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Science Education as a Sense-Making Practice: Implications for Assessment

Beth Warren and Ann S. Rosebery
Technical Education Research Center, Cambridge

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In this paper, we argue for a rethinking of what it means to do science in language minority classrooms by putting forward a view of science as a sense-making practice. We then explore the implications of this view for assessment. But before outlining a sense-making perspective on scientific practice, it is helpful to invoke some familiar images of what science is like in many classrooms in order to lay out a few critical connections among teaching, learning, and assessment. Two examples follow, one descriptive of science in many mainstream classes (although the example itself is drawn from a science class outside of the United States) and the other of science in a Chinese bilingual program in California.

I once witnessed a marvelous science lesson virtually go to ruins. It was a class of young secondary school girls who, for the first time, were let free to handle batteries, bulbs, and wires. They were busy incessantly, and there were cries of surprise and delight. Arguments were settled by "You see?", and problems were solved with, "Let's try!" Hardly a thinkable combination of batteries, bulbs, and wires was left untried. Then, in the midst of the hubbub, the teacher clapped her hands and, chalk poised at the blackboard, announced: "Now, girls, let us summarize what we have learned today. Emmy, what is a battery?" "Joyce, what is the positive terminal?" "Lucy, what is the correct way to close a circuit?" ...And Emmy, Joyce and Lucy and the others deflated audibly into silence and submission, obediently copying the diagram and the summary. What they had done seemed of no importance. The questions were in no way related to their work. ([Elstgeest, 1985:36-37](#))

The problem Elstgeest describes is the disjunction between learning and teaching, between what students learn when they engage phenomena directly and what teachers (or curricula or tests) think they should be -- or are -- learning. For a variety of reasons, teaching in many cases is not connected to students' learning, to the sense students make of the world around them. In Elstgeest's example, in fact, the teacher's questions -- which function as a form of evaluation -- act to undermine rather than encourage the students' learning. Focusing narrowly on definitions and correct answers, the questions ignore the students' scientific explorations and efforts to make sense of phenomena.

In language minority classrooms, science -- when it is taught at all -- is often even further reduced (cf [Moll, in press](#)), as illustrated in the following example:

9:10 Science T (or prep T) comes in to teach science. She hands out a solar system puzzle and

tells students to do it on their own because it is like a quiz. D (NES: Non English Speaking) is playing around. He can't do the handout, so Prep T takes it away. He begins working on his penmanship handout.

The crossword puzzle is too difficult for the NES and LES (limited English speaking) students. I begin working with C (NES) first by explaining the definitions in Chinese (e.g., the largest planet or the ringed planet). He can't recall the word on his own even if he knows the meaning. So I get the encyclopedia volume on the solar system for him to use as a reference book. He is able to answer the first few questions on the crossword puzzle on the planets but gets stuck on the more difficult words. Furthermore, he can't even understand the definition or clue words for the puzzle. ([Guthrie, 1985:161-162](#))

On the surface, at least, this case looks very different from the Elstgeest example and, in some crucial respects, it is. Whereas in the Elstgeest example the students actually got their hands on batteries, bulbs, and wires, in this case the crossword puzzle exercise is abstracted out of any meaningful context of scientific activity. Further, in the second example, science is confounded with English language development. The focus of the exercise is on definition and naming. Students in a class like this memorize the definition of the word "hypothesis" but never experience what it means to formulate or evaluate one.

But, in other respects, Guthrie's example is not so far from Elstgeest's. Underlying the pedagogical approach in both is a view of science as the accumulation of facts, definitions, terminology, and correct procedures. Teachers pose the questions and, more frequently than not, provide the explanations. The Elstgeest example is particularly instructive in this regard because it has at its center hands-on exploration. But hands-on science, it turns out, is not enough. In the absence of a framework for understanding students' scientific sense-making, even the best hands-on curricula can become the occasion for knowledge transmission. It is striking, too, that in both cases teaching doubles as assessment. In the Elstgeest example, the teacher queries the students to see if they have learned the right things: the components of a battery, how to close a circuit. In the Guthrie example, the exercise is set up as a quiz, to assess how much technical English vocabulary the students have acquired.

These images of science are widespread. Recent national and international assessments ([Mullis & Jenkins, 1988](#); [McKnight et al., 1987](#)) and calls for reform ([AAAS, 1989](#); [Shymansky & Kyle, 1990](#)) testify to this fact. More important are the questions raised by these common practices:

- What is the purpose of doing science in language minority classrooms, to learn science or to learn English?
- Is there an alternative to common practice?
- What are the implications of such an alternative for assessment?

In this paper we will explore these questions. Drawing on concrete examples of classroom science, we will elaborate an alternative to traditional practice which we refer to as scientific sense-making and discuss possible contexts and roles of assessment that emerge in a sense-making culture in language minority classrooms. We also explore the implications of this view for improving science education and assessment for language minority students, paying particular attention to issues of teacher development.

Why Do Science?

In bilingual programs this question looms large. In many cases, science is not taught at all. In those cases

where it is a part of the curriculum, it is often seen as a context for learning English. Its intrinsic value as an academic discipline, as a way of thinking and knowing, is either ignored or not recognized.

As we have argued elsewhere ([Warren, Rosebery & Conant, in press](#)), a *pluralistic* view of language and literacy (cf. [Literacies Institute, 1990](#)) not only reframes the problem of what it means to learn science but helps us better understand the relationship between doing science and literacy development. According to this view, knowing a language entails knowing more than *the* English language or *the* Spanish language or any other language. Each language is really many languages, a set of possible discourses people use to communicate with one another in their daily activity ([Bakhtin, 1981](#)). These discourses in turn each constitute a set of beliefs and values in terms of which one speaks, thinks and acts ([Gee, 1989](#)). The particular discourse worlds we inhabit depend on our history, the books we have read, the people with whom we have talked and from whom we have learned, the social circles in which we have moved, our economic class, our generation, our epoch, the institutions (church, political party, schools, societies) to which we have belonged, and so forth ([Booth, 1986](#)). As the Soviet theorist, [Mikhail Bakhtin \(1981:291\)](#), explains:

At any given moment of its historical existence, language ... is heteroglot from top to bottom: it represents the co-existence of socio-ideological contradictions between the present and the past, between differing epochs of the past, between different socio-ideological groups in the present, between tendencies, schools, circles and so forth, all given a bodily form. These "languages" of heteroglossia intersect each other in a variety of ways, forming new socially typifying "languages."

The idea that language is heteroglot poses some difficulties for both our common sense and technical uses of terms such as language (as in "learning the English language") and literacy. In both senses, these terms are often used to suggest a capability that is unitary and univocal rather than pluralistic and multivocal (although the varied definitions of literacy that abound in the literature are perhaps a clue to its inherent diversity). In the same vein, language and literacy often are defined in terms of mastery of certain general skills -- reading, writing, arithmetic skills -- rather than in terms of mastery of whole systems of meaning and practices, each involving a set of beliefs and values or, in Bakhtin's term, an *ideology*.

