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Explaining Explanations

Developing Scientific Literacy in Middle School Project-Based Science Reforms

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Key Points

- Science literacy reform was embedded in project-based science units, with a focus on helping students construct scientific explanations.
- The reform initiative also focused on the teaching of skills for collecting, representing, and analyzing data in investigations.
- Interactive reading materials were created so that they could be closely integrated with the activities of the curriculum units.

In this chapter, we report on our work within the Center for Learning Technologies in Urban Schools (LeTUS) to develop scientific literacy in a systemic science education reform initiative.[1] Begun in 1997, LeTUS was launched to promote inquiry-based science and technology learning at the secondary school level. In the LeTUS collaboration, teachers, curriculum developers, and administrators in the Detroit Public Schools have partnered with University of Michigan researchers, teacher educators, and curriculum developers to develop, enact, and study "project-based science" curriculum units in more than 20 middle schools across Detroit. In the remainder of the chapter, we will focus on describing project-based science (PBS) and our efforts to embed scientific literacy reform in PBS units.[2]

PROJECT-BASED SCIENCE

Project-based science (or any project-based curricula) frames and motivates student learning by real-world questions that are of interest to real people in real places. For example, our units revolve around questions such as, "What affects the quality of air in my community?" (air quality—chemistry); "Can good friends make you sick?" (communicable diseases—biology); and "What is the water like in my river?" (water quality—chemistry and ecology). The features of PBS curricula include

1. Driving questions anchored in real-world problems.
2. Investigations and artifact creation.
3. Collaboration among students, teachers, and others in the community.
4. Use of technological tools (Krajcik, Blumenfeld, Marx, Bass, & Fredricks, 1998; Singer, Marx, Krajcik, & Clay-Chambers, 2000).

Each LeTUS PBS unit is constructed with these features, as well as with the state standards and district benchmarks, in mind. We also continually consider the language and form of the state testing program as we develop various activities (both print and non-print) so that students will experience activities that are consonant with the testing program. The results of this work have been encouraging, with analyses of nearly 5,000 students' test scores demonstrating statistically significant increases for each year of participation. Moreover, the strength of the effects grew over the years, as shown by increasing effect size estimates across years (Marx, Blumenfeld, Fishman, Krajcik, & Soloway, 2001).

Until recently, the curricula have focused primarily on developing electronic technology tools and have not looked as closely at the language and literacy tasks embedded in the curriculum (and within the technology) or at the demands those tools make of students and teachers. We are particularly interested in questions of language and literacy because, although students have made gains, the gains tend to be highest at a basic knowledge level of science content learning. Gains are less strong when it comes to process questions or more cognitively demanding assessments, in which students must read data tables and graphs as they produce short-answer responses to questions about fictional investigations (Marx et al., 2001). In addition, a number of questions and challenges raised by teachers in professional development meetings, together with the Detroit Public Schools' systemic commitment to the improvement of content area literacy learning, has led us to focus a substantial aspect of our current systemic reform efforts on the development of scientific literacy. Our research in these classrooms (e.g., observations of students struggling to read questions or to record data during investigations) supports and informs this new emphasis in our efforts to develop project-based science.

Literacy in Project-Based Science

Although project-based science provides opportunities for students to engage in dialogue and collaboration around investigations of real-world problems, it can make extensive demands on students and teachers (Moje, Collazo, Carrillo, & Marx, 2001). In particular, as teachers attempt to engage students in real-world investigations, they struggle with the role that various print materials—from curriculum worksheets to electronic databases—should play in supporting and extending these investigations. Both teachers and curriculum developers in our current efforts recognize that scientists use print texts extensively in their work. Moreover, the teachers in Detroit are committed to engaging students in reading and writing texts in ways that support students' investigations. And yet, many of their students either struggle with basic reading and writing processes or with the technical and interpretive demands of science text. Most students require support in comprehension, composition, and meaning making or application of science texts (Goldman, 1997; Lee & Fradd, 1998; Nicholson, 1985). Unfortunately, the constrained time periods for doing science during a typical school day make it challenging for teachers to *teach* students how to use print texts to engage in inquiry.

In addition, science learning requires students to bring skills of prediction, observation, analysis, summarization, and presentation to their science reading, writing, and oral language practices (Lee & Fradd, 1998). These scientific literacy and language practices are even more important in project-based science in which students search for and synthesize information across texts and other people (Blumenfeld, Marx, Patrick, & Krajcik, 1997; Goldman, 1997). At the secondary school level, in particular, young people are expected to apply previously learned language, literacy, and technology skills to the comprehension, interpretation, and application of disciplinary knowledge even when not engaged in project curricula.

In addition, PBS presents a bit of a paradox in terms of language and literacy: Because project-based curricula engage youth in textual and experiential inquiry about authentic questions, the curricula can be considered discourse *enabling* and thus represent an excellent way to learn science, as students are engaged in communicating science (National Research Council, 1996). At the same time, however, the extensive discursive demands of the inquiry activities in the curricula can be difficult for students because science discourse and practices are new to them (Krajcik et al., 1998; Merino & Hammond, 1998) and they do not yet have facility with the language of science. As Lemke (1990) has illustrated, the language of science represents a specialized system of language that is based on *thematic formations* or assumptions about what counts as scientific inquiry, which are well understood by scientists who have apprenticed and practiced in the profession for years. For example, scientists know that they must not only report data collected in an experiment but also explicitly articulate their reasoning about the data as they explain findings and draw conclusions about the phenomena, even when the findings, on the surface, may appear self-evident. Scientists recognize that their articulation of logical connections among phenomena is as important as the statistical or observational analyses that they make, for it is in these explicit, articulated interpretations that knowledge is produced and shared among the members of the science community. Becoming a member of the science discourse community, however, can be challenging for any student. For many, the assumptions of science are not explicit, which can lead to confusion as students encounter new ways of thinking, talking, reading, and writing in their science classrooms

(Hicks, 1995/1996). Thus, even fluent readers and writers of narrative or general knowledge texts can struggle with reading and writing science texts simply because they have not yet taken up the assumptions and corresponding practices of science.

