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ABSTRACT

Arguing that the development of a notion of sense-making is of critical importance to improving science learning, this paper examines science teaching in four Boston (Massachusetts)-area classrooms that participated in an experiment on ways of integrating technology into a sixth-grade science curriculum on the earth's seasons. The task of the teachers was to design a unit that included modeling and data collection components and to integrate the use of technology into these activities. As the work progressed, the project took the form of a formative experiment in which teachers modified their approaches and the researchers modified their support as they attempted to achieve a goal of engaging students in active science learning activities. Detailed descriptions of activities in the four classrooms point to the ways that a common curriculum design, which takes the scientific theory as the objective, can result in the dissociation of the data from the theory, and suggest some of the difficulties in bringing together the conditions for helping students make sense of science. It is noted that, in many cases, data are discussed without engaging in questions about why the data have a particular pattern; structural equation models are often taught directly with no explicit discussion of how the model explains specific data; and the systematic dissociation of theory and practice can also apply to the use of simulations, databases, and telecommunications. A discussion of the simulation SunLab examines the use of this computer-assisted instructional program both as a surrogate for the earth-sun system model, and as a data collection device. It is concluded that classroom or group discussion may prove more fruitful than individual exploration, and that the teachers' role is crucial in creating the framework. It is further argued that the design of database and microcomputer learning systems should allow for the sharing of data and models from the start. (29 references) (DB)

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THE WORLD IN THE CLASSROOM: Making Sense of Seasonal Change through Talk and Technology

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In our observations of science lessons in elementary school, we find an almost systematic dissociation of data and theory. Students and teachers are observed either collecting and graphing hands-on data or examining a theoretical model. Very seldom do we find students and teachers using the model to make sense of the data or using the data to develop a theory. Technologies introduced into science classrooms can be expected to participate in the system of instruction already in use. This paper examines science teaching in classrooms that participated with us in an experiment on ways of integrating technology into a sixth-grade science curriculum on the earth's seasons. We developed a framework for looking at the classroom conversations in which students could make sense of the phenomena being studied. Our analysis points to the ways that a common curriculum design, which takes the scientific theory as the objective, can result in the dissociation of the data from the theory and suggests some of the difficulties in bringing together the conditions for scientific sense making. It also points to the ways that technologies such as simulations and telecommunications can fall into the same trap.

We believe that the development of a notion of sense-making discussion is of critical importance to improving science learning. Too often science, like many other subjects, is taught from the textbook as a set of facts to be learned in sequence. But conducting discussions that engage students in sense making is difficult. Researchers at TERC report that only 5% of the classes they observed using microcomputer-based laboratories had the students discuss the data after they were collected (Mokros & Russell, 1988). They also report that a major issue for the National Geographic Society Kids Network project, in which students join a nationwide collaborative data-collection exercise, is to get teachers to discuss the data with the class once they have been collected (C. Julyan, personal communication, January 16, 1990). In virtually none of the classroom sites observed did the teacher and students go beyond graphing the data to discussing their meaning (Lenk, 1990). Telecommunications technology can bring information and data from all over the world into the classroom. But unless a sense-making process can be understood and its conditions supported, the data flowing into a classroom will have little impact on students' scientific understanding.

Recent work in mathematics instruction has provided important analyses of classroom discourse illustrating the ways that authentic problem-solving activities that give rise to extended sense-making discussions can be instantiated in classrooms (Lampert, 1986, 1990; Resnick, 1987; Schoenfeld, in press; Stigler & Perry, 1988). In contrast, typical approaches to school math emphasize rules and algorithms for getting the right answer. Students do not expect and are not expected to make sense of what they are learning. The recent work takes seriously the need to change students' and teachers' assumptions about what mathematical learning is. The issue is not just how more effectively to get content knowledge across. The problem is to change the classroom task into one of sense making so that the educational outcome goes beyond inert knowledge of rules. The new approach has been described as a "cognitive apprenticeship" (Brown, Collins, & Duguid, 1989; Collins, Brown, & Newman, 1989), recognizing the authenticity of the classroom discussions and the importance of the teacher-mediated enculturation.

Teaching of science in schools presents issues entirely parallel to these issues in mathematics teaching. Students and teachers, supported by science textbooks, often approach the subject as a set of facts and terminology. There has been, however, a long tradition in science education that is critical of the usual approach and focuses instead on the inquiry process (Hurd, 1969; Lansdown et al., 1971; Rowe, 1978). These approaches emphasize the importance of both direct hands-on experience and classroom discussions as ways to engage students in the process of science and scientific thinking. These approaches have proved difficult in practice. Hands-on activities are difficult to manage and require reorganizing the classroom for small-group or individual work. Perhaps more substantial problems are found in conducting discussions concerning the classroom investigations. Teachers are not accustomed to asking for and listening to complex conjectures or theorizing by the students. They often lack the mastery of the subject matter and understanding of the learning process for the particular topic that would let them interpret or make use of the students' contributions to the discussion. These limitations make the kind of enculturation into sense making that is now being described in math classrooms difficult to achieve in either math or science.