From within this sociocultural perspective on language and literacy, then, we do not view science as a context for developing English language skills. Nor do we define scientific literacy as the acquisition of specific knowledge ("facts") or general skills (e.g., observation, inference) or correct mental models. Rather we understand scientific literacy to be a socially and culturally produced way of thinking and knowing, with its own sense-making practices, its own values, norms, beliefs, and so forth. In this light, when students learn science, they are *appropriating* socially mediated ways of knowing, thinking, acting and using language (both first and second languages) to construct scientific meanings.

The task facing the second language learner -- and, specifically, in this culture, the learner of English -- is therefore enormously complex. Learning in school really means appropriating whole systems of meaning involved in such tasks as reading and answering questions about stories, talking to the teacher, taking tests, playing with other students in the school yard, doing mathematics, doing science, doing history, and so on (cf. [Gee, 1989](#); [Michaels & O'Connor, 1991](#)). The notion of appropriation is key because it casts the learner as someone who is trying to find ways to take the sense-making practices of science, for example, and make them his or her own, tuning them to his or her own intention, his or her own sense-making purposes. As [Bakhtin \(1981:293-294\)](#) explains, appropriating a new discourse is a difficult process:

(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: it is from there that one must take the word, and make it one's own. And not all word for just anyone submit equally easily to this appropriation, to this seizure and transformation into private property: 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.

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, acts, and thinks ([Bakhtin, 1981](#); [Gee, 1989](#)). As a result, discourses are always in conflict with one another in their underlying assumptions and values, their ways of making sense, their viewpoints, the objects and concepts with which they are concerned. Each gives a different shape to experience. Therefore, appropriating any one discourse will be more or less difficult depending on the various other discourses in which students (and their teachers) participate. As [Michaels & O'Connor \(1991:11\)](#) explain,

This conception of literacy has strong implications for how we think about cultural diversity and the knowledge that students bring with them from home. Each child in this society learns culturally appropriate ways of using language and of taking meaning from written texts in the early years at home. Cultural groups in this society have sophisticated ways of integrating the written language around them into their daily social life. However, ways of using oral and written language are closely tied to culturally different ways of interacting with others and with culturally different values and attitudes. Some children have home-based ways of using language that are more closely related to the ways in which language is used in schools than are the home-based practices of other children.

For language minority students, the appropriation process can therefore be more arduous than for other students, for the distance they must travel between discourse worlds -- ways of organizing an argument, interpreting questions -- is often far greater. As research has shown ([Au, 1980](#); [Au & Jordan, 1981](#); [Michaels, 1981](#); [Mohatt & Erickson, 1980](#); [Philips, 1972](#)), conflicts between school-based ways of using language and minority students' home-based practices can create barriers that limit minority students' access to the discourses that are needed to achieve in this society ([Heath, 1983](#); [Michaels & O'Connor, 1991](#)).

Within the framework we are putting forward here, the key question then becomes: In what ways can language minority children be enculturated into the community of scientific discourse? What does it mean to do science? These are the questions to which we now turn our attention.

Science as a Sense-Making Practice

A new conceptualization of learning is emerging in the research literature ([Brown & Campione, in press](#); [Brown, Collins & Duguid, 1989](#); [Lampert, 1990](#); [Resnick, 1989](#); [Schoenfeld, in press-a, in press-b](#)).

Drawing heavily on [Vygotsky \(1978, 1985\)](#) and on anthropological perspectives on learning and cognition ([Geertz, 1973, 1983](#); [Lave, 1988](#)), this literature views learning as an inherently cognitive and social activity. The child appropriates new forms of discourse, knowledge, and reasoning through his or her participation in socially defined systems of activity. As [Resnick \(1989\)](#) has recently argued, education may be better thought of as a process of socialization, rather than instruction, into ways of thinking, knowing, valuing, and acting that are characteristic of a particular discipline.

Central to this view is the idea that concepts are constructed and understood in the context of a community or culture of practice; their meaning is socially constituted ([Brown, et al., 1989](#)). Within this community, moreover, practitioners are bound by complex, socially constructed webs of belief which help to define and give meaning to what they do ([Geertz, 1983](#)). As [Mehan \(in press\)](#) has noted, members of a community "cannot make up meanings in any old way." Rather, they build up ways of knowing, talking, acting, and valuing, which help to constrain the construction of meaning within the discipline. Within this framework, the learner is conceptualized as one who appropriates new forms of knowledge through apprenticeship in a community of practice ([Brown & Campione, in press](#); [Brown et al., 1989](#); [Collins, Brown & Newman, 1989](#); [Lampert, 1990](#); [Lave, 1988](#); [Resnick, 1989](#); [Rosebery et al., 1990](#); [Rosebery et al., in press](#); [Schoenfeld, in press-a, in press-b](#); [Warren et al., 1989](#)).

What, then, is the nature of scientific practice? For the Nobel Laureate, scientist, Sir Peter [Medawar \(1987:129\)](#), scientific sense-making is a kind of storytelling:

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 criticize and modify as we go along, so that it ends by being, as nearly as we can make it, a story about real life.

Medawar's use of the story metaphor represents a bold challenge to both typical school beliefs about what it means to be scientifically literate and the larger culture's assumptions about the nature of scientific knowledge. First, he challenges the belief that science, at bottom, is the discovery of a reality that exists "out there," pre-given but hitherto concealed (cf. [Latour & Woolgar, 1986](#)). Secondly, he challenges the belief that scientists work according to a rigorously defined, logical method, known popularly as The Scientific Method. And thirdly, through his emphasis on story building, he challenges the belief that scientific discourse -- the construction of scientific meaning -- is represented uniquely by forms of writing and talk that are thoroughly objective and impersonal.

Central to Medawar's vision is an idea of scientific practice in which creativity and construction -- rather than discovery -- predominate. His language suggests that science is projective rather than objective: scientists build stories about a *Possible World*, they do not discover the truth that already exists "out there." Further, he insists on the dialogic quality of scientific activity: fact and fancy, invention and criticism interacting.