Finally, many students in Detroit schools live in homes where mainstream English is not a dominant language. The importance of an emphasis on language and discourse in the curriculum is heightened for children in dual language or dialect schools. As Cummins (1984) argued, students proficient in the English necessary for social interactions are not necessarily prepared to engage in academic and disciplinary discourse. Similarly, Wong-Fillmore (1982) demonstrated that two basic language skills are required for the learning of academic subject matter: an understanding of the spoken language of instruction and an understanding of the language of textbooks. The discourse of science—that is, the thematic formations or assumptions that shape the ways people speak, read, and write with the science community—represents a challenge to understanding the language of instruction and text even for English-dominant students (Goldman, 1997); what is it like for students whose first language is not mainstream English? In other words, English language learners face a triple challenge: They must learn not only the English language but also the language of academic discourse and of the discourse of science. Thus, the discourse-*dependent* aspect of the curriculum may be especially challenging and, without some scaffolding, may constrain learning opportunities for these students.

In our last six years of developing, enacting, and researching project-based curricula in Detroit, we have come to recognize these language and literacy demands as a central dilemma for science teachers and students. As a result, we have developed and piloted a number of strategies and materials without adding to teachers' and students' already overwhelming set of classroom tasks. We also have been studying how these skills shape students' opportunities to learn. In this chapter, we describe just a few of these strategies and present some findings on our initial efforts in the systemic reform of scientific literacy education at the secondary school level.

The Reformers and the Learners

Approximately 75 middle school science teachers in approximately 200 classrooms throughout the Detroit Public Schools (numbers vary from year to year) enact the PBS curriculum units. The schools in Detroit are populated primarily by African American students (91.1%), followed by Latino/a students (4%), European American students (3.7%), Asian and Pacific Island students (0.9%), and American Indian students (0.2%). The average percentage of students eligible for the free or reduced lunch program throughout the district is 70%, although the percentage of eligible students is higher in most of the LeTUS schools. The teachers who participate in LeTUS represent a mix of ethnic, racial, and social class groups, but the teachers in the subset represented in this paper are all African American and Latino/a in racial and ethnic background.

Achievement scores on the state testing program show 13.6% of all students in the district meeting state standards in science, 55% in writing, and

33.2% in reading in 1999. These percentages illustrate that there is a gap between students' achievement in science and their achievement in general literacy proficiency (although the literacy scores also demand improvement). Consequently, our focus on literacy in science learning seems merited not only by our observations of the challenges students and teachers face as they engage in reading and writing in their science classrooms, but also by the disjuncture we have observed in achievement scores. These scores, combined with research on the role of oral and written language in learning science, suggest that a focus on helping students understand and access the language and processes of inquiry in science may support their developing understanding of and achievement in critically important science concepts and processes.

The literacy work that we describe in this chapter is being piloted in 16 science classrooms of four teachers. At the schools in our pilot, a range of 0.8% to 72% of students have met state science standards. Reading scores at the pilot schools range from 19.1 to 61.9% of the students meeting state standards, and in the eighth-grade writing assessment, 28.4–100% of the pilot school students meet state standards. Again, the disparity between science achievement and general literacy achievement seems vast, even in the school in which achievement scores are high. What accounts for this disparity? Is it the amount of time spent on science instruction in the earlier grades? Is it students' lack of scientific literacy skills, which may impede their demonstration of achievement on print-based achievement tests? Could more time be dedicated across the grades to teaching literacy skills as embedded in content area learning? This last question taps into our goals for this systemic reform initiative.

Methods of Enactment and Research on the Reform Efforts

All teachers who participate in LeTUS attend monthly professional development activities, often led by more senior LeTUS teachers. In addition, the teachers, researchers, and curriculum developers involved in the pilot work meet for bimonthly professional and curriculum development work. As a team, we videotape in classrooms and collect students' and teachers' work, which serve as artifacts of students' learning over time. Students' learning is also measured via pre- and post-unit tests on science content and process knowledge, as well as on several performance tasks administered throughout the unit. Finally, at the conclusion of each unit, we interview a subset of students in each target classroom on their content knowledge, attitudes about and toward science, and strategies for sense making in the curriculum. Each of these measures is used to inform our curriculum development and to generate research findings.

EXPLAINING OUR PRACTICE AROUND EXPLANATIONS

Our reform efforts in scientific literacy development follow several different trajectories. Due to space constraints, we will report on only three of these interrelated efforts: (a) a focus on teaching the conventions of scientific communication or discourse, focused particularly on how to construct *scientific* *explanations*; (b) a focus on the teaching of skills for *collecting, representing, and analyzing data* in investigations; and (c) the creation of *interactive reading materials* that support the development of skills required in points (a) and (b). Although we will discuss our practices in all three areas, we will focus our discussion of findings on the teaching of explanation writing because explanations have been a central aspect of our work and because we continue to collect and analyze data in the other two areas.

Scientific Explanations

In project-based science, students conduct investigations for which they must represent their data visually (e.g., chart or graph), represent their interpretation, and use the data interpretation to write an explanation of phenomena. In our recent work with teachers and students, we have focused on explicit instruction in and repeated practice around writing explanations of actual investigations. When we use the term *explicit,* we refer to an approach in which teachers and students make specific distinctions among different kinds of explanations of real-world phenomena. Such distinctions include the everyday explanations of their experiences that they make to friends and family and the scientific explanations that they make after conducting a controlled experiment in the classroom. This engagement with the discursive conventions (e.g., making hypotheses and claims about hypotheses, providing data to support claims, explaining one's reasoning, arguing, etc.) and practices of different discourse communities, we argue, is the key to developing thoughtful literate practices in the content areas.