The study reported here contributes to a growing paradigm of research on the social constitution of cognition and cognitive change (Bruner, 1966; Lave, 1988; LCHC, 1983; Rogoff & Lave, 1984; Vygotsky, 1978, 1986). Building on analyses of the development of scientific expertise, this research paradigm has begun to address the ways in which knowledge is constructed in interaction with others (Newman, in press a; Newman, Griffin, & Cole, 1989), how teachers appropriate student contributions into classroom conversations (Lampert, 1990; Newman, 1990a), and how classroom activities can attain the authenticity of apprenticeship learning (Collins, Brown, & Newman, 1989; Lave & Wenger, 1989; Resnick; 1987, Rogoff, in press). We describe a formative experiment conducted in four Boston-area classrooms in which we were able to refine our analysis of sense making, and from that vantage point, see a number of the difficulties teachers have in conducting discussions in which a theoretical model is brought into coordination with data. We note that, in many cases, data are discussed without engaging in questions about *why* the data have a particular pattern. And often the model is taught directly with no explicit discussion of how the model explains specific data. We find that the typical organization of the curriculum unit around a sequence of topics can militate against a focus on understanding the phenomenon. While there were many successes during the year, there was also a systematic dissociation of data and theory, which we find applies also to the use of simulation, database, and telecommunication technologies. We conclude with comments on the development, through talk and technology, of sense-making communities in the classroom.

A Formative Experiment on Technology Use and Curriculum Design

We worked with four Boston-area teachers who volunteered to join the project understood as an effort to develop and implement a fifth- or sixth-grade curriculum unit on seasonal change. With assistance from the researchers, the teachers' task was to design a unit that included modeling and-data collection components and to integrate the use of technology into these activities. The goal of the unit was to engage students actively in science learning activities. The classrooms were also to be the site for a parallel experiment with the use of drama that was also integrated into the seasons unit. Two of the participating schools were K-6 schools located in a homogeneous middle-class suburb of Boston. In one of these schools—the focal school for the study reported here—two sixth-grade teachers team-taught science and other subjects. The third school was a K-8 school in an ethnically diverse area of the city of Cambridge. This alternative public school served, in particular, the large Haitian population. We worked in a combined fifth-sixth grade classroom.

Our work initially aimed at documenting the impact of different designs for the integration of technology into the curriculum (Collins, in press). The researchers' task was to support the design, conduct interviews, and conduct observations, supported by field notes and video. In the case of the drama activities and some of the activities using simulations, researchers conducted the activities in the classrooms. Teachers and research staff met approximately every three weeks to discuss progress and compare notes. These meetings were an opportunity for the research staff to make suggestions concerning the use of technology, classroom discussions of data, and so on. As our work progressed, it took the form of a formative experiment in which teachers modified their approaches and researchers modified their support attempting to achieve a goal of engaging students in active science learning activities. A formative experiment, in this sense, is a deliberate tinkering working toward a predefined goal (Newman, 1990c). A characteristic of this approach to classroom research is that the goal itself can become more clearly defined as we examine our successes and failures in approaching the initial goal definition. In this case, our observations led us to an analysis of sense making which now serves as a goal for further experimentation. Thus, the outcome of our formative experiment is an understanding of the system of science teaching in terms of this goal and the conditions necessary to achieve it. This system then provides the interpretive framework for understanding the role of technology.

The initial phase of the project was the development of a curriculum that instantiated both the content goals and the instructional approach, which included both data-collection and modeling activities. The teachers, including the principal of one of the schools, assisted by project staff, worked together for a week in the summer to develop a curriculum that covered topics relevant to understanding seasonal change. A seven-page outline was produced that described or indexed a sequence of topics and activities. Students were to gather a wide variety of data and information about seasonal change from direct observations, newspaper weather data, simulations of earth-sun relations, and historical accounts of scientific discoveries. The theoretical model to account for the data, in this case, could be expressed quite concretely—with a model earth and sun.

While the study of seasons is common in elementary school science, the topic is quite complex. At its heart is the fact that the earth's axis has a slight inclination from perpendicular to the plane of the orbit around the sun. As the earth revolves around the sun, this inclination results in seasonal differences in the amount of solar radiation on different parts of the earth, arising from differences in the angle of the sun's rays reaching the earth and from differences in the length of the day. A fundamental problem for understanding this account arises from the fact that the helio-centric model of the earth-sun relation that is the central cognitive tool for mastering the explanation is entirely counter to our geocentric phenomenal experience. The student must translate between the sun rising and setting and the rotation of the model earth. The changing elevation of the midday sun must be envisioned as a changing orientation of the tilt of the axis in relation to the sun. The chain of reasoning required to get from observable phenomena, such as the fact it is warmer in summer than winter, to the model that explains it is complex and provided opportunities for us to study a series of lessons over an extended period. Existing resources such as "Daytime Astronomy" (ESS, 1971), *SunLab Teachers' Guide* (Smallberg, 1990), and Asimov's delightful book, *How Did We Find Out the Earth Is Round*, were used.

A Common Science Teaching System

The curriculum involved a variety of activities from which students might construct for themselves a model of seasonal change. The teachers were committed to not teaching the model directly as is typical of textbook presentations or one-shot lessons on seasonal change. The teachers specifically avoided giving the students the complete answer because of their commitment to the idea that students would be able to work it through using a variety of pieces, clues, and data.

Among the classroom lessons and activities that were planned was data collection that included measuring shadows. Meter-long sticks were mounted to a base so that they could stand straight up on the ground. Large sheets of paper were used to record the lengths of the shadows. There are two distinct kinds of shadow data that were collected. The first kind, which we called "fan" data, involves collecting a series of shadow readings during a single day to determine the pattern of shadows and the time, length and direction of the midday shadow, that is, the shortest shadow that points directly north. The second kind involves recording the length of midday shadow, length of day (based on the newspaper), and midday temperature over a period of months. This second kind of data is the critical data of seasonal change. Students copied their information into a communal notebook, which was the foundation for a computer database with this and other information.

