forge links between learning science and doing science, and among science, mathematics, and language. This is in large part what makes it a powerful model for language minority students, in particular, and perhaps for all students. The heart of the approach is for students to formulate questions about phenomena that interest them; to build and criticize theories; to collect, analyze, and interpret data; to evaluate hypotheses through experimentation, observation, and measurement; and to communicate their findings. Language—in the form of purposeful talk, reading, and writing—and mathematics mediate each of these scientific efforts.

A SOCIOCULTURAL PERSPECTIVE ON SCIENTIFIC LITERACY

The Cheche Konnen approach to learning is informed by a particular perspective on what it means to be, or become, scientifically literate. In Cheche Konnen, as noted above, scientific literacy is conceptualized as a discourse (Bakhtin, 1981; Gee, 1989). This view of science as a discourse helps us to see scientific literacy not as the acquisition of specific facts and procedures or even as the refinement of a mental model, but as a socially and culturally produced way of thinking and knowing, with its own ways of talking, reasoning, and acting, its own norms, beliefs, and values, its own institutions, its shared history, and even its shared mythologies (Gee, 1989; Latour, 1987; Longino, 1990). With this view of scientific literacy comes the view that to become scientifically literate, students (and teachers, too) need to be *enculturated* into the ways of making sense that are characteristic of scientific communities. They must learn to use language, to think, and to act as members of a scientific community.

This view of scientific literacy is at odds with that which underlies most school science practices, whether in mainstream or bilingual programs. Some of the most forceful testimony on this point comes from practicing scientists. For example, in the following quote, Sir Peter Medawar (1987), the Nobel Laureate, describes a scientist's view of scientific activity:

> Like other exploratory processes, [the scientific method] can be resolved into a dialogue between fact and fancy, the actual and the possible; between what could be true and what is in fact the case. The purpose of scientific enquiry is not to compile an inventory of factual information, nor to build up a totalitarian world picture of Natural Laws in which every event that is not compulsory is forbidden. We should think of it rather as a logically articulated structure of justifiable beliefs about a Possible World — a story

> which we invent and criticise and modify as we go along, so that it ends by being, as nearly as we can make it, a story about real life. (p. 111)

In this quotation, Medawar directly challenges some of the typical school beliefs about what it means to be scientifically literate. First, he challenges the belief that science, at bottom, is the accumulation of knowledge or facts about the natural world. Secondly, he challenges the belief that scientists work according to a rigorously defined, logical method, known popularly as the Scientific Method. And thirdly, he challenges the belief that scientific discourse is represented uniquely, or even accurately, by forms of writing and talk that are thoroughly objective and impersonal.

Central to Medawar's vision is an idea of scientific activity as involving dialogue and storytelling. Both strike a discordant note with conventional classroom practices in science. For example, with regard to the methods of science, we tend to confuse the final product of scientific activity, the journal paper with its clearly delineated steps and carefully argued logic, with the process that produced it (cf. Gilbert & Mulkay, 1984; Latour & Woolgar, 1986). One result is that we teach the method of science as if there were only one way in which scientists actually go about their work. Another result is a distorted view of the role of both reason and imagination in science (Kuhn, 1977; Medawar, 1987). Medawar's insistence on the dialogic quality of scientific activity, in contrast, places fact and fancy, induction and imagination on more equal footing.

But what is the character of scientific sense-making? Medawar suggests provocatively that scientific sense-making is akin to storytelling. What does he mean by this? Most of our cultural assumptions about the nature of scientific knowledge and reasoning, at least those that are conveyed through classroom instruction—for example, that scientific knowledge is associated with certainty and is absolute—do not fit with any idea of storytelling. What kind of storytelling, then, does Medawar have in mind?

What Medawar has in mind when he equates scientific inquiry with storytelling is an activity that "begins with an explanatory conjecture which at once becomes the subject of energetic critical analysis" (1987, pp. 134-35). It proceeds by hunch and intuition, invention and criticism; it is a process that, in his view, is "outside logic" (Medawar, 1987, p. 129). And scientific storytelling is exactly this activity of building explanatory structures or theories through hypothesizing and experimentation. Following Medawar, we characterize the discourse of storytelling in science as a discourse of theorizing, one that grows out of a vigorously critical and iterative process involving, at minimum, conjecture, evidence, observation, experimentation, and explanation.

For students to become literate in the ways of making sense that are characteristically scientific, the contexts ("communities of practice") in which they learn science must reflect and support those sense-making practices (cf. Lave & Wenger, in press; Schoenfeld, in press); that is, students must be enculturated into the ways of making sense that are characteristic of scientific communities. But learning the practices and discourse(s) of science is a difficult and complicated process. Students must not simply acquire scientific ways of doing, reasoning, talking, and valuing; they must also find ways of appropriating scientific discourse so that it can serve their own sense-making purposes (Bakhtin, 1981; Cazden, 1989).

The Soviet theorist, Mikhail Bakhtin (1981), helps us see why appropriation is both so important and so difficult:

> [The word in language] becomes "one's own" only when the speaker populates it with his own intention, his own accent, when he *appropriates* the word, adapting it to his own semantic and expressive intention. Prior to this moment of appropriation, the word... exists in other people's mouths, in other people's contexts, serving other people's intentions.... And not all words for just anyone submit equally easily to this appropriation .... many words stubbornly resist, others remain alien, sound foreign in the mouth of the one who appropriated them and who now speaks them; they cannot be assimilated into his context and fall out of it; it is as if they put themselves in quotation marks against the will of the speaker.

> Language is not a neutral medium that passes freely and easily into the private property of the speaker's intentions; it is populated – overpopulated – with the intentions of others. Expropriating it, forcing it to submit to one's own intentions and accents, is a difficult and complicated process (pp. 293-294).

For language minority students, the appropriation process can be even more arduous than for other students; the distance they must travel between discourse worlds is often far greater, owing to both cultural and linguistic discontinuities (Au, 1980; Au & Jordan, 1981; Heath, 1983; Mohatt & Erickson, 1980; Philips, 1972, 1983). What makes appropriation so difficult is that discourses are inherently ideological; they crucially involve a set of values and viewpoints in terms of which one speaks, thinks, and acts (Bakhtin, 1981; Gee, 1989). As a result, discourses are always in conflict with one another—some more or less so—in their underlying assumptions and values, their ways of making sense, their viewpoints, even the objects and concepts with which they are concerned. Appropriating a particular discourse, then, can be more difficult or less difficult depending on the various other discourses in which the students (not to mention the teachers) participate.

In the rest of this paper, we report the method and results of our study of the effects of the collaborative inquiry approach on students' ways of knowing and thinking. The data we present are both quantitative and qualitative. The object of our analysis is a set of problem-solving protocols administered individually in the form of interviews with the students in September 1988 and June 1989.

METHOD

SUBJECTS

Cheche Konnen was pilot-tested in two distinctly different contexts of bilingual education within an urban public school system. One was a self-contained, combined classroom of seventh and eighth graders in a K-8 school. The other was a basic skills program within the general bilingual program in a large high school. These settings represent in microcosm many of the variations that can occur in the ages, skill levels, interests, and cultural and linguistic backgrounds of language minority students in an urban school system.

The city is a multiethnic community that has offered bilingual education since 1970. Currently, the city's public schools serve approximately 8,000 students, of whom 1,000 receive bilingual education. A somewhat larger number of the students in the system do not speak English at home. The city's bilingual population is diverse. To address this diversity, the school system offers bilingual education in eight languages at the elementary-middle school level (Portuguese, Spanish, Haitian Creole, Chinese, Korean, Hindi, Gujarati, and Vietnamese) and in five languages at the high school (Portuguese, Spanish, Chinese, French, and Haitian Creole).

Seventh-Eighth Grade Classroom

At the K-8 school, which houses the city's Haitian Creole bilingual program and a mainstream program, we worked with a combined seventh-eighth grade class. The school has 390 students, one-third of whom are in the bilingual program. It functions as an "alternative" school, offering in its mainstream program a more open-ended and inquiry-based educational program than that found in most schools.