As teachers and students engage in inquiry around phenomena, teachers help students learn the literate practices required to make scientific investigation meaningful. Together with students, the teachers and researchers have constructed, tested, and refined criteria for producing scientific explanations that include

1. Making a claim.
2. Providing multiple pieces of evidence drawn from experimentation or from others' research.
3. Reasoning how it is that the evidence links back to the claim.
4. Writing in precise and accurate scientific language that someone who understands or cares about science, but who is not familiar with the particular investigation, can understand.

We use these criteria in the classroom teaching and in our analysis of classroom data.

This practice follows a certain pattern each year. At the beginning of our first curriculum unit (which is typically the air-quality unit), teachers ask students to read sample explanations, written by actual students, and to evaluate the explanations. The teachers do not necessarily introduce the criteria before asking students to evaluate, with the goal of engaging students in generating criteria that they will apply to their writing of evaluations throughout the year. The teachers, of course, have in mind the criteria that we generated (from just such a process) in Year 1, and they may guide students to frame the criteria in similar language, but they nevertheless take their students through the process each year because they recognize the value in asking students to assess samples and to induce criteria, rather than simply being presented with a list of criteria.

Throughout the unit, the teachers and students work through a series of investigations and electronic text searches that allow them to practice writing explanations both of empirical investigations and of information they must synthesize from multiple texts. As a group, we have also worked out a scheme for thinking about what each criterion means.

Making a Claim. For example, a *claim* is a statement of one's understanding about a phenomenon or a situation, about the results of an experiment, or about other data. If the claim is made in reference to an empirical investigation, then the claim must relate to the hypothesis or the research question. In addition, when drawing a conclusion from an experiment, the claim must show how the dependent variable and the independent variable are related to one another (if there *are* dependent and independent variables in the investigation).

Providing Evidence. To *provide evidence* for the claim, a student may use observations, a controlled experiment, or other sources, such as a review of research already conducted. We remind students that not all data one collects are important to the original question asked or to a particular hypothesis. A good explanation uses only information that relates to the original idea.

Finally, if possible, students should use multiple pieces of evidence in an explanation based on an experiment.

Linking Evidence to a Claim. Often, the most difficult aspect of explanation writing to teach revolves around encouraging students to articulate their reasoning for a claim that they have made. We find that once students realize that they need to use data drawn from their investigations or from data tables provided for them, they tend to simply restate the data without explaining how they have made sense of the data to answer their questions or test their hypotheses. We also find this difficult to teach. Teachers have worked on modeling reasoning, making clear to students that reasoning involves explaining *how* the evidence supports the claim. This "reasoning" aspect typically answers, "How do you know that?" (e.g., I know this because . . .).

Writing a Scientific Explanation. We also encourage the use of precise and accurate scientific language. For this criterion, we emphasize that a good explanation is *focused* on a particular phenomenon. A good explanation is also thorough. It includes all necessary details and no unnecessary details.

We not only hope to see students using technical terms appropriately, but we also look for students' use of specific indexical terms (e.g., "when the temperature increased" rather than "when it got hotter," since the "it" in the second phrase could refer to any one of the objects in the experiment). Teachers have found it helpful to have students think in terms of how a scientist might write the same explanation. We also hope eventually to have students experiment with how different groups of people might write an explanation of the same phenomena, thus emphasizing that the language and literacy conventions and practices of science are only one set of possible conventions and practices they might take up. We also hope to move, eventually, to engaging students in critique of those conventions. To engage in critique, however, requires some facility with the conventions themselves.

The teachers also engage the students in thinking about what each of the criteria mean. What, for example, is precise language that someone who is not familiar with an investigation could understand? One teacher suggested taking students through a direction-writing activity, in which the students gave directions for accomplishing some simple task (e.g., making a peanut butter sandwich) while she attempted to follow their directions to the letter. Through such activities, students began to see what it meant to spell out the objects being studied and analyzed, the details of procedures used in investigations, and how data relate to a particular claim. Some of the examples of student explanations pre- and post-unit that we provide later in the chapter illustrate the students' growth in this area.

Collecting, Representing, and Analyzing Data

In this aspect of our work, we are striving to better support students' mediation of understanding across multiple forms of representation. As inquiry approaches have gained more currency in secondary school science classrooms, students have found themselves faced with actual data from actual investigations. Unfortunately, most students have little experience with developing appropriate questions and hypotheses for investigations and designing studies (i.e., choosing controls, eliminating confounding variables) to carry out the investigations. Far fewer have had experience with the process of collecting, representing, and analyzing the data that they collect in investigations. Our curricula in the past have included explicit scaffolds to support students in planning and designing investigations (e.g., rubrics for good questions and hypotheses, a teacher modeling strategy that we call the "eyeglass model"), but we have not developed as many strategies to support the mediation of understanding across many different forms of representation. Given our emphasis on developing strong and accurate scientific explanations, we decided to simultaneously attend to supporting students' work with the data that they would ultimately need to explain. Our work on meaning making across multiple forms of representation involves four areas that precede the writing of explanations: collecting data systematically and rigorously, representing what one observes in data collection, translating first-level representations into other forms of data representation, and interpreting and synthesizing data from different representations.

Collecting Data Systematically and Rigorously. The focus on data collection includes making explicit the importance of seemingly mundane and obvious requirements that are necessary to clean data collection in science. For example, in the bacteria growth investigation conducted as part of the communicable disease unit, students are reminded of such things as the need to record and maintain the location of a Petri dish and what the conditions are of the location, to check the Petri dish regularly, to make notes about the same qualities of the bacteria under study for each observation (e.g., do not note color on one occasion and size of the colony on the next). We emphasize that such skills can be modeled by teachers even if schedules do not allow students to conduct their own investigations over lengthy periods of time.