The classes also engaged in a variety of modeling activities and, on many occasions, lessons were structured to give small groups of students opportunities to examine sets of data, to theorize about them, and to present their theories to the rest of the class. There were many successes during the year from which we can begin to specify what might be meant by sense making and some of the conditions that constitute it. We can also document a consistent pattern in the instructional approach, resulting from a commitment to the curriculum objective of learning the *model* of how the seasons change, that tended to subvert the constructive sense-making process. In this section, we begin with an example that illustrates what appear to be some of the critical features of sense making, and then turn to describing the system of instruction that we believe is common in science classrooms and that worked against a constructive sense-making process.

An Example of Sense Making

By early March, after several months of data collection and discussions, one of the classes in the focal school was engaged with the question of why the days had been getting shorter up to the winter solstice and now were getting longer. The teacher had developed an exercise designed around a globe, golf tees, and a small "mini" flashlight. These objects were the components of a model that can account for changing day lengths. The students, mostly in groups of two, although there were some students who were alone, took the tee and put it, with the help of a tiny piece of clay, on the globe. They then shone the light on the tee at varying angles, and turned the globe in different ways, and put the tee in different spots. For many of the students, their exploratory modeling was not constrained by any particular question, nor by the data on changing day length. These modeling tools were, however, familiar to the students and they were aware they were modeling the earth-sun relationship. At one point, the teacher volunteered to act as the sun (hold the flashlight) for Erica, who was working alone sitting on the floor of the darkened classroom. The one-to-one interaction that followed raised for us a set of issues that we believe are important for a definition of scientific sense making.

The following excerpt occurs toward the end of this 20-minute interaction. Erica has placed golf tees on Boston, where she lives, and Jamaica, where she spent her winter vacation and, with her family, had actually collected fan data (shadow lengths throughout a day) and midday shadow measurements. By holding the sun in specific positions and having Erica rotate the globe, the teacher modeled the winter solstice with the midday sun overhead at the Tropic of Capricorn; the equinox, with the sun overhead at the equator; and the summer solstice, with the sun overhead at the Tropic of Capricorn. Erica moved the golf tees into sunlight, through midday where they established that the shadow pointed directly north, and onto sunset for each of the positions. The teacher drew attention to features of the model as it was run and at one point engaged in a discussion of what it means for the sun to be overhead (which occurs in Jamaica only near the summer solstice).

T: Here we are . . . morning . . . (as Erica turns the globe toward midday on the summer solstice).

E: How come it took longer to get to midday then . . . today . . . then . . . this is directly . . . (Erica begins to notice a difference between the winter and summer positions).

T: Keep going . . . all right . . . now . . . Erica you said a very interesting thing, so we will try this one more time . . . Tropic of Capricorn . . . (T moves the sun down to its winter solstice position, and they run the model again with Erica turning the globe so that the tee moves from morning through midday.)

E: How come . . . it takes longer . . . It takes more time to like have to . . . have one of them pointing to the north pole . . . from the cap . . . Tropic of Cancer and Capricorn? . . . hard to explain . . . (Erica is noticing that it takes longer to get from morning to midday—when the shadow points to the north pole—when the sun is on the Tropic of Cancer.)

T: Erica . . . very very amazing . . . now, all you need to do . . .

E: Oooooh . . . I see.

T: is use your head, and all that data that you just said . . . all that data you've collected . . . and what you just said and put it together and say it out loud tomorrow . . .

E: Oh it's . . . I know what I'm talking about now.

T: I think you do know what you are talking about . . .

E: It . . . the reason why it's the length of . . . midday gets . . . these two days cause the sun . . . it takes longer for it to get . . . I don't know how to say it, but I know what I'm t ing about.

T: Uh huh.

This interaction was not unique, but was less than common in the classroom. We can use the interaction and Erica's insight to illustrate four features of sense making that distinguishes this episode from many other less successful attempts that we observed.

1. **A question.** The excerpt captures an important moment in which Erica for the first time clearly formulates the question that the teacher has been asking the class for more than two weeks: Why is the day longer on the summer solstice than on the winter solstice? Erica could see that the tee took longer to get to midday when the sun was on the Tropic of Cancer and her question emerged from this display. Sense making takes effort and we can see Erica's struggle with conceptualizing what was happening and putting it into words. We suspect that *having* a question, not just being given a question by somebody else, is a necessary condition for putting in the required effort. Erica's discovery of the question was accompanied virtually immediately with a "realization" that she struggled to verbalize for the next few minutes and even for the next week or so. But the origin of such questions is a central issue here. The question emerged in the interaction between Erica and the teacher as a result of the framework that the teacher constructed, the question that was the teacher's motivation for the lesson, and Erica's concrete experience that was being modeled by the globe, tees, and flashlight. The question e.nerges within the little community of teacher and student, not just spontaneously from Erica.

2. **Coordination of data and model.** In the example, the teacher is quite carefully running a model with very specific features geared to displaying the mechanism that causes the days to be longer in summer than in winter. But the teacher was not just teaching the model and Erica's insight was not just about how the model works. At each step, Erica's experience and the data she collected was broug t in. That the sun rose in the east, the midaay shadow pointed north, that days changed their length were coordinated with the model. The fan data that Erica was very familiar with wa e-created by moving the golf tee under the flashli t. The model made it possible to represent the data. For example, at one point (prior to the transcribed excerpt) the teacher asked Erica to show her midday in Boston. It soon became obvious that Erica thought that at midday the sun was directly overhead. A long side sequence followed in which a common meaning for "directly overhead," as the case in which there is no shadow, was established. While Erica had been out collecting shadow data for almost six months at this point, she had never observed the midday sun the way the teachers had. The model made clear the distinction between high in the sky and directly overhead.