Contemporary sociological and anthropological studies of the nature of scientific activity in laboratory settings add an explicit social dimension to this picture ([Knorr-Cetina & Mulkay, 1983](#); [Latour, 1987](#); [Latour & Woolgar, 1986](#); Longino, 1990; [Lynch, 1985](#)). These studies show that scientists construct and

refine their ideas within a community in which they transform their observations into findings through argumentation and persuasion, not simply through measurement and discovery. The apparent "logic" of scientific papers is really the end result of the practice of a group of scientists whose goal is to eliminate as many alternative interpretations as possible to their account of the phenomena being studied. Rather than the orderly, logical and coherent process that is described in science textbooks as The Scientific Method, actual scientific practice entails making sense out of frequently disorderly observations and negotiating among alternative interpretations. Through graphs, notes, statements, drafts of papers, and published papers, accounts are constructed, claims are negotiated, analogies are sought, arguments are put forward and defended against attack, and objections are anticipated ([Latour & Woolgar, 1986](#)). As Latour and Woolgar show, scientists claim merely to be discovering facts but close observation reveals that they are writers and readers in the business of being convinced and convincing others. (It is hard not to hear an echo of Medawar's storytelling in this.)

Through our work with bilingual teachers and students ([Rosebery et al., in press](#); [Warren et al., in press](#); [Warren, Rosebery, Conant & Barnes, 1990](#)), we are attempting to elaborate an approach to science teaching and learning that supports the development of scientific sense-making communities in the classroom. The basic idea is to create a community in which what the students think -- the sense they are making of the world -- rather than what the text or teacher thinks is at the center of the class activity. This approach entails a radically different orientation to teaching and learning than that found in traditional classrooms, one in which students construct their scientific understanding through an iterative process of theory building, criticism and refinement organized around their own questions, ideas, and data analysis activities. Fundamentally, the idea is to place question posing, theorizing, and argumentation at the heart of students' scientific activity. Students explore the implications of the theories they hold, examine underlying assumptions, formulate and test hypotheses, develop evidence, negotiate conflicts in belief and evidence, argue alternative interpretations, provide warrants for conclusions, and the like. Conceptually, they investigate their own questions and the beliefs or theories from which they derive; epistemologically, they explore relationships among truth, evidence, and belief in science. They, in short, become authors of ideas and arguments (cf. [Lampert, 1990](#)).

In addition, students' inquiries are collaborative in nature, just as is most professional scientific activity. The emphasis on collaborative inquiry reflects our belief, building on [Vygotsky \(1978\)](#), that robust knowledge and understandings are socially constructed through talk, activity, and interaction around meaningful problems and tools. Collaborative inquiry provides direct cognitive and social support for the efforts of a group's individual members. 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 distribution and sharing of intellectual responsibility is particularly effective for language minority students, for whom the language demands of tasks are often overwhelming and can often mask their abilities and understanding. In addition, collaborative inquiry creates powerful contexts for constructing scientific meanings. 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, if not a common understanding ([Barnes & Todd, 1981](#); [Brown & Palinesar, 1989](#); [Hatano, 1981](#); [Inagaki & Hatano, 1983](#)).

Students' investigations are also interdisciplinary; science, mathematics and language use (talk, reading, and writing in both first and second languages) are intimately linked. Mathematics and language are recognized as essential tools of scientific sense-making, which stands in sharp contrast to traditional schooling in which science is separated from math and the role of language in each is hardly acknowledged (or, as in the case

of many bilingual science programs, the relationship between science and language is reversed). The importance of an interdisciplinary approach cannot be overstated with regard to language minority students. It involves them directly in the kinds of purposeful, communicative interactions that promote genuine language use, which arguably are the most productive contexts for language acquisition, such as talking in the context of doing science and trying to solve a meaningful problem. It also creates opportunities for students to use the languages of science and mathematics in ways that schools and the society at large require: not just to read textbooks or do computations, but to write reports, argue a theory, develop evidence, and defend conclusions.

A brief example will help illustrate what we mean. In a Haitian bilingual combined seventh and eighth grade, students explored relationships among truth, belief and evidence in science through an investigation of their school's water. In the Water Taste Test, the students actively tested a widely held belief that the water from the school's third floor fountain was better than that from the other floors. With guidance from their teacher, they formulated their belief as a question and designed an investigation to explore its 'truth'. A blind taste test of about 40 of the school's junior high students revealed that most of them actually preferred water from the first floor although they believed they preferred water from the third floor. This finding prompted the class to pose a new question about the source of the difference and to investigate more deeply the physical and chemical quality of the school's water. Their analysis led them to conclude that temperature was a deciding factor in taste preference, but it also uncovered surprisingly high bacteria levels in the school's water. In the Water Taste Test, and possibly for the first time, the students themselves took control of their learning and, through scientific inquiry, constructed knowledge that was meaningful to them, their teacher, and the larger school community.

This discussion raises the question of the teacher's role in a sense-making culture. Far from backgrounding the teacher's function, a sense-making perspective on classroom practice intensifies it, as [Duckworth \(1986:133\)](#) explains:

The essential condition of having the students do the explaining is not the withholding of all the teacher's own thoughts. It is, rather, that the teacher not consider herself/himself the final arbiter of what the learner should think, nor the creator of what that learner does think. The important job for the teacher is to keep trying to find out what sense the students are making.

"Finding out what sense the students are making" of the phenomena they are exploring and, indeed, of their own thinking process entails a significantly different orientation to teaching, learning, and assessment than that found in most science classrooms. Above all, perhaps, it creates uncertainty by advancing a view of knowledge as a human product and a view of classroom discourse as a social process in which argument and conjecture play central roles ([Cohen, 1988](#)). This was the case in the Water Taste Test in which the teacher had no idea where the students' investigation would lead, what 'answer' it would produce. Sense-making also entails probing students' talk to find out how they are thinking, the assumptions they are making, the rationale behind their method. It includes helping students think through partial ideas or strategies in ways that do not undercut their own intentions, and involving other students in that process. It also includes valuing alternative interpretations and methods, helping students to explore the implications of their ideas and make connections between their own ways of thinking and scientific ways of knowing (cf. [Lampert, 1990](#)). To orchestrate these sense-making interactions, teachers must also have command of the domain knowledge involved in the students' inquiries. For the Water Taste Test, for example, the teacher and students learned about the chemistry of water quality analysis, aquatic ecosystems, hydrology, and water resource management. In a sense-making culture, therefore, "process" and "content" are inextricably linked; teachers guide students in making sense of real phenomena.

Contexts of Assessment in a Sense-Making Community

It may seem odd that in a paper on assessment we have dwelt so long on developing an image of a different kind of classroom scientific practice. But, in fact, this emphasis highlights a crucial point. In the current discussion on the need for accountability ([U.S. Department of Education, 1991](#)), there is a danger that we will neglect a critical question: Accountable for what? What is it that we want our children to learn? What does it mean for a student to be scientifically literate? We must not assume that because we are ready to reform assessment we fully understand the thing it is we want to assess better. For this reason, we have chosen to present scientific sense-making as a way to do science in order to anchor our discussion of assessment in a particular context and to emphasize the importance of taking into account the local -- as opposed to the national -- character of assessment.