In September, the combined seventh-eighth grade had seven students; by January, the number had grown to 20. The students in this class take their core academic subjects (e.g., language arts, mathematics, social studies) in Haitian Creole from their classroom teacher and instruction in English as a second language (ESL) from an ESL teacher. Academically, the students range from a few who function approximately two years below grade level to those who cannot read or write in either Haitian Creole or English. During the year, science was taught in Haitian Creole by the classroom teacher for 45 minutes three times a week.

The classroom teacher is a native speaker of Haitian Creole and is fluent in English. She has taught in the bilingual program for several years. Prior to the 1988-1989 school year, she had only occasionally taught science; she had no formal training in science.

High School Basic Skills Program

The second classroom was in a large urban high school. The school serves 2,700 students and is comprised of several "houses." At the time of the study, the bilingual program occupied its own house and served approximately 250 students, or about 10% of the student body. Although the number of language minority students at the high school has remained relatively stable over the last 10 years, the ethnic background of the students has changed as immigration patterns have changed. In 1977, 75% of the language minority students were Portuguese or Latino, and 25% were Haitian, Greek, or Iranian. Today, 42% are Haitian, 24% are Latino, 10% are Portuguese, and the remaining 24% are Chinese, Vietnamese, Korean, Indian, or Eritrean.

The high school offers bilingual education that in many cases mirrors the curriculum of the regular monolingual program (e.g., general science, biology, earth science, basic math, pre-algebra, algebra, and geometry). These classes are offered in French, Haitian Creole, Portuguese, Spanish, and Chinese. In addition, the bilingual program offers a basic skills program for those students whose low academic and literacy skills prevent them from participating in the regular bilingual program. This is the program into which Cheche Konnen was introduced.

The Basic Skills Program is for the academically weakest students, those who are at greatest risk for dropping out or for school failure. Some of the students in the program are not able to read or write in their native language or English, and most have only the most rudimentary mathematics skills and no previous exposure to science. There were 22 students in the Basic Skills Program in the 1988-1989 school year from a variety of linguistic and cultural backgrounds. Six language groups were represented: Haitian Creole, Spanish, Portuguese, Amharic, Tigrinya, and Cape Verdean Creole.

Four teachers worked together in the Basic Skills Program: two math teachers, an ESL teacher, and a social studies teacher. The math teachers co-taught science and mathematics four times a week during back-to-back periods of 45 minutes each. One of the math teachers was a native speaker of Haitian Creole, was fluent in English, had a working knowledge of Spanish, and had occasionally taught science in the past. The other teacher was a native speaker of English, had a good working knowledge of Haitian Creole and Spanish, and had never taught science before. Neither had any formal science training.

In this paper, we report the data from those students who (a) were native speakers of Haitian Creole,[1] (b) entered class prior to November 1, 1988, and (c) completed the school year. Sixteen students met these criteria, twelve from the seventh-eighth grade and four from the high school Basic Skills Program.

PROCEDURE

Students in both classes planned and carried out investigations into local aquatic ecosystems throughout the school year. The work in the classrooms was collaborative on many levels: among students, between teachers and students, and among researchers, teachers, and students. As participant observers, we worked directly with both classes. Outside of class, we also met regularly with the teachers to work through both conceptual and logistical problems in the design and development of the investigations.

As background to their investigations, the students studied aspects of the chemistry, biology, and ecology of local water sources. For example, they directly studied and evaluated such determinants of water quality as salinity, pH (what acids and bases are, how they affect the health of water, how to test pH, the causes and effects of acid rain), and bacteria (what they are, what they look like, how to test for them, associated diseases and health problems); they analyzed micro- and macroscopic aquatic life; they studied water treatment (floccing, chlorination, desalinization), and so forth. The students in the combined seventh-eighth grade class built on this knowledge by designing and conducting an investigation into the quality of their school's water. The high school students designed and carried out a field study of the ecology of a local pond. We describe both investigations briefly below. (For a more detailed discussion and analysis of the investigations, see Warren et al., 1989.)

Water Taste Test

Prompted by their teacher, the students in the combined seventh and eighth grade class investigated a belief widely held among the school's junior high students: that the water from the fountain on the third floor (where the junior high is located) was superior to the water from the other fountains in the school. The teacher had noticed that the junior high students (both bilingual and mainstream) refused to drink from the first and second floor fountains, claiming that the third floor water was superior. The teacher challenged her students to investigate their belief scientifically. Using their belief as a starting point, the students developed a study that evolved to include three stages: a class blind taste test, a junior high-wide blind taste test, and an analysis of the water in the school's fountains.

Class blind taste test. To determine whether they actually preferred the third floor water or only thought they did, the students conducted a blind taste test of the water from the first, second, and third floor fountains. Neither the teacher nor the students knew in advance whether the results of the test would confirm or challenge the students' belief.

As part of the blind taste test, the students collected data as to which water fountain they thought they preferred and, after tasting the unmarked samples, which water they actually preferred. The students expected that their pre-taste test preference, the third floor, would, in their words, "win." They also expected the first floor water, which is near the kindergarten and first grade classrooms, to receive no votes; it was regarded as the worst water in the school because "all the little kids slobber in it."

When they analyzed their data, however, the students found that although they all *said* they preferred drinking from the third floor fountain, in the blind tasting $^2/_3$ of them *chose* the water from the first floor. Neither the teacher nor the students believed the results, although for different reasons. The students doubted the data because it not only contradicted their deeply held belief about the superiority of the third floor water, but it suggested that the water from the first floor, which according to their myth was the "worst," was preferred. For her part, the teacher believed that there were no differences among the water fountains and expected each floor to receive approximately $^1/_3$ of the votes. Therefore, when the first floor received a majority of the votes, she suspected that the students had biased the results by speculating about the identities of the waters among themselves. This skepticism led the class to conduct a second experiment with a larger sample.

Junior high taste test. With minimal guidance from their teacher, the students planned a larger water taste test for the rest of the junior high. They decided where to do the taste test, when, and with whom. They discussed the issue of water: how to collect it, how to hide the identity of the sources, and, crucially, how many fountains to include, deciding on the same three as before so their data would be comparable. They worried about bias in the voting process: what if some students voted twice?

They conducted their taste test during lunch on Valentine's Day. Approximately 40 students participated. After collecting their data, the students graphed and analyzed it. They found their earlier results confirmed: 88% of junior high students thought they preferred the third floor water but 55% actually chose the first floor water. To share their results with the school, the seventh and eighth graders displayed their graphs outside their classroom, wrote reports of their findings, and composed an announcement for the principal to read over the school's public address system.

Analysis of school water. Now the class had a final problem: *Why* was the first floor water preferred? To determine the source of the preference, the class embarked on an analysis of the school's water fountains, investigating several variables including bacteria and temperature. They found that *all* the fountains in the school had unacceptably high levels of bacteria, and that the first floor (the one most preferred) had the highest counts. The class reported these findings to a chemist at the local water authority who suggested that their samples had been contaminated. He agreed to retest the water on the condition that the students not share their results with the local newspaper. Unfortunately, the school year ended before the chemist was able to retest the school's water.

In their analysis, the students also found that the water from the first floor fountain was colder than the water from the other floors. To account for the observed temperature difference, they developed a theory that the water was naturally cooled during the winter months (the study was conducted in February) as it sat underground in city pipes and warmed as it travelled from the basement to the third floor. In the end, they decided that temperature was probably an important factor in taste preference.

Black's Nook Pond Study

The Basic Skills class in the high school conducted an investigation into the ecology of a local pond, called Black's Nook Pond. In consultation with us, the teachers decided to combine their goals for teaching science with their goals for literacy development and have the students design and produce a field guide to the pond.