When the data and the model are brought into coordination, it is possible to go beyond the student's opinion and commonsense beliefs. The data constrain the model and give the model its connection to the real phenomenon. The model is a framework for interpreting the data, giving the data a more specific meaning. The coordination requires a struggle, which we are calling sense making. Mastering this epistemology might be considered the central objective of science instruction.

3. **Expert provides a structure.** The teacher provided an enormous amount of structure for Erica and continually challenged her with questions and examples using the model and drawing on her own experience. In contrast, many of the other students, working alone or in pairs, had the flashlight simply follow the tee around with no apparent plan or no sense that the light needed to be constrained in some way in order to properly model the sun. The teacher constrained the model for Erica by concentrating the sun's rays on a specific place on the globe and in a specific manner. Within this structure, there was an

implicit challenge to Erica to make sense of the model. The teacher never explained the model to Erica, she just "ran" it. The questions the teacher asked helped Erica focus on relevant features of the model.

Using this structure, the teacher was able to appropriate Erica's remarks and clarify her conceptions. As soon as Erica began to ask her first question about how come it took longer to get to midday, the teacher immediately noted the question and re-ran the model. By appropriating Erica's question, the teacher gave it significance, reinforcing to Erica that the question was central to their task together. The teacher was not teaching Erica how the model worked. She was guiding Erica through the system of relevant observations, relationships, and questions.

4. **Grounding in students' experience of phenomena.** It is not accidental that the teacher chose Jamaica and Boston as the points to be modeled. Gathering daily shadow data had become a family activity over their winter vacation in Jamaica. Grounding science in the child's experience of the real world is not a new idea. The choice of seasonal change as our topic was driven in part because students are very familiar with the phenomena. The phenomena in this sense is the real world experience available to common-sense observation. It is distinct from the data or the model which are artifacts useful for understanding the phenomena scientifically. Disciplined data collection can reveal patterns that are not noticed in everyday experience. Data, as an artifact, can also be in error. At one point in their interaction, Erica becomes convinced by examining the model that the midday shadow will always point north:

E: Oh so it's gotta be pointing north, but how come in Jamaica it pointed east at midday?

T: Well, perhaps when you were in Jamaica you weren't as sure as you might have thought you were about which directions were which, but if it's midday . . .

Data, as opposed to the actual phenomenon, can be in error. "Hands-on" data collection should not be confused with experience of the real world, not only because of the possibility of measurement error. The data may take an abstract form that does not assure a connection to the phenomenon. For example, for many students, including Erica, shadow length was not understood as an index of sun elevation.

Models are a critical class of artifacts for scientific work. They are not the phenomena, they are simplified in specific ways, and they differ in other ways from the phenomena that are not yet understood. The model the teacher constructed with Erica was very much a partial model designed to show a particular relationship. The globe was not tilted and was not revolving around the sun. In fact, the sun was moving up and down. In science instruction the artifactual nature of the model is often not communicated. The instructional objective is to master the model rather than understand the phenomena. The interaction with Erica may have been successful because it was grounded in her experience but also because both the data and the model were treated as artifacts that are useful in coming to an understanding.

A More Common Example: Dissociation of Data and Model

Another episode that occurred two weeks earlier illustrates a more frequently observed pattern in which the features of sense making we have outlined are to a large extent absent. For this lesson, the specific data was the length of day in Boston collected by the class from the newspaper over a period of several months spanning the winter solstice. Erica's group, the NKASS (new kids at Stratton School), consisted of Erica and Leah (the third member was missing).

T: So we need NKASS to be next then.

E: We think that, like from September first to the winter solstice, the days keep getting uh . . .

L: Shorter.

E: Shorter.

L: And then from the winter solstice till March . . .

E: Feb 14, today, the days are getting longer.

T: Okay, that's your pattern. Now, why do you think that happens? Erica, let's do why you think that happens before you write it.

E: Well, because for the winter solstice it's the shortest day of the year. So from the winter solstice, the days keep getting longer 'cause like the sun . . . well, 'cause like you go like this, right, this is summer . . . 'cause we're facing the earth and then it turns and then this is spring, and when the sun's away from us, this is . . . (Erica carries the globe, walking around Leah who is holding the sun. She correctly maintains the tilt of the axis as she moves around.)

L: Winter.

E: Winter for us, but it's summer for here (indicating the southern hemisphere).

T: Uh huh.

E: And then it turns like this and it's fall here, but it's spring here. Then it turns around—this is summer and this is winter (continues walking around Leah).

At this point, the teacher has them walk through the positions of the earth for each of the seasons that she calls out.

T: All right. Now, are you ready? Let's start with summer—show us summer. All right, show us winter, show us summer, show us winter. All right, spring, summer, fall, winter. Okay, now that's the reason that we are getting more daylight up until . . .

E: It's because . . .

T: Well, that we have gotten more daylight each day since the winter solstice.

E: 'Cause we had more rays.

L: It's the sun's getting closer in summer.

The teacher now tries to define more closely the difference between getting closer and turning towards something and asks the students if they were giving a theory of the sun's moving, to which the students answer no.

T: Now, I didn't see you move the sun at all, Leah. I saw Erica move the earth a lot.

L: The earth the earth's getting closer because . . .

E: No, the earth . . .

L: Well, it's turning towards it.

E: It goes like . . . (Erica models).

L: The earth's turning towards the sun.

E: 'Cause . . .

T: But getting closer and turning towards it are two different things.

E: It doesn't get closer.