As outlined in the previous section, scientific sense-making reconfigures teaching and learning in some significant ways. Unlike conventional classrooms, teaching and learning in such a culture are not bound to textbooks, canonical experiments with their correct out-comes, or even a curricular scope and sequence. Students pose questions, design research, use tools to make sense of the world, collect data, build and argue theories, and document and communicate their findings and interpretations in various ways. Students' inquiries stretch over long periods of time, not just weeks but in many cases months. They take unexpected turns. The context of students' scientific work is social rather than individual. Further, in a sense-making culture, teachers take on a variety of roles; they coach and model scientific practices, and they act as co-investigators.

Given this radical change in the classroom culture, in the kinds of processes and products that characterize learning, our concern in this section is to explore some possible contexts of assessment that are congruent with sense-making and that tap the full range of students' learning. In particular, we explore the varieties of learning ([Michaels & O'Connor, 1991](#)) that are made manifest through students' talk and writing as they construct scientific meanings. The examples are drawn from classrooms that are working to establish sense-making communities in science. We have chosen examples from a collaboration involving two Kindergartens -- one Haitian bilingual and one English monolingual -- and a multilingual/ multicultural basic skills high school class to show that the kinds of activity and reasoning that emerge in a sense-making culture are as appropriate for five-year-olds as they are for sixteen-year-olds. In the concluding section, we explore how the role of assessment in a sense-making culture can be extended beyond student monitoring to promoting learning and teacher reflection.

Students' Talk: Examples from a Kindergarten Collaboration

Talk is highly valued in a sense-making community as a means for negotiating and constructing scientific meanings. Through talk, students make their thinking public, argue alternative theories, collect data, elicit assumptions, pose questions and conjectures, among other things. Classroom talk falls on a continuum; at one end, it can be organized as a teacher- moderated classroom discussion and at the other it can be spontaneous as in an informal conversation between students analyzing data at a computer. It is, in short, socially situated and multidimensional.

Research has shown that classroom discourse in various domains is enormously complex ([Adelman, 1981](#); [Barnes, 1976](#); [Cazden, 1988](#); [Cazden, John & Hymes, 1972](#); [Cook-Gumperz, 1986](#); [Edwards & Mercer, 1987](#); [Michaels, 1981](#); [Heath, 1983](#); [Wells, 1981](#)). Recent studies have begun to explore the discursive,

linguistic, and cognitive characteristics of science and mathematics and the relationship between student learning and the ways in which teachers orchestrate talk ([Lampert, 1990](#); [Lemke, 1990](#); [Michaels & Bruce, 1989](#); [Michaels & O'Connor, 1991](#); [Rosebery et al., in press](#)). In at least one case, classroom discussion in science has been explored as a context for assessment of students' thinking ([Chittenden, 1990](#)). Taken together; these studies suggest that talk represents a rich, but challenging, context for learning about how students are making sense of the world.

In the following, we explore several examples of classroom talk from a collaborative weather investigation conducted by two Kindergartens, one Haitian Creole bilingual, the other English monolingual. The teachers of these classrooms informally observed and monitored their students' daily use of scientific tools (e.g., thermometers, wind socks, anemometers, rain gauges, bargraphs and charts for representing data) and their talk as a basis for assessing their learning. Our focus is on the varieties of learning that emerge from an analysis of talk.

For the better part of the school year, a Haitian Creole bilingual Kindergarten and a monolingual (English) Kindergarten collaborated on an in-depth investigation of their local weather. Students investigated and collected data on clouds, wind direction and speed, precipitation, and temperature to explore their influence on local weather patterns. They learned to use an anemometer to calculate wind speed, and wind socks and a stationary compass painted onto their school playground to determine wind direction. They observed clouds, noting their color, formation, number, approximate height, and movement; based on these observations, they invented a taxonomy of cloud types. They also learned to use a thermometer to determine air temperature and to check the accuracy of their daily temperature predictions (which became increasingly accurate as the investigation progressed).

Each day, small groups of students collected and recorded data, represented those data in graphs, composed stories of their observations, and the like. They also worked in large groups, reporting their data and observations to one another, and asking and answering each others' questions. Some of their questions included: "What makes the clouds change so quickly?" "Why does the wind sock blow one way and the clouds go another?" "What makes the wind?" "Does it always get colder when it rains?" In the spring, the classes met together on a daily basis to report and discuss their findings and to examine their data (wind speed and direction, temperature, precipitation, cloud cover) for interesting patterns and relationships.

In the following examples of classroom talk, students demonstrate both scientific and mathematical reasoning through tool use and data analysis. The first two examples are taken from a class held in the Spring of 1990 in which three Haitian Kindergartners are reporting the day's weather data to an audience comprised of both bilingual and monolingual Kindergartners and their teachers. In Example 1, Georges, Jonese, and Frantzia are being prompted by their teacher, Christine, to report on wind direction. The exchange takes place in English.

Example 1

Christine: What about the wind? Where was the wind blowing to?

Georges: FROM, Christine!

Christine (smiles and laughs): FROM! ... Where was the wind blowing FROM?

Georges, Jonese, Frantzia: From east to north.

Christine: How did we find that out? What did we use for that? Jonese: The wind socks.

Christine: And where did we stand?

Jonese: In the middle ... of the ... the compass.

The focus of this exchange is the reporting of the day's wind direction. The most remarkable aspect of the exchange, which lasts under a minute, is the opening two lines when Georges notes aloud that the teacher has misspoken, saying "...to..." instead of "...from..." in talking about wind direction. In correcting Christine, Georges demonstrates that he has not only learned to use the wind sock to determine wind direction but has also learned the standard meteorological convention for reporting it. This standard, incidentally, is not intuitive and is easily confused by adults (as Christine demonstrates). A wind sock, for example, shows very clearly the direction to which the wind is blowing; determining the direction from which it is blowing requires an inference. Georges's two word counter to Christine makes clear that he has learned how to talk and think about wind direction, and that he is not afraid to assert this knowledge. That he insists on maintaining the convention they have established through their own field work is also evidence of the value he places on their work. As we noted earlier, citing [Mehan \(in press\)](#), a discourse community collectively builds up its ways of talking and knowing; it doesn't "make up meanings in any old way." Georges's concern for maintaining the classroom community's standard does not go unnoticed by Christine who laughs good naturedly at his correction and then takes it up in her restatement of the question.

Example 2 takes place a few minutes later in the class. It is an exchange involving both bilingual and mainstream students under the guidance of Christine, the bilingual teacher. Georges, Jonese, and Frantzia have finished reporting their weather data, which included discussion of two different readings obtained for wind speed. In the front of the school they observed that the anemometer made one revolution which calculated to a wind speed of zero miles per hour; in the back of the school (specifically in the teachers' parking lot on top of Christine's car), they observed it make two revolutions which calculated to a wind speed of one mile per hour. At the point we join the conversation, Christine has invited the students to ask questions (a standard practice) and Johnny, a bilingual student, asks Georges why they got two different wind speed readings. Later in the conversation, Susan, a monolingual student, joins in. The exchange takes place in English.