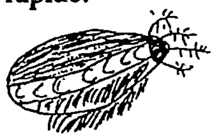
The investigation started with a visit to the pond, which was visibly polluted. The students observed oil on the water's surface and discarded trash such as bottles and a shopping cart. The state of the pond concerned them because of its proximity (about 500 feet) to the city's drinking water reservoir. As a result, the class decided to conduct a study of the pond's health as the basis for their field guide. They generated a list of questions they wanted to answer, including the following: Was the pond cleaner in the past than now? Is it clean enough to drink? How deep is the pond at different places? Are there any fish? How do the fish get there? Can you swim in the pond? What kinds of birds live there? What kinds of animals live there?

To investigate their questions, the class divided into small groups, each of which was responsible for tackling one question. One group designed and built tools that they used to measure the depth, length, and width of the pond. A second group created a profile of the air and water temperatures at the pond. After much discussion, they decided to obtain temperature readings at different locations and depths within the pond in an effort to correlate temperature and forms of microscopic life. A third group analyzed the pond's chemistry, measuring its pH, turbidity, and salinity. A fourth catalogued the plant and animal life they observed, noting the presence of water irises, water bugs, bird life, and other animals, such as turtles and snakes. In class, each group also constructed an aquarium from plant and water samples and used it to examine microscopic life. In the end, the students used their data to produce the field guide. A sample page from the guide is given in Figure 1.

FIGURE 1

Esto es lo que escribi sobre estos animales.
Este es un gusano que se mira sin el microscopeo. Es un animal pequeño que se mueve y es largo. El animal es de color rojo. Hay cosas pequeñas moviendo rapido cerca del animal.

Este animal se mira sin el microscopeo. Se mira como puntos. Es un animal pequeño negro y esta moviendo muy rapido.



Estos son unos animales pequeños que se miran sin el microscopeo. Se ven como puntos estos animalitos se mueven muy rapido.

A sample page from the field guide written by students in the Basic Skills class.[4]

ASSESSMENT INSTRUMENTS

We turn now to the research study. The specific question we address is this: To what extent did the students begin to take control of the discourse of science to build their own understandings of the world? To explore this question, we analyzed protocols from interviews conducted with the students in September and June for changes in what they knew and in how they used their knowledge to reason scientifically. For our purposes, we were concerned with students' use of hypotheses, explanations, and experiments to organize their reasoning. This kind of analysis could be extended to other aspects of scientific discourse including, for example, the use of questions, observation, evidence, argument, models, and theories.

To assess changes in students' scientific literacy, the students were interviewed individually in September 1988 and June 1989 on two think-aloud problems. The interviews were conducted in Haitian Creole by a fluent speaker. The problems used in the September and June versions of the interview were identical.

Think-Aloud Problems

For the think-aloud problem, the students were asked to reason aloud about how they would investigate and try to explain two ill-defined but realistic problems. One problem focused on pollution in the Boston Harbor (the "Boston Harbor" problem) and the other on a sudden illness in a school (the "Sick Kids" problem). The Boston Harbor problem was based on a *Boston Globe* newspaper report, the Sick Kids problem on an article entitled "Mass hysteria among schoolchildren: Early loss as a predisposing factor" (Small & Nicholi, 1982).

The problems were chosen to represent different degrees of transfer. The Boston Harbor problem represents near transfer; it asks students to reason through a problem involving water contamination, a subject they studied during the school year. It is therefore a problem to which they can apply directly knowledge they acquired in the context of the water quality investigation. The Sick Kids problem represents far transfer; the students did not study anything directly relevant to it during the school year. The question of interest in this case is how they reason through a problem on a subject they have not explicitly studied, that is, whether they have assumed enough control over scientific discourse to apply it in unfamiliar domains.

The procedure was as follows. The interviewer explained to the student that she was going to read him or her a story about the Boston Harbor or about what happened to some kids one day in school. After reading the story, she posed some questions. A small set of core questions was developed, but the interviewer was instructed to go beyond them to probe the students' meaning and answers. The text of the two problems and the core set of questions are shown in Table 1.

TABLE 1

Problem 1: Boston Harbor

I'm going to tell you a true story; it's sort of a mystery. It's about the Boston Harbor. In the last few years, people have noticed that there is something wrong with the water in the Harbor but no one knows exactly what is wrong.

Fishermen have noticed that there are fewer fish in the Harbor. And they have seen a lot more algae. People who spend time near the Harbor have noticed that the water looks dirty; it is brown and foamy. It also has garbage in it. Tin cans, paper, and old food float in the water. Sometimes you can even see dead fish floating on the waves.

You are a famous scientist. The Mayor of Boston asks you to find out what is wrong with the water.

What is the first thing you do?
What do you think might be wrong with the water?
How will you find out if you are right?
Do you have any ideas about how you could make the water clean again?

Adapted from: Tye, L. (1988, May 16). Boston Harbor: Cleaning the waters. *The Boston Globe.*

Problem 2: Sick Kids

I'm going to tell you another true story; it's a mystery, too. It's about some children in a school who get sick and, when it happened, no one knew what was making them sick.

It happened in a town around here, just outside Boston. All the children in an elementary school were watching a play put on by the sixth graders. Suddenly, a boy in the play fell off the stage and cut his chin. He said he felt sick and some teachers carried him to the nurse. Then a student watching the play got dizzy and fainted. Then some other students felt sick to their stomachs. Suddenly, lots of students were sick.

You are a famous scientist and you live next door to the school. When the children get sick, the principal runs over to your house and asks you to come and find out what is making the children sick. You agree and go to the school.

What is the first thing you do?
What do you think might be wrong with the children?
How will you find out if you are right?

Adapted from: Small, G.W., & Nicholi, A.M. (1982). Mass hysteria among schoolchildren: Early loss as a predisposing factor. *Archives of General Psychiatry, 39,* 721-724.

The protocols were translated from Haitian Creole to English for analysis purposes.[2] The students' responses to the Boston Harbor problem were coded for (a) specific content knowledge developed in the context of the water quality investigation, (b) the number of hypotheses, and (c) the number of experiments proposed. Their responses to the Sick Kids problem were coded for the number of hypotheses and experiments only; knowledge was not considered in this problem because the students did not study this or related topics during the year. The number of hypotheses, experiments, and appropriate uses of content knowledge were counted for the September and June interviews, respectively. The interviews were coded independently by two raters who, before undertaking the main coding task, reached a high degree (95%) of agreement on two transcripts not included in the analyses. After coding, the raters met to review their results. Any disagreements were resolved through discussion.

Content knowledge encompassed the appropriate use of concepts related to water quality or scientific methods, including reference to possible causes of water pollution, explanation of their effects, methods for detecting the presence of pollutants, and the procedures for applying these methods. As an example, we include the following excerpt[3] from a seventh grader's June interview in which we coded three instances of appropriate content knowledge use: (1) acid as a possible pollutant; (2) a description of how litmus paper works; and (3) an explanation that too much acid can cause fish to die.

Example 1: (June/Boston Harbor)

Interviewer: ...are there other things you'd check?

Elinor: Yes. You can look to see if it was something acid doing that to the water, too.

Interviewer: How do you find out if there's acid in water?

Elinor: There's a kind of little paper you brought to show us, you can leave it in [the water]. It's the color; if it's acid, you'll know according to the way it's colored. You look to see which is the most acid and which is less acid. If there is too much acid in the water killing the fish, you can look at that to see.

Hypotheses were defined as explanatory conjectures, statements that suggest a cause for the situation described in the problem. Furthermore, to be counted, they had to be testable, although the student may not actually have proposed a test. Hypotheses that reiterated examples (or symptoms) stated in the problem story were not counted. Each hypothesis was counted only once, regardless of the number of times it was articulated or rephrased. For instance, in Example 1 above, acid was counted as one hypothesis because it was offered as a possible cause of dead fish and because it is testable. In Example 2 below, car gas was counted, but spoiled food, nasty fish, and garbage were not counted because they are mentioned in the problem. "Things they left in it" was not counted because it is not testable.