T: I'm turning towards you now but I'm not getting any closer to you. I'm turning away from you but I haven't gotten any further away. I haven't moved other than the way that I'm facing (teacher models).

E: That's what . . .

T: So, are you giving me a theory that has the sun moving or not?

E: No.

L: No, the sun stays.

E: Stays, yeah, and then like the earth goes . . .

L: Goes like around.

E: (Erica models)

T: What are you showing me now, Erica?

E: This is how the sun like the earth would go.

T: When?

E: All year.

T: All year. All right. Now, can you write your theories please?

This episode is fundamentally different from the one in which the teacher worked one-to-one with Erica. First, the question being addressed was unclear. The teacher overtly asked them to explain the pattern of day length. However, at this point in the curriculum, the students were well aware that the objective was to get the theory of seasonal change. While Erica said she was explaining the data the demonstration was a rendition of the model of seasonal change. She marked the transition between discussing the data and displaying the model with the phrase "well, 'cause like you go like this," suggesting that she was about to enact a commonly known model. The performance appeared to come more from the students' sense making about the curriculum than from questions about the phenomenon nominally under discussion.

Second, the model they demonstrated and the data they reported were not in contact. The data were about day length but the model was about the earth facing the sun or the sun being away from the earth. The model did not include the earth spinning on its axis, which would seem to be necessary for an explanation of day length. Only in some vague way, can "the sun's away from us" and "'cause we had more rays" be considered a cause of shorter days. This level of description is not a specific mechanism so much as a commonsense association.

Third, the teacher did not put any constraints on the modeling activity or challenge the students with alternative models or unaccounted-for data. Her questions at the end were clarifications not challenges. She established that the girls were not asserting that the sun moves. The teacher did not use the NKASS model as part of a class discussion of the question of why day length changes; there was no attempt to compare it with other theories or to draw out its strong points. The episode was structured as a recitation and correction of the model rather than an opportunity for the class to construct an understanding.

Fourth, both the data and the model appeared unconnected to any personal experience. The disengagement of Erica in this episode compared to the episode described earlier is striking. The objective was a demonstration of the model, not an understanding of the phenomenon of changing day length. The model had taken over. It no longer had a role as a useful artifact in trying to understand the real world. Without a grounding in a phenomenon, the data and the model have drifted apart in spite of the explicit attempt in this lesson to explain specific data using a model.

The Effect of Our Curriculum Design

We can trace the origin of the dissociation of the data and the model to the curriculum design that was developed in a week-long summer workshop. The goal of the workshop was to compile a sequence of classroom activities that had as their goal teaching the seasons, while providing the students with hands-on data-collection and modeling activities. During the initial two days, the researchers conducted discussions of our general approach to inquiry, gave suggestions for the use of database and simulation technology and, with the help of an astrophysicist, covered background content about seasonal change. For the next three days, the teachers, with assistance from the researchers, compiled a set of activities each tied to a learning objective. These were recorded on file cards and then ordered on a timeline. Combined with notes about text and other resources, this sequence of activities became the curriculum plan that was carried out to a greater or lesser degree in the participating classrooms.

Our account for the absence of sense making in the NKASS example points to this initial curriculum plan as a important determinant. The curriculum plan we believe was typical of school curricula, which are essentially taxonomic in their approach (Newman et al., 1989). In this case, the set of categories were the components of the earth-sun system model, including the fact that the earth is round, latitude and longitude, rotation, revolution, the fact that the earth is tilted toward the north star, and so on. Essentially, this sequence of classroom activities that constituted the curriculum decomposed the theoretical model into aspects that could be illustrated in modeling activities. That is, the ultimate curriculum objective, considered as the earth-sun model, was decomposed into its parts and taught separately. The modeling activities that were developed were subordinated to these topics. Data-collection activities were also planned but not clearly integrated with the topic sequence. That is, the data collection activities were not tied to the specific topics which formed the curriculum sequence. From the beginning, then, the hands-on data collection and the modeling activities were not integrated. As this plan was implemented in the different schools, the data-collection activities were either not done to any significant degree or were conducted with tremendous regularity but in such a way that the discussions of the data were not coordinated with the topics that were being covered. In this section, we document the ways that the model-based curriculum militated against sense making in which data and model are coordinated.

Discussion of the model with no data. All the teachers began their units with class discussions in which groups of students were asked to explain why the seasons change. Students were asked to present their theories using globes and balls as props. Since no actual data had been collected at this point, the "data" they were explaining with their theories are the students' everyday knowledge of what the seasons are, something that Boston area sixth graders are certainly familiar with. Summers are warmer and winters are colder was the assumed phenomenon to be explained. One common theory to emerge was what we called the "time zone" theory: the side of the earth that is facing the sun is in summer while the back side, away from the sun, is in winter. Another common theory was that the earth is closer to the sun in summer. Either of these theories is consistent with a warm and cold season. More specific data—for example, that Boston and Japan have winter at the same time or that Boston and Chile have winter at different times—might help in deciding among them. However, in these initial discussions, the notion that data can be introduced to constrain the models was not part of the classroom conversation. For example, in one of these early discussions at the focal school, it happened that one of the students had lived in Australia. The teacher elicited from Cathy the report that at Christmas it is their summer season. While some students were curious or amazed by this, there was no discussion of its implications for their theories of seasonal change. While Australia's "green Christmas" appears inconsistent with the distance theory, it was not treated as a specific challenge to the students' theories. In an important sense, students were not presenting their theories as ways to account for data so much as expressions of their everyday beliefs or commonsense opinions about the seasons.