Example 2

Johnny: To Georges, why when you put the anemometer on Christine's car did it turn but not in front?

Christine: That's a good question. Johnny said, "Why when we put the anemometer on the top of the car we had two revolutions and when we had it in front there was only one revolution?" Who can answer that question?

Jonese: Me!

Christine: Jonese? Ok, Georges wants to try it first because it was to Georges.

Georges: (inaud)...

Christine: Ok, Jonese wants to try it.

Jonese: I think that when it was in front it didn't have no wind and when we were in the back and put it on the top of the car it was a little windy and cold and we had two revolutions; first there was one in the front; then there were two.

Christine: WHY is it more windy in the back than in the front? Susan wants to try that.

Susan: Maybe because the building keeps the wind from going around to the front.

Christine: OKAY! Who else has a question. Susan?

Susan: I have a question for you.

Christine: Me!?! I hope I can answer it!

Susan: Since it went around two times, does it always go one less miles per hour on the computer?

Christine: Mmmhumm, when it goes around two times, it's one mph, but when it goes around one, it's zero.

In this exchange the students' reasoning is striking. First, Johnny shows that he is thinking critically about the data that have been presented. He articulates what he feels is an inconsistency in the data and demands an explanation. This is exactly the kind of scientific thinking the teachers have been trying to promote in their students throughout the year. The discourse context is not simply Show and Tell but a forum for making sense of the data the students have generated through their own scientific activity. In this context, then, making sense of an inconsistency in data is standard practice.

Secondly, the explanations that Jonese and Susan generate provide information about each girl's control over the discourse of scientific explanation, at least on this day and in this situation. Their explanations differ in crucial ways. Most significantly, Jonese's response does not meet the (implicit) criterion the teachers have established for scientific explanations. She offers a reason for the difference in wind speed, saying that in front there wasn't any wind while in back there was, but, according to the teachers' standard, it is tautological; it doesn't explain the data so much as repeat them. Christine notes this in her response by rephrasing Johnny's question to emphasize causation ("WHY is it more windy in the back than in the front?"). Susan's response, in contrast, is closer to the teachers' notion of explanation; it contains an explicit marker ("because") and elaborates a plausible reason ("Maybe because the building keeps the wind from going around to the front."). This example raises an important question. While Jonese and Susan respond very differently to the call for an explanation, the talk itself does not help us understand why. Is it because Jonese is less familiar with the discourse of explanation in this context? Does she not understand the teacher's question and its implicit discourse assumptions ([Michaels & O'Connor, 1991](#))? Are the criteria for explanations too implicit ([Delpit, 1986, 1988](#))? Regardless, Jonese's difficulty should serve as a signal to her teacher to probe its source more deeply, or in Duckworth's words, "to find out what sense the students are making." We will return to this example in the next section when we discuss the role of assessment in a sense-making culture.

A third and final snapshot of students' learning in this exchange is represented in Susan's question to Christine ("Since it went around two times, does it always go one less miles per hour on the computer?"). This question is noteworthy for what it reflects about the depth and nature of Susan's thinking. On the basis of the data presented in class that morning, Susan poses a question to test a rule for calculating the wind speed in miles per hour based on the number of revolutions of the anemometer (something like: wind speed = number of revolutions - 1). While her algorithm is not correct, it is evidence that she is examining the data for patterns and then using those patterns as the basis for generating rules, a highly sophisticated form of reasoning. At the time of the exchange, neither Christine nor the monolingual teacher understood that Susan was testing a generalization. Prompted by one of the researchers, Christine follows up with Susan the next day (unfortunately their conversation was not recorded). Christine reported afterward that once she understood Susan's intended meaning, they went to the cumulative weather chart the classes had been developing and together examined several days' worth of wind speed data (revolutions and mph). In this way, Susan discovered for herself that her rule was not supported by the data. This has implications for assessment. By asking Susan to join her at the chart to evaluate the rule against the data, Christine is helping Susan to answer her own question and in the process is introducing her to a standard scientific practice for evaluating a rule or conjecture. Moreover, by scaffolding Susan's activity, she is enabling her to accomplish more than she could have done on her own ([Palincsar & Brown, 1984](#)). Although Susan's rule was

disconfirmed, her impulse to build generalizations based on observed patterns was shaped, extended, and reinforced through the teacher's action.

By way of closing our discussion of students' talk as a context for assessment we will examine an exchange that took place between three boys in the bilingual Kindergarten, Johnny, Pierre, and Josef, in an informal interview situation. The boys are being asked to read and interpret a set of daily temperature graphs (bar charts) their class has developed over several months. The discussion takes place in Haitian Creole and appears below in Haitian Creole followed by English translation.

Example 3

Interviewer: Ki sa ki deye nou la? (They turn.)

Johnny: Yon bagay ki pou weather a.

Josef.: Le-I fe cho oubyen fret. Le bagay la ba, se cho I ap fe.

Interviewer: Se vre?

Johnny: No, fret!

Josef: Yeah--I wo se

Johnny and Josef.: *cho!*

Interviewer: OK, ou ka gade sou premye a, sa ki an le a, ou ka di nou ki jou ki te fe pi cho an janvye? Ki jou ki te fe pi cho?

Johnny: Saa? (Pointing to the highest bar in the middle of the graph.)

Interviewer: Ki nimewo ou we li ba ou?

Johnny: Yon sis avek yon kat.

Interviewer: OK--

Josef. Men ni, men ni men ni! (Pointing to the highest bar at the end of the graph, also with a value of 64.)

Interviewer: Konben li fe, Josef?

Josef. Yon sis avek yon kat.

Pierre: Mwen we *sa* ki cho (pointing to a day when the temperature was zero and another when it was around 30).

Interviewer: Se sa ki pi cho?

Pierre: Yeah.

Johnny: Sa ki pi fret la, se saa (pointing to the lowest bar on the graph).

Pierre: Pi *cho*, sa ki pi *cho*, sa ki *fret* la (pointing, it seems, randomly at bars on the graph).

Interviewer: Sa ki fe ou di sa? Sa ki fe ou konn se sa ki pi cho?

Scott: Paske li menm ki pi gwo pase saa, pase, sa pi gwo pase ... (tracing with his finger up the side of the graph). Interviewer: Johnny, ou ka ede-l? Li di se premye a ki fe pi cho, eske se vre?

Johnny: (Shakes head "No".) Saa ki pi cho (pointing to the highest bar at the end).

Pierre: Sa ki gwo pase a (pointing to the highest bar in the middle).