Example 2: (September/Boston Harbor)

Interviewer: What do you think could make the water like that?
Guerline: The things they left in it, like the spoiled food, and things, the nasty fish that died, and car gas.
Interviewer: Car gas?
Guerline: And the garbage they left in.

In looking at *experiments*, we considered several facets of experimentation relevant to the students' experience during the water quality investigation. Much of the students' experience with experimentation consisted of testing water for the presence of a given pollutant using commercially available methods (e.g., litmus paper, growing bacterial cultures). They did not have much experience with classical experimentation (e.g., controls and treatments). For the purpose of this analysis, therefore, we did not define experiments in the classical sense. Rather, we looked for the following kinds of evidence in identifying experiments in the students' protocols: first, that they knew when and how to apply a given test in relation to a specific hypothesis; secondly, that they had the idea that it is necessary to isolate a variable, even if they did not know how to do so in a controlled way; thirdly, that they had some notion of treatment (that is, of doing something to someone or something that will produce the expected effect). Clearly, if students defined more rigorous experiments, we counted them as well.

Example 3 contains an experiment testing for the presence of fecal coliform bacteria. (Caroline's description of this experiment is a heavily context-dependent reference to fecal coliform bacteria tests performed in class using Millipore Samplers.) In contrast, in Example 4, Tony does not put forward any experiments. His response to the interviewer's question is an assertion of fact rather than a procedure for testing an idea.

Example 3: (June/Boston Harbor)

Interviewer: Can you think of another reason the fish might die?
Caroline: If the water had too much fecal in it?
Interviewer: How would you know if it had fecal in it?
Caroline: I'd take the water and put it in the same thing we had to see if the water had fecal in it (referring to a Millipore Sampler). I would put it in, then the same (...), after that I would look at it.

Example 4: (September/Boston Harbor)

Interviewer: What do you think might have made the fish die?
Tony: Because the garbage is a poison for them.(...)
Interviewer: How would you know if it were the garbage that was making the foam and the fish die?
Tony: The garbage made the fish die.
Interviewer: How would you make sure?
Tony: Because fish don't eat garbage. They eat plants under the water.

RESULTS

In this section we report the quantitative results for the two problems. In the discussion following this section, we will consider the results from a broader, more qualitative perspective, examining in detail some of the changes in students' discourse from the beginning of the year to the end. The following results focus on changes in what the students knew and in how they used their knowledge to reason scientifically in terms of hypotheses and experiments.

CONTENT KNOWLEDGE

For the Boston Harbor problem only, paired t-tests were performed to compare students' use of content knowledge about water quality in September and June. There was a significant increase in the number of appropriate uses of content knowledge in the June interviews (Figure 2). The mean number of appropriate uses of content knowledge increased from 0.50 in September to 5.75 in June ($t=8.72$, $p<.001$).

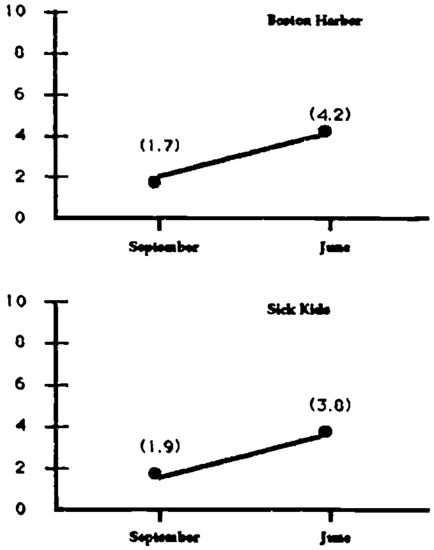
FIGURE 2

Mean number of concepts related to water quality mentioned spontaneously by students in September and June interviews for Boston Harbor problem (t=8.72, p< .001).

HYPOTHESES

Paired t-tests were also performed on the number of hypotheses the students generated in the September and June interviews. In both the Boston Harbor and Sick Kids problems, the mean number of hypotheses put forward increased significantly from September to June. The results for each problem are shown in Figure 3. For the Boston Harbor problem, the mean number of hypotheses increased from 1.7 in September to 4.2 in June (t=8.26, p<.001). Similarly, for the Sick Kids problem, the mean number of hypotheses was 1.9 in September and 3.8 in June (t=7.3, p<.001).

FIGURE 3

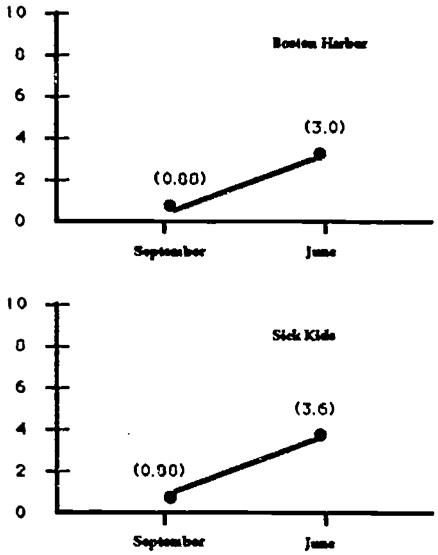


Mean number of hypotheses produced by students in September and June interviews for the Boston Harbor and Sick Kids problems, respectively (t=8.26, p< .001 and t=7.3, p< .001).

EXPERIMENTS

For each problem, we also found a significant increase in the mean number of experiments (see Figure 4) as defined in the previous section. For the Boston Harbor problem, the mean number of experiments proposed was .88 in September and 3 in June (t=7.1, p<.001). For the Sick Kids problem, the results were similar: a mean of .88 experiments in September as compared with 3.6 in June (t=11.0, p<.001).

FIGURE 4



Mean number of experiments proposed by students in September and June interviews for the Boston Harbor and Sick Kids problems, respectively (t=7.1, p< .001 and t=11.0, p< .001).

All in all, the results suggest that the students knew more in June than in September and that they were better able to organize their reasoning around hypotheses and experiments. A closer look at the students' protocols will help us understand more deeply the nature of those changes and, in particular, whether the students were beginning to acquire some degree of control over scientific discourse as a way of thinking and talking.

DISCUSSION

The foregoing results suggest that in June the students' reasoning had changed. But it is not easy to tell from such results in what ways specifically it has changed or why. From a discourse perspective, we want to know if, in general, the students' ways of talking science are different in June than in September and, if so, why they are different. Specifically, what kinds of discourse strategies do they use to organize what they know into hypotheses, experiments, and explanations?

SEPTEMBER INTERVIEWS

As the numerical results from the September interviews attest, at the beginning of the year the students did not reason scientifically: They offered few hypotheses and even fewer experiments. But what do we mean when we say their reasoning was unscientific, that they did not talk scientifically? How did they reason through the problems? To address this question, we examine the discourse strategies they used to answer the interviewer's questions, particularly those that were intended to elicit hypotheses and experiments.

Asked in September, "What could be making the water like that (i.e., full of garbage, foam, dead fish)?" or "What could be making the children sick?", the students, with few exceptions, tended to respond with short, unelaborated, often untestable hypotheses that simply restated the phenomena included in the problem description.

Example 5: (September/Boston Harbor)

Interviewer: What do you think might make the water like that?

Marie Rose: People throwing garbage in it.

Interviewer: How would you make sure it was people?

Marie Rose: I'd take the garbage out and tell them not to throw it in again.

Interviewer: Why do you think the fish died?

Marie Rose: Because they threw dirty things, stinky things in it.

Example 6: (September/Sick Kids)

Interviewer: Why do you think they all got sick at the same time?

Laure: That's a thing.

Interviewer: What kind of thing?

Laure: Ah, I could say a person, some person that gave them something.

Interviewer: I don't understand.

Laure: Anything, like give poison to make his stomach hurt.