Representing What One Observes in Data Collection. This aspect focuses on what teachers should model for students about how they could record their data in any given investigation. We encourage teachers to provide students with several different options, from drawing pictures to making tables. Teachers ask their students to think about whether it is better to represent a phenomenon with numbers, with words, or with shapes. Teachers ask students to think about the kinds of changes they might look for and to think carefully about what is worth recording, all in relation to one's research questions and hypotheses. The teachers talk with students about how their data representation choices depend in part on the nature of the data (drawing bacteria colonies in the communicable disease unit may be most useful, but drawing the cases of people who have syphilis would not be), *and* they model what such representations might look like in each instance. Depending on schedules, some teachers ask students to try to come up with their own systems for recording the data, often in small groups, and then groups share the different methods with the whole class.

Translating First-Level Representations Into Other Forms of Data Representation. In this phase, teachers provide students with opportunities to work across a number of data representations, explaining that scientists (both natural and social) often do this because it allows them to think about the data differently. These representations, then, are tools that help them make sense of the data. The teachers also help students recognize that people use tools like this all the time in life. We draw pictures of things we want to remember, then we redraw them into some other kind of representation, perhaps with words, with numbers, on a chart, or on a graph. Then the teachers can ask students what they think they could do to represent the pictures differently, or they can walk students through three other forms: verbal (a written description), tabular, and graphic.

It is also important for teachers to help students see that certain forms are often used by scientists and journalists to report data because they can show complicated concepts in a small amount of space. Such conversations about how writers choose different ways of representing their ideas helps students begin to see that print, while important and useful, is not always the best way to represent ideas. In addition, students can come to see that people use different representational forms for good reasons, not just to make their writing look interesting. And finally, students can start to see that different forms of representation, from print to drawings to graphs, can work together to communicate some concept that is deeper and more all-encompassing than any single form of representation can communicate.

Interpreting and Synthesizing Data From Different Representations. This aspect of data analysis leads into writing a formal scientific explanation. The students have to draw conclusions about what their data say *in relation to their hypotheses*. They may have to look across multiple representations they have made (from a graph to a table to a drawing to words), or they may have to look across the data sets of multiple groups of "researchers." This work comprises opportunities to talk about what the different representations might mean and then to focus on trying to make some claims, use data from different representations, and reason through the data to turn the data into evidence that supports their claim(s). Teachers have engaged students in what the teachers call "museum walks" in which they examine the representations of other groups and then engage in constructive peer critique. Maintaining the constructive focus but encouraging thoughtful critique is the most challenging aspect of this practice, and the teachers in our group continue to refine this strategy to scaffold students' critiquing skills and their ability to make the best use of helpful critiques.

Interactive Reading Materials

We have sought to develop student reading materials that are tightly integrated with the everyday activities of the curriculum units (in a way that a general textbook could not be) and that both draw from and lead into new ideas introduced in each lesson. To support our pilot work on developing students' abilities to make scientific explanations, we are currently weaving into the reader opportunities to explain findings of investigations, concepts learned from literature searches, and everyday experiences with the physical world.

In addition, we have identified different text forms that students may encounter in and out of school: (a) *constructed expository text* (such as one might find in a textbook or science journal); (b) *constructed narrative text* (such as case studies); and (c) *real-world texts* (such as one might find in a newspaper or citizen's action group publication). We work from the stance that, for students to learn optimally from text, texts must be *considerate*. That is, they must (a) present clear organizational patterns; (b) make relationships among ideas clear; (c) contain only the most relevant information; and (d) be sensitive to the knowledge base of the imagined reader (Anderson & Armbruster, 1984). In addition, print texts of any type need to include other forms of representation (e.g., graphs, icons, models) that illustrate, highlight, or present concepts that cannot be clearly explained in print form.

We are working from the hypothesis that constructed narratives—or case studies—can support students' literacy development and science learning as they provide a link between real-world texts and constructed expository texts. That said, however, case studies alone cannot provide the depth of information that expository texts can provide, nor do they represent the real world of students' experiences as do real-world newspaper texts. Students need many different kinds of texts for optimal learning. They need considerate expository texts from which to glean content information, and they need real-world texts that are situated in actual community and world events to fully contextualize the science concepts. They need constructed narratives, or case study texts, to link the other types of texts together. What is more, students need to develop strategies for navigating many different types of science text. If carefully sequenced and linked to classroom inquiry activities—particularly to our scientific explanation activities—as well as to students' real-world experiences, these three text types can function as a unit to promote conceptual understanding, the development of process skills in inquiry, and the development of scientific literacy. Although we have been using reading materials that we have developed according to the guidelines for considerate expository text, we are only at the beginning stages of developing multiple-genre readers that draw from the real-world, popular cultural texts that students use daily in sophisticated ways.

Materials That Support Our Work (Samples in Appendix)

As illustrated in the Appendix, teachers, researchers, and curriculum developers have worked together to develop materials for teaching and research purposes. A sample of each of the materials described is included in the Appendix.

Rubrics for Writing and Scoring Explanations. One of our primary tasks was to develop rubrics to assess the explanations that students produce from each investigation. The scoring rubrics in Figure 13.1 are directly tied to the criteria that teachers and students generate together at the beginning of the semester. The teachers in the pilot work use the rubrics holistically to make regular assessments of students. That is, they rank the explanations from a high of 3 (accurate, complete with evidence and reasoning, and clearly written) to 1 (inaccurate, lacking evidence and reasoning, or poorly written). In addition, our team (teachers, developers, and researchers) reviews the students' explanations using the rubrics in order to determine next steps in our curriculum development and ways to enhance the day-to-day enactments. Finally, we use these scoring rubrics to analyze the growth over time in students' scientific literacy development.