Interviewer: Ou ka explike I poukisa, ou ka di Pierre poukisa?

Johnny: Se paske sa pi wo, li gen pi plis.

Pierre: Sa pa pi gwo (pointing to the highest bar at the end).

Josef. Li gen karant kat.

Pierre: Se paske sa (pointing to the highest bar in the middle) ki pi gwo pase saa (pointing to the highest bar on the end), epi sa pa pi gwo (pointing to the low bar next to the highest one on the end) sa (pointing to the highest bar in the middle) ki pi gwo pase a.

Interviewer: Sa ou panse, Josef? Kiles ki pi cho?
 Josef.: Saa ki pi wo (pointing to the highest bar at the end).
 Interviewer: What's that behind you? (They turn.)
 Johnny: A thing for the weather.
 Josef.: When it's cold or hot. When the thing is low, then it's hot.
 Interviewer: Is that true?
 Johnny: No, cold!
 Josef.: Yeah, when it's high it's --
 Johnny and Josef: hot!
 Interviewer: OK, can you look at the first one, the top one? Can you tell me which is the hottest day in January? Which day is the hottest?
 Johnny: This? (Pointing to the highest bar in the middle of the graph).
 Interviewer: What number is it?
 Johnny: A six and a four.
 Interviewer: OK--
 Josef. Here it is! Here it is! Here it is! (Pointing to the highest bar at the end of the graph, also with the value of sixty-four.)
 Interviewer: How many is it, Josef?
 Josef: A six and a four.
 Pierre: I see *this* is hot (pointing to a day when the temperature was zero and another when it was around 30).
 Interviewer: That's the hottest?
 Pierre: Yeah.
 Johnny: This is the *coldest* one (pointing to the lowest bar on the graph).
 Pierre: Hotter, this one's hotter, this one's cold (pointing, it seems, randomly at bars on the graph).
 Interviewer: Why do you say that? How do you know it's hotter?
 Pierre: Because this is bigger than this, this is bigger than this (tracing with his finger up the side of the graph).
 Interviewer: Can you help him, Johnny? He says that the first one's hotter, is that true?
 Johnny: (Shakes head 'No'.) This is the higher one (pointing to the highest bar at the end).
 Pierre: This one's higher than it (pointing to the highest bar in the middle).
 Interviewer: Can you explain to Pierre why?
 Johnny: Because this is the tallest, it has the most. Pierre: That's not the biggest.
 Josef. It's forty-four!
 Pierre: It's because this one (pointing to the highest bar in the middle) is bigger than this one (pointing to the highest bar on the end), and this one (pointing to the low bar next to the highest one on the end) isn't big[-ger than] the one bigger than it.
 Interviewer: Is that what you think Josef.? Which is the hottest?
 Josef: This one is the highest (pointing to the highest bar at the end).

While this discussion took place in an informal interview, we observed similar conversations taking place spontaneously as the children examined their graphs and data charts. It is clear from the above discussion that Johnny knows how to read and interpret a bar graph, relate it to the phenomena it represents ("This is the coldest one."), and articulate its meaning to others. Pierre, on the other hand, does not seem to understand the graph and, perhaps most distressing from a teacher's perspective, seems unaware of his own confusion. The state of Joseph's understanding is somewhat less clear from this bit of transcript. At the end,

however, when he explains in response to the interviewer's question "Which is the hottest?" that the hottest day is the highest bar suggests that he does understand how the graph represents hot and cold temperatures, and that he can translate between different ways of making sense of the graph.

Our purpose in presenting the above examples is to demonstrate the richness of classroom talk and its relationship to student learning. Through their talk, students showed varieties of sense-making. They mastered the use of specific tools and the concepts underlying their use; they interpreted graphs, critically analyzed numerical data and suggested generalizations based on those data; they built explanations and posed questions focused on data they had generated. In addition, the focus on classroom discourse brought to light instances of talk in which the meaning of that talk was not understood, either by the teacher or the student. These instances underscore the need for explicit discussion of the standards and assumptions for talk in a scientific community ([Delpit, 1986](#); [1988](#); [Michaels & O'Connor, 1991](#)). But this suggestion should not be construed as a call for teaching students the "rules" of talk or specific forms of explanation or vocabulary. Rather, it means that the classroom community itself needs to reflect on its talk in order to establish its own standards and uncover implicit assumptions. Concern for talk -- how to put forward effective arguments, pose provocative questions, and marshal convincing evidence -- should become an integral part of the work teachers and students see themselves doing, that is, a distinguishing feature of their work as members of a scientific sense-making community (cf. Brown & Campione, in press).

Students' Writing: Examples from a High School Field Ecology Study

Portfolios represent one variation on the theme of alternative assessment in writing, one that also has potential in science. As [Wolf, Bixby, Glenn & Gardner \(in press\)](#) explain, the concept of a portfolio itself has begun to evolve from a structured sampling of a student's work over time to the idea of a process-folio ([Gardner, 1989](#), in press; [Wolf, 1990](#)) which differs in several ways from the traditional conception:

[Process-folios] differ from familiar portfolios in a number of ways. The generation of these process-folios is embedded in a much larger classroom context where teachers and students frequently discuss what goes into creating worthwhile work, what makes for helpful critique, and how to plow comments back into ongoing work. In addition to finished works, these collections contain sample "biographies of work" -- documentation of the various stages of a project. When collected at diverse points, these biographies permit a longitudinal look at a student's changing control of the processes for shaping a final piece. Students often keep journals and write reflections about their work ([Seidel & Zessoules, 1990](#)). Finally, the collections of work students build are anything but archival. They regularly return to earlier works to revise or make comparisons with later ones. At the close of the year, students reenter their collections to make a final selection of biographies, reflections, and final pieces that can serve as the basis for a course grade and/or part of a permanent record of their development ([Camp, 1990a, 1990b](#); [Howard, 1990](#); [Wolf, 1989](#)). In this sort of work, students have the opportunity to see samples of different levels of work and to discuss the criteria that distinguish strong performances. They also witness the multidimensional nature of such work (i.e., that it involves the ability to pose an interesting problem, to learn from and comment on someone else's work, or to revise an earlier draft.) ([Wolf et al., in press:34](#))

The idea of process-folios strengthens the link among teaching, learning, and assessment by blurring the boundaries which in conventional practice separate them. Process-folios represent an intriguing possibility not only for capturing the complexity and richness of students' scientific sense-making but for making

assessment a more integral part of what teachers and students see themselves as doing in the classroom. In a sense-making culture, students' work is not only sustained over long periods of time but is subject to critique, review, false starts, new questions, and a variety of choices that are often contextually contingent. As students conduct investigations, they keep notebooks that contain a wide range of informal "writing" including questions, hypotheses, data tables, graphs, notes about experimental procedures, informal analyses and interpretations of data, and the like. They also produce formal texts such as charts, graphs and reports for publication, i.e., for an outside audience.