These examples are typical of the students' responses. They invoke an anonymous agent, "people," as the cause of the pollution or the sudden illness among the schoolchildren. Most of the hypotheses they put forward are of the "black box" variety: "something" they left in, a "thing," even a "poison" which, although semantically richer by definition, is functionally equivalent to the other terms (i.e., poison makes the children sick). Not one of these notions has any explanatory power. None therefore qualifies as a hypothesis by our definition.

These examples suggest that the students are relying on two discourse strategies to address the interviewer's why-questions. One is to invoke anonymous others ("they," "someone," "people") as the cause of the problem. Another is to treat the symptoms as the cause, literally to extract items from the problem story itself and assert them as the cause of the harbor's problem ("garbage"). And, having identified a particular agent, however vaguely defined, the students do not then pursue any further analysis. It is as if they are saying: "You asked me a question and I have given you the answer. What more is there to say?" In virtually every case in the September interviews, the students stayed at the surface of the problem, treating it as if it were a text that had all the answers. Their job, as they saw it, was not to reason through the problem but simply to locate and identify the answers in the text. Thus, in September, it seems clear that the students do not have a strong sense of what counts as a reasonable hypothesis or explanation. Put more strongly, at the beginning of the year, the students do not have any sense at all of what a hypothesis is functionally, let alone formally, in science.

The students' text comprehension strategy is not surprising if we consider the kinds of worksheet- and textbook-based practices to which they are accustomed in the typical American classroom. If anything, the students' school experiences in Haiti, where rote recitation and memorization are the rule, were even more restrictive. These prior schooling experiences had not prepared them for active, critical inquiry of the kind that is characteristic of scientific practice.

Another strategy was also in evidence in the September interviews. Students used the discourse strategy of invoking personal experience—either firsthand experiences or secondhand stories—to organize their answers to questions calling for experiments. In these cases, they invoked personal experiences as evidence to justify a particular hypothesis (cf. Michaels & Bruce, 1989). A few examples of this kind of reasoning follow:

Example 7: (September/Boston Harbor)

Interviewer: How would you find out what kind of poison it was?

Elinor: I don't know what kind of poison it is, but what makes me say it is that in Haiti they used to drop something in the water and the fish would die and they said it was poison, too.

Example 8: (September/Boston Harbor)

Interviewer: How would you find out if you were right?

Louis: And people might have thrown in things to kill them, too.

Interviewer: Like what?

Louis: In Surinam there's a thing the people do, they leave something in the water. You need fish to eat now, they leave it in the water and, you see people don't know, but it is they who did it. The next day you see a lot of fish and they go sell them.

Interviewer: Mm. How would you know it was because of that that the fish died? You see the fish are dying, you think it might be that, how would you check?

Louis: Because the water got black...

Example 9: (September/Sick Kids)

Interviewer: ...How would you know if it's that [the food]?

Marie Elsie: I don't know. Sometimes when I ate here at school, they gave me food I didn't like, and it didn't...suit my body, and I got sick.

These examples, which are representative of the September protocols, suggest that at the start of the year the students did not have any sense of experimentation as a critical, hypothesis-testing process. In fact, they did not take up the interviewer's bid at all (see immediately following paragraphs for more on this point). Rather, the students seemed to be conceptualizing evidence not as data produced through experimentation but as information already known, either through personal experience or secondhand sources. The evidence offered is not, in these examples, even common knowledge; it is personal knowledge, plain and simple.

The recourse to personal experience is actually only one instance of a more general strategy for dealing with "How would you be sure?" questions in the September interviews. This question actually took several forms, among them: How would you make sure (you were right)? How could you check to see if your idea was right? How would you know it's because . . . ? How could you know it's true? The intent of these questions was to elicit experiments or other analytic methods (e.g., microscopic analysis, observation) that could help in evaluating a given hypothesis. It also led, as we have just seen, into questions of evidence: What would it take to confirm or disconfirm a given hypothesis?

The students' responses to the experiment-elicitation questions in September suggest that they did not interpret them in the way they were intended, as calling for experiments. Rather, they interpreted them as calling for an explanation or an assertion of their knowledge: How do you know? Why do you say that? What did the story I just told you say about this? Some examples follow:

Example 10: (September/Boston Harbor)

Johnny: It's because the water is dirty that the animals are dying. If the water weren't dirty, the animals wouldn't be dying.

(...)

Interviewer: How would you be sure, make sure that it's that that made the fish die?

Johnny: It's because of that, because the water is too dirty.

Example 11: (September/Sick Kids)

Interviewer: OK. You said something they ate made them sick. How would you be sure it was because of that that they got sick? How would you check? How would you know?

Louis: Because he ate something bad at home. Then, he might have had an illness and the doctor had given him a pill but he didn't take it. That might have caused it. Then he might have taken too many pills which made his head swim. Then he might have had a seizure.

As these examples make clear (see also Example 4), the interpretation of the experiment-elicitation question as a call for an explanation or an assertion of knowledge was a favored one among the students in September. That they are interpreting it in this way is most clearly revealed by the way each one explicitly marks his or her answer as an explanation. Note how in each example, the students use "because" to initiate virtually every turn. We see this over and over again in the September protocols. Moreover, the explanations, as we have seen before, are drawn from the text of the problem story, from prior knowledge, and from narrative invention. Like the students' earlier hypotheses, they have no explanatory power.

A similar interpretation was in evidence in the context of another question with which the interviews typically opened: "What is the first thing you would do?" Several students interpreted this question to mean, "What do you think happened?" rather than "What would you, as the scientist, do first?":

Example 12: (September/Boston Harbor)

Interviewer: What's the first thing you do?

Ezekiel: What happened in the water, there was a poison in the water, so that people can't wash, it put something in the fish so they die. All the fish died because the water was spoiled. Because it's dirty.

Interviewer: What kind of poison?

Ezekiel: A poison for water, they put it in to make the water dirty, so all the water will be dirty.

Interviewer: Why would they do that?

Ezekiel: If someone wanted to kill someone, he needs to kill the person, he can't figure out in what to do it, he kills him in a water.

Example 13: (September/Boston Harbor)

Interviewer: What's the first thing you do...to find out what's wrong with the water?

Guerline: Because...

Interviewer: What's the first thing you do?

Guerline: They dropped nasty things in the water, like garbage...that's why the fish can't live, because they die....The water gets dirty and then the fish can't live, they die.

On first glance, putting forward an explanation is not necessarily an unproductive response to the opening question, if it is intended as a hypothesis that initiates further inquiry. But the language of the students' responses does not invite the inference that they are proposing a hypothesis which they will then evaluate. Rather, as we have seen in earlier examples, their discourse is the discourse of school. They are literally trying to explain what happened, as if they were answering a reading comprehension question. Questions of the "What happened?" variety, it hardly needs to be noted, are among the most prevalent kinds of questions in most school literacy tasks (Durkin, 1978-79).

To summarize, then, in the September interviews, students showed almost no evidence that they understand what it means to reason scientifically and, specifically, to put forward hypotheses having deductive consequences that can be evaluated through experimentation. Instead, it is as if they have determined that the discourse context in which they find themselves is no different from that of most school tasks, in which literal comprehension is valued over inferential reasoning and in which questions are asked by a knowing adult to ascertain whether the student knows the right answer. As we have seen repeatedly, the students do not adopt the perspective suggested to them by the interviewer in her introduction to the problem: "You are a famous scientist . . . . What is the first thing you would do to find out what was wrong with the water?" Nor do they show any tendency to analyze the information given, to go beyond it, unless it is to use personal experience as evidence for a particular belief. Rather, they limit the range of their thinking to what is contained within the problem as given.

In contrast to everyday school discourse, the discourse of conjecture and experimentation calls for critical, analytic evaluation of given information or evidence: What are the symptoms? What could possibly explain them? How can I evaluate my ideas? It remains to be seen to what extent in the June interviews the students began to take control of scientific discourse.