Student Sheets. For each lesson set in each unit, we develop sheets that give students opportunities to practice their scientific literacy and process skills. For example, the student sheets included in the Appendix provide a scaffolded space for students to carry out an investigation on how much oxygen is in air (see Figure 13.2) and to practice writing a scientific explanation of their findings (see Figure 13.3). This sample comes early in the first curriculum unit. As we move throughout each unit, we eliminate more and more scaffolding so that by the end of the unit, students are addressing the questions and activities without reminders and supports. The most important aspect of these sheets is that they are not intended to be used as seat work or even as homework. Instead, they are intended to support the work of students and teachers—as individuals or in groups—as they move throughout the curriculum units. For example, as illustrated in the sample provided in the Appendix, these student sheets provide guidance during investigations that students carry out during class time. And in this particular example, students begin by making predictions in small groups, working in small groups to carry out the investigation and record observations, writing claims as a whole class, and, finally, writing individual explanations with the scaffolding provided on the student sheets.

Reading Materials. Readers are provided for each curriculum unit that LeTUS produces. To date, our only reader that includes multiple text genres is the reader that accompanies the communicable disease unit; however, all of our other readers include constructed expository text that seeks to integrate the readers with classroom inquiry activities and provide a space for students to interact with the concepts discussed in the readers. We continue to develop multiple-text-genre readers according to the design principles described earlier, and we have planned an experimental study for the fall and winter of 2003–2004 in which we will test different versions of the reader in different classrooms. Two pages from the communicable disease curriculum reader are included in the Appendix as Figure 13.4.

Findings From Research on Our Practice

Findings from our first year of work indicate that although we obtained gains on lower-level content knowledge measures, a majority of the middle school students we work with experience some difficulties with abstract concepts and processes encountered in project-based science. (This pattern was not new to us, as it had been the driving force behind our focus on scientific literacy.) We found that students have difficulties with

1. Science process skills, especially analyzing, interpreting, and reporting data in verbal or graphic representations.
2. Scientific thinking that underlies understanding of these processes, such as causal and analogical reasoning, representation, and explanation.
3. Using scientific discourse to communicate and build understanding of scientific ideas.

These difficulties influenced the degree to which students could benefit from the opportunities to engage in inquiry offered via project-based science.

Explanation Writing. As we have engaged in the systematic teaching of how to represent one's understandings of real-world phenomena according to the conventions of a scientific discourse community, we have observed students articulating their internalization of these conventions in both everyday classroom interactions, on classroom written artifacts, and on formal curriculum post-tests. Initial data analyses of the post-tests and performance tasks from our pilot enactment indicate that the students showed gains in the production of written explanations that met the major criteria of our analytic rubric. Using criterion scoring rubrics based on the categories of the holistic rubric that teachers use in the classroom (see Figure 13.1 in the Appendix), we have found that approximately 50% of students in all classrooms are able to produce more accurate and more detailed explanations at the end of each unit.

Consider the difference in the following explanations offered in response to a written air-quality-unit pre- and post-test question that provided the students with the details of a fictional experiment, together with data presented in tabular and graph form (same data simply represented differently). Students were asked to read the details of the investigation, analyze the data presented in the table and graph, and then explain the data in relation to the hypothesis the fictional class of students had posed. The experiment proposed to investigate whether there was a difference in the amount of particulate matter released by cars produced in different years by using a sock placed over the exhaust pipe. The fictional class's hypothesis is "The age of the car will have no effect on the amount of particulate matter the car releases." The following examples are taken from students at three different schools and represent a range of student ability levels (spelling, punctuation, grammar intact in each exemplar):

Student 1

Pre: The old one is black and when they made the new one it start to get lighter and lighter.

Post: Old cars got more pollution the new cars because the old cars average sock color at end of experiment is black that mean the old cars polluted the air the most. The average car got dark gray average sock color at end of experiment because is also polluted the air but not more pollution then the old cars. The new cars also polluted the air but not as much as the old cars and the average cars.

Student 2

Pre: The age does have an effect on the amount of particulate matter that the car releases.

Post: The older the car the more particulate matter it's going to realease. I know this because according to the charts the old car sock turned black the average turned dark gray and the new turned light gray. The class hypothesis was wrong.

Student 3

Pre: This probably happened because the old cars weren't very up to date. They were regular cars, but they probably ran on something

> else or some additional electronics. The new cars were up to date and probably ran on something different that used less fuel than the old cars. The students had a very good guess, but they were completely wrong.
>
> *Post:* The hypothesis was first of all wrong. When the car was made before 1978 and was old there was more particulate matter released and the sock was black. When the car was made between 1978 and 1989 there was a little less particulate matter released and the sock was dark gray. Last when the car was made after 1990 there was alot less particulate matter released into the air and the sock was light gray. So over all the newer the car the less particulate matter that was released.

We have noted several areas of growth in analyzing responses such as these. First, students appear to be developing a higher degree of facility with scientific discourse. For example, Student 3 shifts from "the students had a good guess" to "The hypothesis was first of all wrong." Similarly, Student 2 refers to the hypothesis in his post-test explanation but not in the pre-test explanation. The same student took up the phrase "particulate matter" in her post-test explanation. Student 1, who uses the least scientific terminology in the post-test, does, however, use more detailed and precise language to explain her accurate claim about the investigation.

These exemplars also illustrate a second pattern that we have observed. In making post-unit explanations, students now tend to marshal the data to be used as evidence to support their claims rather than simply list or restate the data they noted in the tables or graphs (e.g., "the old one is black and when they made the new one it started to get lighter"). This developing ability to use data to provide evidence or warrant for their claims demonstrates the students' developing reasoning practices using data from investigations.