In another classroom, a similar initial discussion was conducted about what causes the seasons. In the discussion, a spokesperson for each of the science groups explained the theory that the group had decided upon in previous small-group discussions. At one point, a student refused to model his theory by walking the globe around the model sun as the teacher had requested. A subsequent interview of the student revealed that he was going to explain a distance theory and felt he only needed to move the earth in and out from the sun. The teacher, however, insisted that the whole model be presented. (It became clear, subsequently, that many students did not understand the orbit of the earth at all or saw it as very irregular.) This teacher's insistence on modeling the solar system in a specific way was consistent with his focus on the model itself. In his view, the solution to the students' misconceptions was to get them to model it correctly. The next topic he felt it necessary to cover was the north star, which would establish the need for a consistent tilt. This approach to the curriculum as covering the components of the model was seen in many instances.

Discussions of the data with no model. In the focal classroom, students began collecting data on shadow length and day length early in the unit. The classes came together regularly to report their findings, to chart the data, and to examine the patterns. These discussions went on concomitantly with the classroom activities in which the earth-sun system was being modeled. While a considerable amount of class time was spent on reporting the data, for the first four months of the unit, the data were not used as the basis for a discussion of *why* the days were getting shorter or the midday shadows were getting consistently longer.

Getting firsthand experience in the school yard with the changing position of the sun might be expected to provide a grounding in the phenomenon that would prove useful in theoretical discussions later on. But their experience in the school yard was not as rich an experience as we might assume. In the course of discussion, the teachers discovered that many students had not been clear on the relation of the sun's elevation to the shadow length, having thought that a longer shadow was a result of the sun's being further away. This confusion was a surprise to us since we had assumed that, in collecting the hourly shadows, it would be intuitively obvious that the sun was moving through an arc in the sky, and the higher the sun the shorter the shadow. The data on shadow length for these students were not an index of sun elevation but a number dissociated from the real world phenomenon that was supposed to be the object of study. Their hands-on experience with the world did not lead spontaneously to relevant observations.

There was evidence that students could make use of the hands-on experience if it was coordinated with modeling. To deal with students' beliefs about why the shadow gets longer or shorter, the teachers devised a set of activities with flashlights and golf tees and other objects that could stand up on the floor. The teacher did not say in introducing the lesson that the goal was to model the change of the sun's shadow during the day. The activity led some students to confirm their distance misconception because by moving the tee away from the stationary light source they were simultaneously reducing the angle and thereby lengthening the shadow. Each group presented their findings in turn. Several groups, in moving the light up and down, referred to the meter stick and the daily movement of the sun. The students recognized this model as an explanation for their shadow data. One student also showed that by moving the tee under the light, representing the moving earth, similar shadow patterns were produced. Other students suggested an experiment in which meter sticks were placed at different places on the school yard to determine if there were differences in the sun shadows that they predicted on the basis of the model. It is likely that, without firsthand experience, the students would not have made the connection between the model and the way shadows changed in their school yard. The personal experience of being in the school yard allowed the students to move between the model and the actual phenomenon.

Difficulties in bringing the data and model together. As the unit progressed in these classrooms, a pattern emerged in which lessons either focused on the model without considering data or focused on the data without an attempt to use a model to account for them. The researchers suggested a different approach to one of the teachers who had not involved his students in data collection. Instead of focusing on constraining the model through asserting features of it, could he attempt to focus the students' model construction by introducing data that might constrain it? This teacher, who had previously worked as an astrophysicist, understood the point very well from a scientist's perspective: the data is what is given; the model has to account for it. By this point, the researchers had obtained several data points on midday shadows and day length from schools in New York City and Toyama, Japan. We graphed the data and provided it to the teacher to try out with his class. In the next lesson, the teacher distributed the graph to each of the science groups and asked them to come up with a collective theory. The subsequent class discussion differed remarkably from previous discussions that addressed only why the seasons changed. For example, the first spokesperson to get up began to explain something about why shadows should be longer in Toyama, but then looked at the data and the globe and mumbled that he had to look at it again because he made a mistake, clearly indicating that he was attempting to coordinate his presentation with the data. The second spokesperson to get up asked the teacher if he wanted to hear their shadow theory or the seasons theory. The teacher, quite remarkably, pointed to the graph on the board and said he wanted an account of the data. With the same level of insistence that he had shown in earlier discussions about the earth orbit model, he made it very clear that this discussion was about accounting for the data, not a general discussion of the causes of the seasons. Subsequent presentations addressed the data quite specifically. In this lesson, in comparison to earlier lessons, students exhibited a struggle with the data and their explanation. They proposed partial solutions and made use of points made by students in earlier presentations. One factor in this change was the teacher's framing of the question, which included drawing the graph on the board to maintain the data as the center of focus. Another factor may have been the selection of spokespeople, which favored the most articulate member of each group in essentially solo performances but left most of the students out of the process.

This lesson was striking in the engagement of students in a struggle to make sense of the data the teacher put up on the board. We note, however, that at the end of the session of presentations, the teacher summarized the discussion with the following comment:

> Okay, so we have different theories and they all have interesting aspects to them, and next week I have another proposal taken from some of the information we had earlier, that we're going to make another model. Using these models, we'll see if you can come up with a little more understanding about it. There's one thing that I noticed, and I think in every one of your explanations that will come out with a little more clarity next week.

What the teacher had in mind, again, was that the models that the students were presenting did not have the earth's axis oriented in a consistent direction. Anticipating that material to be covered in the next lesson would correct their misconception, the teacher did not appropriate the students' partial understandings or their actual introduction of the concepts into the current discussion. The sense making that the students achieved in this lesson was not taken advantage of as a building block because their models were compared to the end-point objective yet to be covered rather than looked at as the first step in the students' own construction of an account of the phenomenon.