In this section, we look at examples of the informal scientific writing of two Haitian students, Rose and Marie. We analyze their texts for evidence of the ways in which they are making sense of data they developed. Both students were in a multilingual basic skills class in a large urban high school. (Six different languages were spoken in the class.) Their class was composed of students who were judged not ready for the regular bilingual program because of low academic skills. For the most part, these students could not read or write their first language or English.

During the school year, the class studied water quality using their home tap water as the basis of study. In the spring, their interests broadened to encompass an ecological study of a local pond that bordered the city's water reservoir. The students were concerned that the pond, which was obviously polluted, posed a threat to the city's drinking water. To address their concern, the students decided to study the health of the pond, including an analysis of its chemical, biological, and physical characteristics, and to investigate the city's water supply, learning about its sources, how it is purified, and how it is piped throughout the city. To complete their investigation, the students broke into small groups to work on particular aspects of the study.

Rose's group, for example, was responsible for determining the bacteria level of the pond. In keeping with their year-long interest in home water, the group decided to compare the bacteria level of the pond to that of their local drinking water. They were interested in two things: How much bacteria was in the pond? How much bacteria was in their drinking water? To answer their questions, they collected water samples from the pond, their homes, and school drinking fountains and tested them.

To perform this test, the students used commercially available culture kits called Millipore™ samplers. These samplers are made of an absorbent, nutrient-filled pad which is marked with a grid. To test for bacteria, the pad is immersed in a water sample, placed inside a plastic container, and incubated under a lamp for twenty-four hours. At the end of twenty-four hours, the grid is inspected for bacteria colonies which appear as tiny black, blue, or green spots. A pamphlet accompanying the samplers allows the user to assign a water quality grade based on the number of colonies that grow. To be drinkable, water must have a count of zero.

For undetermined reasons, many of the students' cultures did not grow. A few did, however, and Rose used them as the basis for investigating the bacteria level in the city's tap water. Her first step was to document her results. She drew a facsimile of the Millipore™ sampler in her lab notebook, reproducing the position and size of each of the 57 bacteria colonies that had grown. Her drawing was a meticulous and accurate reproduction of the culture. She then interpreted the significance of her findings. According to the standards stated in the Millipore™ pamphlet, the tap water, which had come from a student's home, was not fit to drink. Rose documented her findings in her notebook in English as follows:

I counted the bacteria in the tape water.
I find fivety seven bacteria in the tape

water. That's mine you can't not drinking
 but you can swim on that water --
 Grade B for that water because whole body
 contact no more than 200/100 ml.

Rose's report, brief as it is, draws on diverse resources and voices to communicate her finding and its significance. For example, because she is concerned that her report be viewed as credible within her scientific community, she uses two devices common in the discipline to lend her argument validity -- referring to other literature and making her data publicly available. She establishes a connection, if only implicitly, with the standards that accompany the MilliporeTM samplers ("That's mine you can't not drinking but you can swim on that water -- Grade B for that water because whole body contact no more than 200/100 ml."). To lend a sense of precision and verifiability to her report, she includes her representation of the sampler and reports the bacteria count in her analysis, in this way documenting her interpretation.

The discourse strategies Rose uses to organize her report also reflect her desire to communicate her scientific activity in accurate detail. She describes how she came to her results and what she found, clearly marking them as the product of her own efforts through use of the first person authorial voice ("I counted..." "I find..."). Not only is she reporting her scientific method but, by using the first person, she marks her result as a personal construction which does not exist apart from her work or reasoning. Note, however, that when she interprets the data according to the standards, Rose switches from the first person to the more authoritative, objective voice signalled in: "That's mine (That means) you can't not drinking but you can swim on that water. Grade B for that water because whole body contact no more than 200/100 ml." Here she is appropriating the words of the MilliporeTM pamphlet to interpret her finding and to inform others of its significance: the water used in this sample is fit for whole body contact but not for drinking. (Grade B water, which is suitable for whole body contact such as swimming, can contain a bacterial count of 1-200 colonies per 100 ml of water.) This switch in voice suggests that Rose is aware that scientific results are reported "objectively," apart from the agent who produced them. The presence of both personal and objective statements in her report reflect her struggle to coordinate these voices as part of a coherent whole.

From an assessment perspective, what stands out in Rose's work is the way in which she takes control of the bacteria study, shaping it to her own purposes, taking a point of view, and then interpreting her activity and its significance for a larger community. Rose's activity and her report are evidence that she is beginning to think, act, and write like a scientist. The mixed levels of description and explanation, the orchestration of multiple voices, the recourse to standards and multiple representations reflect her own efforts at sense-making and belie the surface simplicity of her report. These sense-making efforts reflect her struggle to appropriate scientific ways of thinking, knowing, and writing. She is working through for herself the relationship between the processes by which she produced her finding ("I counted..." "I find...") and the means for communicating that finding ("That's mine..."). This effort is a key aspect of scientific practice, one that is well-known to anyone who has struggled to craft a "story" about data. That Rose does this in English, by her own choice, only adds to the complexity of her task. From a sense-making perspective, then, Rose's report, which on the surface seems simplistic and full of errors, is actually a complex text that shows she is beginning to forge a scientific voice.

About the time that Rose was finishing her study, the Basic Skills class was preparing for a field trip to the city's water treatment facility. The trip was set up so that the students would be able to ask questions of the city's water chemist at the end of their tour. In anticipation of this, the students were asked to generate questions they wanted to ask the chemist.

Many students had just finished reading a booklet, "The Story of Water," prepared by the city's Water Department which explains in pictures and words the water cycle and water treatment process. Under the direction of a classroom teacher, many of the students had developed a set of questions based on their reading. A quick survey of students' notebooks showed that approximately two-thirds of them contained the following kinds of questions:

"What machines are used to purify water?"

"What is chlorination?"

"What is filtration?"

From a sense-making perspective, these questions are odd. They are about science content without being linked to authentic inquiry. They seek knowledge that is already known rather than knowledge that needs to be constructed. In short, there is little sense-making to be found in them. They are, however, typical of the kinds of questions students are frequently asked in school where the focus is on factual comprehension and recall.

In contrast, Rose and her partner, Marie, used the bacteria results as the basis for developing a different set of questions that grew directly out of their own scientific activity. The students first composed the questions that follow in Haitian Creole and then translated them into English:

"I went a (sic) know how come bacteria come in the water?"

"How come they clean (sic) the water but it still has bacteria in it?"

"I went to know how often they clean the water?"