A third pattern in these exemplars and in the larger data set is that students are more likely in post-unit explanations to make some generalizations from the data, and thus are more likely to make claims. In addition, the claims that students make at the end of the unit are more likely than not to be scientifically accurate, even if their explanations are not complete with data.

Finally, students are simply writing longer and more detailed explanations post-unit than they were at the beginning of the units. Even when students came into the unit able to make sophisticated "guesses" as to the answers on pre-tests (as in Student 3), they typically included ideas that appeared to be drawn from their own prior knowledge rather than from the data provided in the charts. By the end of the unit, the majority of students in the pilot used data from the charts and tables they were provided in test questions and were able to provide reasons for using the data to support their claims.

Constructing Explanations Across Discourse Communities. In addition to students' growth in scientific explanation writing, we have seen evidence on post-tests and in classroom practices that students can distinguish between the kinds of explanations they might make for different purposes and different discourse communities. We believe that the ability to recognize the literacy and language conventions and standards of any given community or context is an important skill for the scientifically and generally literate person. For example, in a performance task we designed for the unit on communicable disease, we asked students to analyze data from a hypothetical experiment designed to test a mother's advice that two young women wash their hands for at least 15 seconds in order to reduce bacteria growth. We asked students to write in their conclusions a scientific claim based on the data and to write what they would tell their mothers about their experiment. To do so, students had to read data from charts, synthesize the data, link their findings to the original hypothesis posed, and then write the two kinds of claims. An exemplar from one student illustrates her understanding of *claim* in a scientific explanation. When asked whether "Yes, our mother was right" is a good scientific claim, the student wrote (spelling, punctuation, and grammar intact):

> No it is not. I would improve it by giving 2 pieces of evedence a illustiation and make sure anyone can understand.

This exemplar illustrates what we found in many of the students. That is, they recognized what the criteria were for constructing a good scientific explanation, but they did not necessarily produce such explanations unless coached. When asked what she should tell her mother, the same student wrote:

> They should tell there mom that she was right and they were wrong and they should of believe her in the first place cause mama knows best.

This "everyday" explanation illustrates the difference in the roles that explanations play in students' lives in and out of the classroom, as well as their awareness of the discursive conventions of different communities. This young woman was well aware that a scientific explanation needed to be written in a way that a broad audience of other people interested in the phenomenon could make sense of it (written clearly) and should include a certain amount of evidence and some sort of illustrative example. Her explanation to her mother, by contrast, simply involved confirming her mother's initial claim and reinforcing the adage that "mama knows best." This student saw her everyday explanation to her mother as an explanation embedded in an existing relationship and a mutually understood context, whereas a scientific explanation was one that might be made to relative strangers, across a number of science contexts. Thus, this student was implicitly aware of the different ways that people explain in various communities.

Students also demonstrated similar discursive conventions on the same task, with many echoing the idea that "mama knows best" and that the students should "tell her they were sorry for not believing her, Even know across the district, schools range from well below to well above state standards on these achievement measures. Thus, although many of the students we work with are sophisticated literacy and language users in their everyday lives, they often struggle to read and write with proficiency the academic texts of the classroom—particularly of the science classroom. The range of skill levels and abilities with different types of literate practice present a challenge for individual teachers, and make the production of a districtwide curriculum that strives to meet *all* students' needs and interests even more difficult.

As a result of these challenges, we plan to expand our professional development efforts to model for teachers new to the reform a variety of practices and strategies that can support students' learning to read and write according to the conventions of science. We want to encourage the LeTUS teachers (and other interested teachers) to make use of the University of Michigan's Center for Highly Interactive Computing in Education's online professional development resource, Knowledge Networks on the Web (Fishman, Marx, Best, & Tal, in press; http://know.soe.umich.edu). We hope to use video clips and teacher documentaries to provide novice teachers with specific strategies that they can use to integrate literacy learning with science learning (Fishman, in press).

Another goal is to engage in professional development that increases teachers' awareness of the need to teach students how to navigate across and learn to critique the practices of different communities. Even as our students learn the conventions of science, we hope that they learn that these are human conventions, ones that were produced in certain contexts and for certain purposes, and ones that can be changed.

To support that goal, we also hope to be able to develop a wide variety of curriculum readers that will give students the opportunity to practice scientific literacy skills across many different genres and discourse communities. Because the readers are portable—and, eventually, will be more interactive, as we move toward CD-ROM or DVD versions—they can be used beyond the classroom as homework, support for action projects, or resources for carrying out long-term investigations. More important, once the readers are developed in electronic formats, students will be able to *add to the readers,* thus constructing curriculum reading materials that are current, focused on their interests, and connected to the science they are studying.

Finally, we hope to continue our research on the enactment curricula that support inquiry in science, whether through an empirical investigation or through the use of textual tools. As we continue to develop these curricula as the integration of empirical and textual research, we need to document the processes that teachers and students engage in the classroom, the joys and woes of teaching via these curricula, and the extent of students' learning. We are just beginning in these efforts, and we have developed partnerships with school and university teams in Illinois and North Carolina, working together from similar principles or assumptions about science and literacy learning, while also taking care to make curriculum development efforts responsive to the local and particular communities in which these efforts are embedded.

Given the impact the larger PBS project has had on student learning, and given the enthusiasm of the pilot teachers and the encouraging results of the Detroit pilot data, we believe that this work will have significant and lasting impact throughout Detroit and beyond.

NOTES

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2. Additional information can be found about LeTUS and a related center, the University of Michigan's Center for Highly Interactive Computing in Education (hi-ce), at http://www.hi-ce.org.