Difficulties in maintaining the data orientation. The class discussion of the New York and Toyama data was videotaped, and excerpts of the video were shown at a meeting of the teachers and researchers as part of a discussion of the teachers' progress and plans. Shortly thereafter, a teacher from the focal school conducted the class discussion described in the example of the NKASS. This discussion was clearly influenced by the notion of having students account for a specific set of data that had been discussed at the teacher-researcher meeting. The difficulty of maintaining this focus is clearly illustrated. The students drifted from the specific data to a general theory of the seasons. The teacher was inconsistent in holding the focus, and only at the end of the discussion did she raise the issue of the earth's rotation which, while not yet covered in their unit, was essential to accounting for the data.

The students and teacher drifted from a consideration of specific observed phenomena to general characterizations of seasonal change. From the students' point of view, it is a reasonable piece of sense making about the lesson that is part of a unit on seasonal change to consider the real goal of the lesson to be the seasons. The teacher certainly provided sufficient signals that theirs was the appropriate interpretation. Students came into the class with their existing conceptions of seasonal change and found an occasion to display them. It is difficult to switch gears into a very focused discussion of something that was actually observed. The notion that data and a model could stand in a strictly coordinated relation to each other was fragile, if existing at all, for most students. While these students had spent considerable time collecting and observing the patterns in the data they were now reasoning about, the sequence of instruction did not provide support for sense making. The sense-making task was not familiar to most students and it was easy to fall into vague generalities.

Making Sense of Real Phenomena

We have identified a major impediment to sense-making discussions that is a fundamental feature of school curricula that have a theoretical or taxonomic model as their objective. The curriculum sequence was geared toward reaching an ultimate goal of being able to reproduce the accepted model for the causes of seasonal change. With this goal in mind, the curriculum was designed to cover the components of the model. From the teachers' point of view within this framework, the students' understandings were matched against the template of the final objective. The missing components were diagnosed and the next remedial actions were thus specified. The data were not taken seriously as a means for constraining the model. Most important, the partial models were not used as adequate accounts for parts of the data. Fundamentally, the data were not used as a basis for constructing the model, which ultimately was to be covered piece by piece.

Is there an alternative mode of curriculum design that could be more successful? Accepting the objective of understanding seasonal change, a sequence that is phenomenon-based rather than model-based might help. That is, we could start by defining the objective as *understanding the phenomena* rather than understanding the accepted model. It may be useful to decompose the topic into phenomena such as the cycle of day and night, the climate zones, and then seasonal change. Each phenomenon has its own data and model, but each is a coherent problem about which the students can ask specific questions. There may be many models at any point and even several ultimately—the model would be understood as a useful artifact to help in understanding the phenomena but not as an end in itself. The data would be collected about more specific phenomena for which models could be constructed using the information and modeling tools the students had mastered. A chunk such as day and night is very different from rotation, since day and night is a phenomenon for which the students have everyday experience. Rotation is part of a model that can account for day and night.

The dissociation of data and model and reification of both of these at the expense of commonsense experience of real phenomena takes sense making away from a central position in the science classroom. In the next section, we describe how technology can participate in the same dissociation.

How Technology Participates in the Science Teaching System

We have described a typical science teaching system in which there is a dissociation of the data and the model. We find that technology also participates in this system. But we note that technologies provide some unique capabilities that can perhaps subvert a rigid sequence and open the way to sense making. For the most part, however, in the classrooms we studied, the technology was used in ways that could be predicted by our model of the teaching system.

We noted that the curriculum sequence was based on the model of the sun and tilted earth that was seen as the ultimate objective. While the curriculum is covered in some sequence, the actual phenomenon of the seasonal change that the class is studying is unfolding in real time. We can use this distinction between a real-time phenomenon and an abstract model in looking at the impact of the technologies such as simulations, databases, and telecommunications. We can see immediately that a simulation of the solar system breaks out of the real-time constraints of the real yearly cycle. Telecommunications, on the other hand, is a link into the real-time phenomenon itself. While a simulation can be accommodated to a model-based curriculum sequence, telecommunications may tend to cause problems for the sequence. We might expect also that different technologies will gravitate to either the model or the data. In this section, we make some conjectures about the conditions under which these technologies might help or hinder the coordination of models and data.

A Simulation as a Surrogate Phenomenon

The teachers in our focal school used a simulation called SunLab, beginning in the spring. Two members of the research team also used it in several lessons taught at the other schools as a way to examine the utility of the technology in contrasting approaches. SunLab simulates the earth-sun system and offers several views, including a view of the solar system, a view of the sun's path through the dome of the sky, and several combination views. A view is also available that shows a person standing on the ground creating a shadow with a meter stick. With a click of the mouse the elevation of the midday sun in degrees is displayed. Any location on earth can be examined. For any location, the student can view a day, hour by hour, in any month or move through the months holding the hour constant.

A simulation such as SunLab is both a model of the phenomenon and, when the simulation runs, a generator of data. In the classroom, however, SunLab serves as a surrogate for the phenomenon rather than the kind of theoretical model used in science. That is, in contrast to simulation models used in scientific research, SunLab cannot be modified to model empirical data. SunLab is not treated as hypothetical.

Within the context of this project, SunLab was, for the most part, integrated into the sequence of instruction. In other words, it participated in the dissociation of data and model. Mainly, it was used as a data-collection device, but at times it was used as a "model," albeit with the understanding of the term "model" as noted above.