JUNE INTERVIEWS

The quantitative results reported earlier clearly suggest that the June interviews differ significantly from the September ones. In this section we will examine, again through examples of students' talk, changes in their knowledge and in the ways they use their knowledge to organize their reasoning in terms of hypotheses, experiments, and explanations.

In June, the students are beginning to reason in terms of a larger explanatory framework. They know more about water pollution and aquatic ecosystems than in September, and they use that knowledge to generate explanations and hypotheses. In the following example, Marie explains how she would clean the water, describing in fairly precise chemical detail how she would rid the water of bacteria and other matter:

Example 14: (June/Boston Harbor)

Interviewer: What would you do first?

Marie: I'd clean the water.

Interviewer: You'd clean it? How?

Marie: Like you look for the things, take the garbage out of the water, you put a screen to block all the paper and stuff, then you clean the water, you put chemical products in it to clean the water, and you'd take all the microscopic life out.

Interviewer: What chemical products would you put in?

Marie: Chlorine and alum, you put in the water.

Interviewer: What would that do?

Marie: They'd gather the little stuff, the little stuff would stick to the chemical products, and they would clean the water.

In the example, Marie paints a chemically accurate account of how alum works in the process of flocculation: It "gather[s] the little stuff, the little stuff would stick to the chemical products . . . " How did she learn this?—From a tour of the local water treatment plant in February, which was conducted in English by one of the plant's chemists. It is striking that in June—five months later—she is using that knowledge productively and spontaneously. Also note that Marie wasn't asked in the interview how she would clean the water; she was simply asked what she would do first. It is clear from this example, which is one of many, that students knew more about water quality and treatment in June than in September.

Students also used their newly acquired knowledge to generate hypotheses. Recall how in September the students' hypotheses often repeated facts reported in the problem story itself. The rare original hypothesis was unelaborated and, more often than not, untestable. In the June interviews, a different explanatory strategy emerges. Not only do the students put forward more testable hypotheses, but they begin to link them to the larger aquatic ecosystem. For example, the September hypothesis that garbage caused the fish to die is elaborated in the June interviews of several students in terms of the effects of waste disposal systems on local water sources:

Example 15: (June/Boston Harbor)

Interviewer: What do you think could make the water like that?

Laura: Like the things people flush, and like when you finish in the kitchen, the dirty water, garbage would enter into the water. The water would be contaminated and now it wouldn't be any good for people to use.

Interviewer: What do you think could make the fish die?

Laure: Like what comes out of the bathrooms and what comes from the kitchen mixed together. They'll mix together. Because there are certain things you use in the kitchen that fish don't eat.(...)

Interviewer: But, like, I don't understand exactly how the garbage kills them.

Laure: The garbage could have other things in it, too. Chemical products could kill them too, maybe.

In this representative June interview example, Laure—who talked about "things" in the September interview—identifies waste disposal systems as a possible source of contamination by linking everyday household activities such as flushing to the Harbor's pollution. What is significant here is the way in which she uses a larger explanatory framework generatively to formulate her hypothesis and then to specify it in terms of chemical products as a possible cause of the Harbor's pollution. Laure's response suggests that she is beginning to understand that hypotheses do not come out of nowhere; they are not the product of naive observation, nor are they simply guesses. Rather, they are informed conjectures, generated from a larger conceptual framework, that have the power to explain observed effects. Note, too, how Laure no longer ascribes the problems in the Harbor to anonymous agents as she did in the September interview. In the June interview, ordinary people are responsible, or the systems that serve them are, not bad people or other unusual agents intent upon doing bad things to others.

The larger system framework was also invoked for other hypotheses. For example, some students speculated that high acidity levels might be killing the fish. When asked how acid can kill fish, Elinor explained:

Example 16: (June/Boston Harbor)

Elinor: The acid can kill if it's too strong. Like if it's used to living in a water that doesn't have... that has a little bit of acid and you leave something in it that is more acid, it can die.

This awareness of system was also in evidence in other parts of the June protocols. Later in her interview, for example, Elinor explains how water could be cleaned using a machine that filters it. The interviewer asks her what she would do with all the bad stuff the machine extracted from the water:

Interviewer: And what would you do with the bad stuff?

Elinor: When you finish you'd take it out, out of the machine.

Interviewer: And where would you put it?

Elinor: You can't leave it on the ground. If you leave it on the ground, the water that, the earth has water underground, it will still spoil the water underground. Or when it rains it will just take it and, when it rains, the water runs, it will take it and leave it in the river, in where the water goes in. Those things, poison things, you aren't supposed to leave it on the ground.

Elinor's answer reveals that she has begun to develop a model of an integrated water system in which an action or event in one part of the system (e.g., "when it rains") has consequences for other parts of the system (e.g., the water "will take it [the bad stuff] and leave it in the river").

These examples of change from September to June are at least in part attributable to changes in the students' knowledge base: They know more about water and aquatic systems than they did at the beginning of the year. But knowledge alone cannot explain the fact that the students put forward more hypotheses and experiments in the June Sick Kids interviews—a topic they did not study during the year. Rather, taken together, the results suggest that the students are doing more than acquiring factual knowledge; they suggest that students are beginning to be enculturated into a new discourse community in which conjecture and experimentation are characteristic modes of inquiry. What is the evidence for this claim?

In both problems in the June interviews, the students tend to put forward a chain of hypotheses of the "if not this, then this" or the "I'd check this and this" variety. In the Sick Kids problem, they enumerate such possible causes as illness, air, water, and food, as in the following examples:

Example 17: (June/Sick Kids)

Interviewer: What do you think might be making the children sick?

Elinor: (Laughs) I'd think it would be an illness someone had and he infected the ones sitting next to him, like one sat next to the other and got it and the next got it until everybody got it... or if, something they ate, each might have eaten something, the same thing, the thing didn't agree with them.

Example 18: (June/Sick Kids)

Interviewer: What would you do to know what was making them sick?

Marie: Like, you could test to see what the kids had eaten and, like, test the water, too, it could be a water that wasn't good, that had microbes, that might have microscopic animals that the children drank that made them sick.

As you can see, the character of the students' hypotheses about the cause of the Sick Kids phenomenon has changed. As in the Boston Harbor problem, in the June interviews they are putting forward testable hypotheses (e.g., illness, food, water), and they are not invoking outside agents to explain the problem. This result holds true for all sixteen students on the Boston Harbor problem and for fourteen on the Sick Kids problem. Moreover, the conditional language (the "ifs," "woulds," and "coulds") they use contrasts sharply with the at once assertive yet vague language they used in the September interviews (e.g., "What happened was," "Someone dropped something in," "Because"). What this suggests to us is that the students are becoming aware of the probationary status of hypotheses as a methodological tool in scientific inquiry.

In summary, then, in the June interviews, the students go beyond the information given to put forward hypotheses that are at once explanatory and testable. They are no longer bound, as in the September interviews, to the problem statement for their answers. Hypotheses now serve to give direction to their inquiry, to link stated symptoms to possible causes and to confine the domain of observation to something smaller and more precise than the phenomena noted in the problem. Moreover, there is the sense from the students' language—in the way they put forward more than one hypothesis and in their use of conditionals—that they are becoming aware of the tentative character and methodological function of hypotheses; hypotheses do not guarantee answers but they do help delimit the scope of one's inquiry. Indeed, as we shall see shortly, the students' June protocols suggest that hypotheses now function as part of a larger inquiry process linking conjecture and experimentation. In the rest of this discussion, we focus on the ways the students participating in the June interviews interpreted and responded to the "How would you be sure?" questions (i.e., those that were intended to elicit experiments and evidence).

Recall how in the September interviews the students interpreted the "How would you make sure/ How would you check?" and also the "What's the first thing you'd do?" questions as calling for an explanation based on the facts of the story as given or for an assertion of personal knowledge. They did not interpret those questions as calling for experiments or other forms of analysis. In the June interviews, students respond to these questions in a distinctly different way, suggesting various analytic procedures and, in several cases, explicitly linking them to a specific hypothesis (e.g., bacteria, water flow):

Example 19: (June/Boston Harbor)

Interviewer: How would you find out if what you think is true?