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APPENDIX

Teachers, researchers, and curriculum developers have worked together to develop materials to aid instruction and to guide the research process. Included in this Appendix are excerpts of three types of materials used regularly: an Explanation Rubric, for evaluating the quality of students' growth in explanation writing; a two-page excerpt from the Student Sheets that accompany the air curriculum; and a two-page excerpt from the Student Reader that accompanies the communicable disease curriculum.

EXPLANATION RUBRIC FOR EVALUATION

How to write a good scientific explanation:

1. Make a claim about the problem.
2. Provide evidence for the claim.
3. Provide reasoning that links the evidence to the claim.
4. Use precise and accurate scientific language.
5. Write clearly so that anyone interested in science, anywhere, can understand the explanation.

	Level 1	Level 2	Level 3
Makes a claim about the problem.	Does not make a claim, or makes an inaccurate claim.	Makes a claim that reveals *partial* understanding. The claim may include both accurate and inaccurate details, or it may omit important details.	Makes an accurate claim.
Provides evidence for the claim.	Does not provide evidence, or provides inaccurate evidence for the claim.	Provides some accurate evidence for the claim, but not sufficient. (May include some inaccurate evidence for the claim.)	Provides accurate evidence and sufficient evidence for the claim.
Provides reasoning that links the evidence to the claim.	Does not provide reasoning, or provides rationale that does not link the evidence to the claim.	Provides some reasoning that links the evidence to the claim, but the rationale is not sufficient. (May include rationale that does not link the evidence to the claim.)	Provides sufficient reasoning that links the evidence to the claim. (May use linking words like *because, so, therefore* to make the connections.)
Uses precise and accurate scientific language.	Does not use scientific language, or uses scientific language incorrectly.	Uses some scientific language correctly, but some may be incorrect (or imprecise).	Uses precise and accurate scientific language.
Is written clearly. (Anyone interested in science, almost anywhere, can understand it.)	Is not written clearly. Does not provide necessary contextual details.	Is written relatively clearly. (May include only some of the necessary contextual details, or may include both necessary and unnecessary details.)	Is written clearly. Focuses on a particular phenomenon, includes all necessary contextual details (and no unnecessary details).

FIGURE 13.1. Explanation rubric: general.

AIR CURRICULUM STUDENT SHEETS EXCERPT

POE: Is air only oxygen?

Step 1: Predict what will happen when:

1. The jar is placed over a lit candle standing upright in a pan with water.

   What will happen? ______________________________

   ____

   Why? ______________________________

   ____

Step 2: Record your observations:

—Draw a picture of what you observe before you place the candle over the jar and after you place the candle over the jar.

—List the properties you observe and any changes you see inside of the jar.

Before:

After:

Properties observed:

____

____

____

____

____

Properties:

____

____

____

____

____

Changes inside the jar:

____

____

____

____

____

FIGURE 13.2. How much oxygen is in air? The investigation. "POE" stands for "Predict, Observe, Explain." The students are taught this acronym early in the curriculum.

AIR CURRICULUM STUDENT SHEETS EXCERPT

Step 3: Explanations—Writing a scientific explanation for "Is air matter"?
(1) *Think* about your observations
(2) *Review* your initial claim
(3) *Write* your explanation using your claim and supporting evidence

Think:

1. Summarize what happened to the water level after the candle went out.
2. How much volume of air space did you lose to water?
3. Propose a reason for why the water didn't move all of the way into the jar.

Review:

4. Does your original claim make sense after making your observations? If not, describe what you would change about it below.

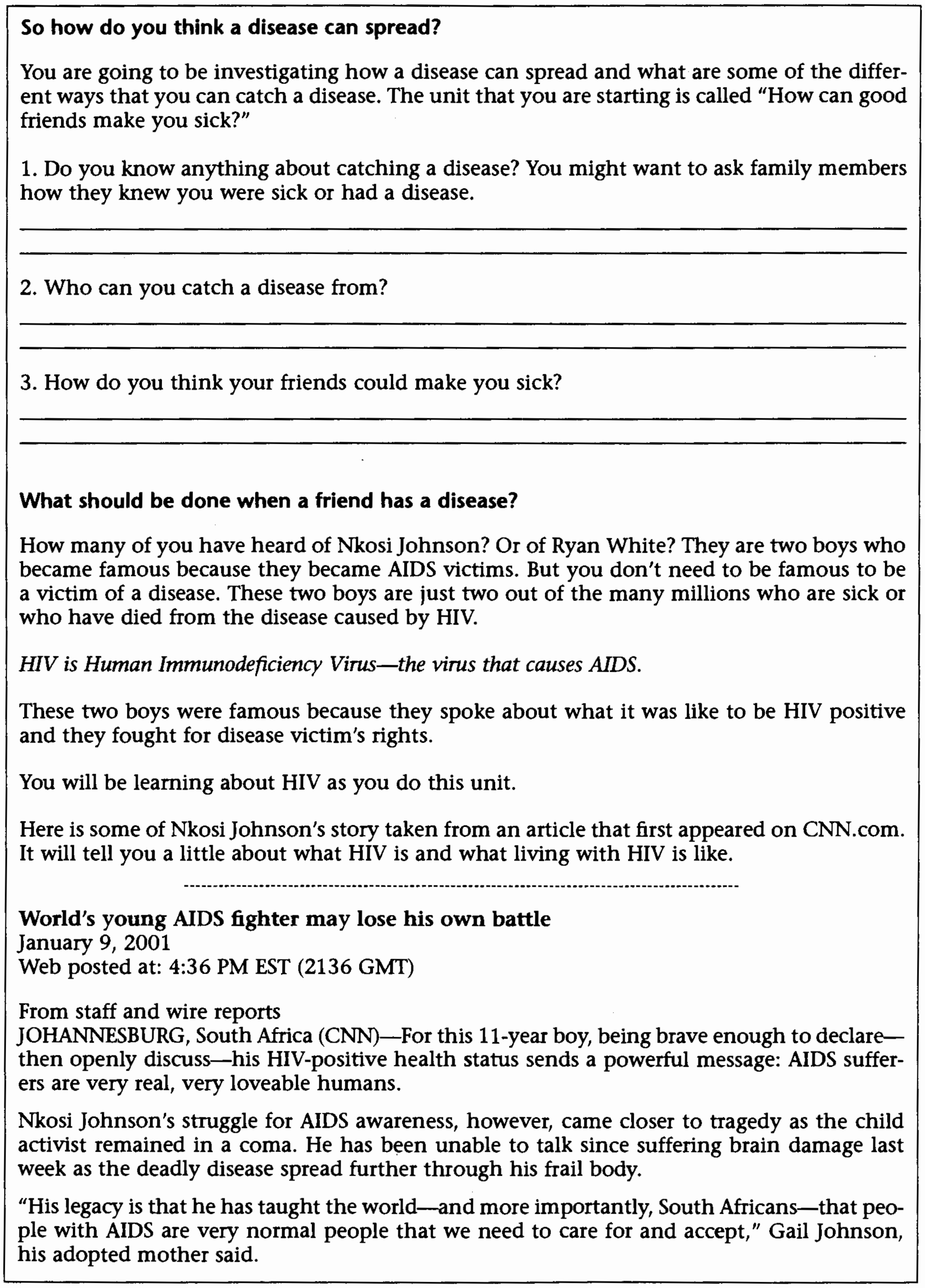
Explanation:

5. Is air only made up of oxygen? Write out your scientific explanation below.

Remember that:
An explanation needs to have:
—A *claim* about the question being answered
—*Evidence* or observations that support your claim
—*Clear* reasons why the evidence supports your claim
—Clear and understandable *sentences*

FIGURE 13.3. How much oxygen is in air? The explanation.

COMMUNICABLE DISEASE CURRICULUM READER EXCERPT



So how do you think a disease can spread?

You are going to be investigating how a disease can spread and what are some of the different ways that you can catch a disease. The unit that you are starting is called "How can good friends make you sick?"

1. Do you know anything about catching a disease? You might want to ask family members how they knew you were sick or had a disease.

____

____

2. Who can you catch a disease from?

____

____

3. How do you think your friends could make you sick?

____

____

What should be done when a friend has a disease?

How many of you have heard of Nkosi Johnson? Or of Ryan White? They are two boys who became famous because they became AIDS victims. But you don't need to be famous to be a victim of a disease. These two boys are just two out of the many millions who are sick or who have died from the disease caused by HIV.

HIV is Human Immunodeficiency Virus—the virus that causes AIDS.

These two boys were famous because they spoke about what it was like to be HIV positive and they fought for disease victim's rights.

You will be learning about HIV as you do this unit.

Here is some of Nkosi Johnson's story taken from an article that first appeared on CNN.com. It will tell you a little about what HIV is and what living with HIV is like.

World's young AIDS fighter may lose his own battle
January 9, 2001
Web posted at: 4:36 PM EST (2136 GMT)

From staff and wire reports
JOHANNESBURG, South Africa (CNN)—For this 11-year boy, being brave enough to declare—then openly discuss—his HIV-positive health status sends a powerful message: AIDS sufferers are very real, very loveable humans.

Nkosi Johnson's struggle for AIDS awareness, however, came closer to tragedy as the child activist remained in a coma. He has been unable to talk since suffering brain damage last week as the deadly disease spread further through his frail body.

"His legacy is that he has taught the world—and more importantly, South Africans—that people with AIDS are very normal people that we need to care for and accept," Gail Johnson, his adopted mother said.

FIGURE 13.4. Communicable disease curriculum reader. *(Continues on next page.)*

COMMUNICABLE DISEASE CURRICULUM READER EXCERPT

Nkosi prompted national soul-searching when he applied to join a primary school in 1997. This caused an uproar among some parents and the school in the Johannesburg suburb where he lives. Now his classmates and friends are among those who wait for word of hope outside the hospital.

"I would like to tell him to come back to school to get well," said Edward Bikie, a classmate and friend. His mother said Nkosi, who could speak and walk normally as recently as a month ago, was now deathly ill.

The small boy became the unofficial spokesman for AIDS in a country where 4.2 million, or one in 10 people, are stricken with the disease. He gained worldwide attention when he stepped to the podium at the opening of the world's biggest AIDS conference in Durban last year and called on the South African President to allow AIDS-fighting drugs be used on pregnant mothers and urged others to change public behavior.

After birth, Nkosi was HIV positive. His mother was HIV positive.

"His greatest contribution was to get public awareness of HIV-AIDS . . . ," said Daniel Ncayiyana, editor of the South African Medical Journal.

Nkosi "spoke . . . with enormous courage and eloquence. He showed that you can hug and love a child without risk to yourself," said Yvonne Spain.

To make sure his legacy is not forgotten, Nkosi and his mother have created a shelter home for HIV-positive mothers and children. Called "Nkosi's Haven," the center is funded by donations.

Johnson said Nkosi's wish for the home was simple, but powerful: "He said to me, 'Gail, the mommies and babies must stay together.'"

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4. How did Nkosi Johnson get HIV?

5. Did he give it to his friends and family?

6. Do you think anyone can get it?

In this real life story, Nkosi attended a public school and had friends in this school. His friends were concerned about him and his health. His friends didn't seem to worry about getting sick. In fact, the story points out that Nkosi was important in changing how people thought about how you could get sick from HIV.

7. So how do people get sick? Why didn't Nkosi's friends worry about getting sick?

FIGURE 13.4. *Continued.*