It is interesting to explore from an assessment perspective how Rose and Marie's questions differ from those of the rest of the class, and what they tell us about the students' scientific reasoning. As we noted earlier, the questions taken from the Water Department booklet have little to do with the students' own sense-making. "(I)t is as if they put themselves in quotation marks against the will of the speaker" ([Bakhtin, 1981:293-94](#)). The lack of student agency and purpose is perhaps most clearly reflected in the impersonal, objective voice in which the questions are cast. There is no sense of ownership, of the students actively asking and answering questions.

Rose and Marie's questions, however, presume an active, critical stance toward the world and, in particular, toward their finding. In a very real sense, their questions represent an action and assert a will to know ("I went to know..."). They literally call into question the dilemma posed by Rose's findings ("How come they clean the water but it still has bacteria in it?") and seek to resolve it. Unlike the class questions, these questions are openly purposeful and evaluative, expressing a particular point of view and designed to produce knowledge. Through their questions, Rose and Marie continue the process of sense-making initiated by Rose. Thus, while at first glance the class questions seem to be scientific in content and tone because they are "objective," they are not. In contrast, Rose and Marie's questions, which are markedly "subjective," are solidly grounded in scientific activity, evidence, and reasoning.

Writing of the kind presented above represents only one aspect of the work students produce in their scientific investigations. In addition, they write notes and make drawings of their observations, tabulate and represent data, design data collection instruments, and draft and finalize reports, among other activities. These texts are sometimes the work of an individual and sometimes the work of a group. They may represent half-baked ideas, rejected plans, or revised thinking. Thus, their role and use in assessing student learning needs to be carefully thought through. In fact, as [Wolf et al. \(in press: 27-28\)](#) suggest, such

"assessment is not a matter for outside experts to design, rather it is an episode in which students and teachers might learn, through reflection and debate, about the standards of good work and the rules of evidence."

Roles of Assessment in a Sense-Making Culture

With the emphasis on performance, portfolios, and exhibitions, the assessment reform effort is attempting to blur the edges separating learning, teaching and assessment ([Gardner, in press](#); [Hein, 1990](#); [Sizer, 1984](#); [Wolf, 1989](#)). These kinds of alternative assessments acknowledge the situated nature of cognition as they seek to explore student learning in complex, multidimensional activities that are representative of the work of a particular discipline. In some cases, they recognize both students and teachers as active participants in the process who set the standards to be applied to their work ([Stock, 1990](#); [Wolf, in press](#)). In this atmosphere of critical reform, it becomes possible to rethink not only the means of assessment but also the roles it can play in teaching and learning. In this section we explore the implications of our prior analysis of student talk and writing for uses of assessment in the science classroom, particularly in promoting student learning and teacher reflection.

In the preceding section, we noted a difference in the kinds of explanations Jones and Susan put forward for the wind speed data. We also commented that based on the talk itself it was impossible to determine why Jones responded in the way she did. Moments like these represent one of the strongest arguments for linking teaching, learning and assessment as part of a larger enculturation process. It would be easy to judge Jones as not having a theory to account for the difference in wind speed readings whereas Susan does. But her talk doesn't allow that inference. It is unclear from what she says whether she doesn't have a theory or doesn't understand the discourse assumptions underlying the teacher's question. In moments like these, it becomes the teacher's job to find out the reason and then to build on this knowledge to promote Jones's learning, to help her gain access to the assumptions and rules that govern discourse in science in that classroom.

Teaching of this kind calls for a level of reflective practice ([Schon, 1983, 1991](#)) that is not only rare in schools (largely because it is not valued) but is also likely to be difficult to achieve without considerable effort and dedication of resources. But the benefits far outweigh the costs. To be convinced, we have only to consider the subsequent episode when Christine, after initially misunderstanding Susan -- and, as a result, missing the real import of her question -- returns to it the next day to find out her intended meaning which they then test against the evidence. Not only does the teacher learn something important about the depth of her student's reasoning but, by her action, she also places a high intellectual and psychological value on that reasoning. Taking students' questions seriously, probing their intended meaning, working to understand the assumptions on which they are based represent the kinds of actions that make teaching and assessment part of a larger reflective practice.

Not only do teachers need to become more aware of the complexity of classroom talk, writing, and activity and their relation to higher order thinking and discourse appropriation, as [Michaels & O'Connor \(1991\)](#) suggest, but they also need to develop better articulated views of science as a sense-making practice. These deeper understandings are needed if the effort to develop new forms of assessment is to succeed. For example, the scientific value of Rose's text and Rose and Marie's questions is not transparent. Indeed, it would be easy to be misled by the surface features of the texts (grammar, spelling, brevity) into underrating their scientific merit and the work that went into them. To appreciate the character of their sense-making requires having an insider's view of what it means to do science. This implies that teachers must become

sense-makers themselves, as doers of science, teachers, and researchers interested in understanding and amplifying their students' ways of knowing. Indeed, in expert practice, these three roles interact; the ideal is a teacher who embodies and enacts all three as part of his or her classroom practice (Duckworth, 1986; Schon, 1983).

Helping teachers to think more deeply about science and classroom talk does not mean simply teaching teachers about new curricula or new teaching strategies. As a vehicle for change, innovative curricula are not enough; nor is current in-service (or preservice) education. While these may provide teachers with a grounding in the underlying scientific concepts and with hands-on activities to use in the classroom -- and, in the case of some in-service courses, with direct experience using those activities -- they do not touch on the deeper issue on which teacher change depends, namely, teachers' views of science and science pedagogy. The real issue is epistemological change, to bring about a shift in teachers' beliefs about science and pedagogy as well as a shift in their teaching practices toward a sense-making perspective.

Attempts to redraw the face of assessment in science must therefore be grounded in teacher development. The standards of good scientific practice cannot be imposed from outside the teaching community; they must be constructed from within, ideally through active debate not just between teachers and researchers but also between teachers and their students (Wolf et al., in press). In these ways assessment can become an occasion for both improving teaching and amplifying students' learning. Issues like these must be addressed as part of our reconceptualization of science assessment.

The significance of the links connecting teaching, learning, and assessment should not be underestimated.

The analyses of student talk and writing we presented earlier represent our interpretation of students' scientific thinking based on our own view of what it means to be scientifically literate. The teachers' assessments were more informal, less tied to a view of science as sense-making. They tended to focus more on conventional categories such as students' facility with numbers, growth in language, quantity of talk, although as the year progressed they placed more value on the quality of the students' questions, their understanding of data, their critical-mindedness, and their initiative in defining questions or problems to explore. Their thinking on these issues continues to evolve. This, we believe, is where the hard work of assessment resides, in translating a view of what it means to be scientifically literate into criteria that can capture diverse student performances and varieties of thinking. This translation, moreover, cannot be made for teachers; rather it must be made by teachers based on their own elaborated understanding of what it means to be scientifically literate.

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