Caroline: ...I would follow, I would look to see what kind of thing was next to the water, if there was water that was coming from other places into the water.

Example 20: (June/Boston Harbor)

Interviewer: What's the first thing you would do?

Louie:	What would I do? I'd take the water and I would see what it has in it, if it has, bacteria, I'd see if it had bacteria in it.

In these examples, the students are now treating the facts recounted in the problem as evidence in need of an explanation rather than as the explanation itself. One of the students proposes to begin her analysis by monitoring the flow of water into the Harbor; the other proposes to analyze the water for bacteria content. In both cases, the actions they suggest are exploratory but directed, two qualities that are clearly marked in their discourse through verb tense and selection: "I would look to see . . . if there was water that was coming from other places into the water." "I would see what it has in it . . . I'd see if it had bacteria in it." Given what they know about water systems in general and about polluted water systems in particular, they have an idea — an "imaginative preconception" in Medawar's (1987, p. 122) phrase—of what they might reasonably expect to find.

Similarly, in their June responses to the question, "How would you check?", the students begin to reason in terms of experiments, in the simple sense we defined earlier. Most involved testing one variable without controlling for other variables, although several did build in explicit comparisons. In the following example, one student, having hypothesized a cause (garbage) for a reported effect (dead fish), then describes her experiment, the goal of which is to reproduce the effect (the fish die):

Example 21: (June/Boston Harbor)

Interviewer:	Okay, but how would you make sure what you think is true?
Caroline:	I would take a little garbage in the water, I would take a fish and then give it to it to eat to see if it would die.
Interviewer:	What it if doesn't die?
Caroline:	If it doesn't die, it's another reason.

What is significant about Caroline's reasoning is the step forward it represents from the September interviews where the students had no sense of the critical connection between conjecture and experimentation. To be sure, she still has some distance to go to refine her experimental logic. In its current form, it is as if the goal of her experimentation is to produce the expected effect, not to understand its cause. Nevertheless, what is clear is that, whereas in September, the students viewed their problem-based or personal knowledge-based explanations as sufficient evidence to explain phenomena, in June they seem to be developing some sense, if still incomplete, of the way in which conjecture and experimentation function in scientific inquiry. This is perhaps most evident in the last line of the example when Caroline acknowledges iteration as part of the inquiry process. Her use of iteration to generate a new hypothesis, "reason" is her term, is especially significant in light of the students' initial reaction to the results from the first Water Taste Test when they felt strongly that there was something wrong with the experiment but did not consider the possibility that their belief itself could be suspect. In the June protocol, Caroline's reasoning suggests that she is very much aware that hypotheses drive scientific inquiry and that experimentation is a means for developing evidence. Evidence is no longer conceptualized simply as information already known or given, as in the September interviews, but as the product of experimentation undertaken to determine the value of a specific hypothesis.

Not all the one-variable instances were of this simple type, however. In a few cases, the students embedded the testing of variables in an iterative process, in which one variable after another would be tested until the reported effect was produced. In some other cases, the students went beyond this simple model and built contrasts into their experimental design, as in the following example:

Example 22: (June/Boston Harbor)

Laure:	I'd put a fish in fresh water and one fish in a water full of garbage. I'd give the fresh water fish food to eat and the other one in the nasty water, I'd give it food to eat to see if the fresh water, if the one in the fresh water would die with the food I gave it, if the one in the dirty

water would die with the food I gave it.

Interviewer: Would you give them the same food? What would you give the second one?

Laure: The second one, yes. I would give them the same food to see if the things they eat in the water and the things I give them now, which will make them healthy and which wouldn't make them healthy.

Interviewer: ...What do you think you would find?

Laure: I see the one in the clean water might sooner not die than the one in the salty, the dirty water. Because I see, I wouldn't have something in the dirty water and then see the one in the fresh water die and the other survive! I wouldn't think that. I'd think the one in fresh water has more vitamins in it than that, because the one in the dirty water eats any garbage it finds under the water. The other one doesn't eat just anything, he only eats what I give him.

In this example, Laure explicitly builds a treatment into her design to evaluate the effects of garbage; a strong notion of contrast permeates her description (dirty water versus clean water; garbage or unhealthy food versus healthy food). Moreover, she is quite clear on what she expects to find and why. Specifically, she has thought through the deductive consequences of her hypothesis and shows that she understands her experimental design, the key phrase being: "The other one doesn't eat just anything, he only eats what I give him."

To summarize, in the June interviews there is a distinct change in the students' scientific knowledge, reasoning, and discourse. They clearly show that they have acquired knowledge about aquatic ecosystems and that they can use that knowledge productively for scientific inquiry. They no longer limit the range of their thinking to the problem as given. They reason in terms of a larger system where that system is part of their knowledge base, as in the Harbor problem. Furthermore, they use hypotheses to organize and give direction to their reasoning. And they have begun to develop a sense of the function of experimentation in producing evidence to evaluate hypotheses.

That the students have begun to acquire a new discourse is perhaps most evident in the voice they use as they answer the interviewer's questions. In the September interviews, much of the students' discourse was enacted through the omniscient third person, with occasional uses of the first person to tell stories from personal experience. In the June interviews, in contrast, it is the first person that dominates, but it is an "I" distinctly different from the "I" occasionally heard in the September interviews. In June, as several of the preceding examples have shown, the "I" now functions authoritatively, that is, as the voice of an active problem solver.

As we have tried to suggest in this paper, the problem of trying to make sense in science (as much as in other disciplines) is in many respects exactly this problem of finding a voice, or controlling a new discourse, through which one can express one's own intentions, knowledge, experiences, and values. As Cazden (1989) has suggested, following Bakhtin (1981), the struggle is not just to learn new ways of thinking, acting, and using language but ways of appropriating particular discourses and the values of the contexts with which they are associated to one's own purposes. From the foregoing results, we hope it is clear that for these students, as for any students, learning to tell—in Medawar's phrase—good stories in science is not simply a matter of mastering a particular syntactic or explanatory form, as is typically emphasized in English as a second language instruction. Rather, learning to think and talk scientifically is a matter of understanding the approach to knowledge and reasoning, and the values and assumptions that science embodies, and of finding a way to accommodate one's purposes and values alongside those of the scientific and the school cultures. Authentic scientific activity, of the kind realized in Cheche Konnen, is a means to that end.

ONGOING RESEARCH

We are continuing our investigation of scientific sense-making among Haitian seventh and eighth graders. During the 1990-91 school year, these students used traditional Haitian drums to investigate the relationships among acoustics, mathematics, and music. They explored the concepts of frequency, loudness, time, and pitch by experimenting with different sounds and studied the concept of ratio by listening to and analyzing different rhythms. The students' scientific investigation coincided with the production of a school play based upon a well-known Haitian folktale. The young scientists provided music for the play in the form of traditional Haitian drumming, and they prepared an exhibit on drum-making and Haitian drum rhythms for display during the performance.

In this study, we are focusing our analyses on the orchestration of classroom dialogue and joint activity in order to understand how students' scientific understanding of sound and pitch is socially and linguistically mediated. The classroom teacher has been an active participant in the research effort and has spent the past year working at TERC (Technical Education Research Center) while on sabbatical.

The participation of teachers is a significant part of the research effort. Our collaboration is organized around a seminar on scientific sense-making in which we address such issues as how students and teachers can build a culture of authentic scientific practice in language minority classrooms. In the seminar, the teachers do science; explore what science is and how scientific knowledge is constructed; and analyze and redefine their own classroom practice in relation to their work in the seminar. As a group, we are analyzing the videotapes from the teacher seminar and the teachers' classrooms to further our understanding of how students and teachers appropriate scientific ways of thinking, knowing, and talking.

NOTES

[1] Latino and Portuguese students were not included in these analyses because of flaws in the June interview process. Two students, one a speaker of Amharic, the other a speaker of Tigrinya, were not interviewed.

[2] The original protocols in Haitian Creole are available as part of the working paper on which this article is based (Rosebery, Warren, & Conant, 1991).

[3] In all excerpts presented here, the following transcription conventions are used:

... = pause
(...) = unintelligible
[ ] = text inserted by authors for clarification

[4] Translation of Spanish in Figure 1:

This is what I wrote about these animals.

This is a worm looked at without a microscope. It is a small animal that moves and is long. The animal is red. There are small things moving rapidly near the animal.

This animal may be seen without a microscope. They look like dots. It is a small black animal and it moves very fast.

These are small animals that may be seen without a microscope. They look like dots and these little animals move very fast.

REFERENCES

Au, K. (1980). Participation structures in a reading lesson with Hawaiian children: Analysis of a culturally appropriate instructional event. *Anthropology and Education Quarterly, 11* (2), 91-115.

Au, K., & Jordan, C. (1981). Teaching reading to Hawaiian children: Finding a culturally appropriate solution. In H.T. Trueba, G.P Guthrie, & K. Au (Eds.), *Culture and the bilingual classroom: Studies in classroom ethnography* (pp. 139-152). Rowley, MA: Newbury House.

Bakhtin, M. (1981). *The dialogic imagination.* Austin: University of Texas.

Barnes, D., & Todd, F. (1977). Talk in small learning groups: Analysis of strategies. In C. Adelman (Ed.), *Uttering, muttering: Collecting, using and reporting talk for social and educational research* (pp. 66-77). London: Grant McIntyre.

Brown, A., & Palincsar, A.M. (1989). Guided, cooperative learning and individual knowledge acquisition. In L.B. Resnick (Ed.), *Cognition and instruction: Issues and agendas* (pp. 393-451). Hillsdale, NJ: Lawrence Erlbaum.

Cazden, C.B. (1989, April). *Vygotsky and Bakhtin: From word to utterance and voice.* Paper presented at the annual meeting of the American Educational Research Association, San Francisco.

Cazden, C.B., John, V.P., & Hymes, D. (1972). *Functions of language in the classroom.* New York: Teachers College Press.

Durkin, D. (1978-79). What classroom observations reveal about reading comprehension instruction. *Reading Research Quarterly, 14,* 481-533.

Gee, J.P. (1989). *What is literacy?* (Tech. Rep. No. 2). Newton, MA: The Literacies Institute.

Gilbert, G., & Mulkay, M. (1984). *Opening Pandora's box: A sociological analysis of scientist's discourse.* Cambridge: Cambridge University Press.

Hatano, G. (1981). Cognitive consequences of practice in culture specific procedural skills. *The Quarterly Newsletter of the Laboratory of Comparative Human Cognition, 4,* 15-18.

Heath, S.B. (1983). *Ways with words: Language, life, and work in communities and classrooms.* New York: Cambridge University Press.

Inagaki, K., & Hatano, G. (1983). Collective scientific discovery by young children. *The Quarterly Newsletter of the Laboratory of Comparative Human Cognition, 5,* 13-18.

Kuhn, T. (1977). *The essential tension: Selected studies in scientific tradition and change.* Chicago: The University of Chicago Press.

Latour, B. (1987). *Science in action.* Cambridge, MA: Harvard University Press.

Latour, B., & Woolgar, S. (1986). *Laboratory life: The social construction of scientific facts.* Princeton, NJ: Princeton University Press.

Lave, J., & Wenger, E. (in press). *Situated learning: Legitimate peripheral participation.* New York: Cambridge University Press.

The Literacies Institute. (1989). *The Literacies Institute: Its mission, activities and perspective on literacy* (Tech. Rep. No. 1). Newton, MA: Educational Development Center.

Longino, H. (1990). *Science as social knowledge.* Princeton, NJ: Princeton University Press.

Medawar, P. (1987). *Pluto's republic.* Oxford: Oxford University Press.

Michaels, S., & Bruce, B.C. (1989). *Discourses on the seasons* (Technical Report). Champaign, IL: University of Illinois, Reading Research and Education Center.

Mohatt, G., & Erickson, F. (1980). Cultural differences in teaching styles in an Odawa school: A sociolinguistic approach. In H.T. Trueba, G.P. Guthrie, & K. Au (Eds.), *Culture and the bilingual classroom: Studies in classroom ethnography* (pp.105-119). Rowley, MA: Newbury House.

Moll, L. (in press). Bilingual classroom studies and community analysis: Some recent trends. *Educational Researcher.*

Philips, S. (1972). Participant structures and communicative competence: Warm Springs children in community and classroom. In C. Cazden, D. Hymes, & V. John (Eds.), *Functions of language in the classroom* (pp. 370-394). New York: Teachers College Press.

Philips, S. (1983). *The invisible culture: Communication in classroom and community in the Warm Springs Reservation.* New York: Longman.

Rosebery, A.S., Warren, B., & Conant, F.R. (1989). *Making sense of science in language minority classrooms* (BBN Tech. Rep. No. 7306). Cambridge, MA: Bolt, Beranek, & Newman.

Rosebery, A.S., Warren, B., & Conant, F.R. (1991). *Appropriating scientific discourse: Findings from language minority classrooms* (Working Paper). Cambridge, MA: Technical Education Research Center.

Schoenfeld, A. (in press). Learning to think mathematically: Problem solving, metacognition, and sense-making in mathematics. In D. Grouws (Ed.), *Handbook for research on mathematics teaching and learning.* New York: MacMillan.

Trueba, H.T., Guthrie, G., & Au, K. (Eds.). (1981). *Culture and the bilingual classroom: Studies in classroom ethnography.* Rowley, MA: Newbury House.

Vygotsky, L.S. (1978). *Mind in society.* Cambridge, MA: Harvard University Press.

Warren, B., Rosebery, A.S., & Conant, F.R. (1989). *Cheche Konnen: Science and literacy in language minority classrooms* (BBN Tech. Rep. No. 7305). Cambridge, MA: Bolt, Beranek, & Newman.

Warren, B., Rosebery, A.S., & Conant, F.R. (in press). Discourse and social practice: Learning science in bilingual classrooms. In D. Spener (Ed.), *Biliteracy: Theory and practice.* Englewood Cliffs, NJ: Regents Prentice Hall/Center for Applied Linguistics.

RESEARCH REPORTS

RR 1 *Sociological Foundations Supporting the Study of Cultural Diversity* (1991)
Hugh Mehan

RR 2 *The Instructional Conversation: Teaching and Learning in Social Activity* (1991)
Roland G. Tharp & Ronald Gallimore

RR3 *Appropriating Scientific Discourse: Findings from Language Minority Classrooms* (1992)
Ann S. Rosebery, Beth Warren & Faith R. Conant

EDUCATIONAL PRACTICE REPORTS

EPR 1 *The Education of Linguistically and Culturally Diverse Students: Effective Instructional Practices* (1991)
Eugene E. Garcia

EPR 2 *Instructional Conversations and Their Classroom Application* (1991)
Claude Goldenberg

EPR 3 *Language Minority Education in the United States: Implications of the Ramirez Report* (1992)
Courtney B. Cazden

EPR 4 *Rating Instructional Conversations: A Guide* (1992)
Robert Rueda, Claude Goldenberg & Ronald Gallimore

To order copies of these reports, please write or call:

Dissemination Coordinator
National Center for Research on Cultural Diversity
and Second Language Learning
Center for Applied Linguistics
1118 22nd Street N.W.
Washington, D.C. 20037
202-429-9292

THE NATIONAL CENTER FOR
RESEARCH ON
CULTURAL DIVERSITY AND
SECOND LANGUAGE LEARNING
399 KERR HALL
UNIVERSITY OF CALIFORNIA
SANTA CRUZ, CA 95064
PHONE: (408) 459-3500
FAX: (408) 459-3502

recycled paper