The initial introduction of SunLab into the classrooms was very different, depending upon the teacher. In one case, Sun Lab was put in the back of the room so that students who were finished with their projects could experiment with it. In another case, the teacher afforded only a few privileged students the opportunity to work with the simulation. In that school, the program was introduced to the class by a researcher who provided a worksheet with questions that could be answered by inspecting the helio-centric views of the earth and sun. Questions such as "Is Australia in the hemisphere that is tilted toward the sun in August?" were intended to draw students into the earth-sun model as it was run through a yearly cycle. This focus on the model contrasted with a purely data orientation in the focal school.

In the case of our focal school, the two teachers used SunLab in whole-class sessions in a computer lab, controlling the introduction of SunLab to the c[illegible] and allowing the students little freedom for the first month or so. These teachers, in keeping with their commitment not to teach the whole model directly, only allowed the students to use the "dome of the sky" view; that is, the geocentric view from which data could be collected. The teachers had the students use SunLab as a data-collection device—students filled out sheets of paper on day length, angle of sun, etc., for a variety of different places. Most of the data they collected was used to help create posters for a "Sun Festival," the final presentation at the end of the school year for the parents and friends of the school. As a data-generation device, the SunLab simulation had advantages over hands-on data collection since the data could be collected at any time during the year and data for sites that would be difficult or impossible to get data from, such as the Tropic of Capricorn or the north pole, could be obtained easily.

One of the researchers working in another school also experimented with collection of data from SunLab as a preliminary to a class discussion within the same period. In a sequence of two lessons, pairs of students were assigned to each of the ten computers in the computer lab. Each computer had been loaded with a different city or other location; for example, the north pole. Students were given a blank graph with months of the year on the x-axis and elevation in degrees on the y-axis and asked to use SunLab to collect the data for their location. In about 10 minutes, students had filled in their graphs. A discussion began with a comparison of Boston and Istanbul and the question, "Why are the graphs the same?" Students specifically addressed the data, which were copied from their separate graphs to a larger graph on the blackboard as required by the ongoing discussion. The researcher/teacher got students to model their conjectures using a globe and overhead projector as a light source. As in the focal school, the class's use of SunLab did not go beyond the dome of the sky view. The models provided by SunLab were not brought into the discussion.

While the teachers in the focal school avoided the views that displayed the heliocentric model, it began to come into play when inadvertently two students, Billy and John, found themselves in one of the three-part views that had an earth moving around a sun, a large earth which rotated on its axis, and a smaller dome of the sky view. They were ecstatic, exclaiming that this view "has it all," "it's all right here," and so on. They immediately tried to show some of their friends and to keep it hidden from the teacher, who asked them to go back to the dome of the sky when she found out. During the course of the next few weeks the researcher found them occasionally surreptitiously sneaking peeks at other views.

All the students continued to work with the dome of the sky view over the next few weeks until a lesson in which the teacher asked the students whether or not a certain place in the USSR with the same latitude and longitude as Boston had the same seasons as Boston. The task was not specifically to collect data in the sense that the students did not bother getting out their notebooks to record anything. Nevertheless, the teacher gave no indication that the students were to use anything other than the dome of the sky view, which was the only view most of the students were familiar with. While most of the students did use this view in order to answer the question, Billy and John went directly to another view, telling the researcher it was easier to answer the question in this view, and answered the question to their own satisfaction within a few minutes. By spinning the SunLab globe, they could see quite directly that the two locations passed through the same location in relation to the sun during a day. They proceeded to show their friends how to use the view, and went on to belittle the question, saying how easy it was. On this occasion, the teacher called the other students around the boys' machine and conducted a lesson about the different views available in SunLab. Later, in a classroom discussion, the "model" students had a difficult time explaining to the rest of the class how they had solved the problem since their reference to the two locations being at "the same location" could only be interpreted in terms of the rotating globe bringing the two locations to the same point relative to the sun. This was distinctly different from the observations of other students, who noted that the sun was in the same position for the two locations from the "data" point of view. That discussion actually brought the two points of view together in a way that had not occurred previously in any of our teaching.

The commitment to withhold the "answer" from the students and to avoid simply giving them a fully formed model to inspect (the strategy tried out by one of the researchers at one of the other schools) lead to a use of SunLab restricted to data collection. As illustrated by John and Billy, the SunLab model views are well suited to a style in which the model is taught directly. SunLab is not a model in the sense used in scientific theory building and testing where models represent hypotheses to be tested. It is an inspectable surrogate for the real phenomenon. It is not treated as hypothetical; it represents the way things are and generates correct data. A different kind of modeling tool may better serve a sense-making process. If students were able to build their own models from components such as light sources, orbits, planets of differing shapes and sizes, then the resulting models could be viewed as artifacts of the classroom scientific community. With this tool, the model would not stand in the place of the phenomenon but would be used to predict events that could be measured in the school yard or perhaps elsewhere in the world. SunLab in its current form can play into the dissociation of data and model through its use exclusively as a display of the accepted model or as a source of data. The integration of the two components is built into the parallel views (e.g., the window showing both the dome of the sky and the solar system view), but the use of those views for sense making was not a planned part of any of the lessons we observed.

Databases and Telecommunications: Real Data

Collecting the data of real seasonal change is problematic because the phenomenon is global and takes considerable time to unfold. Simulated data may be more conveniently integrated into a neat curriculum package, but tracking the actual seasons may have some advantages in providing personal experience with the phenomenon. Database and telecommunications technologies can play a role in gathering and reviewing real data. Our interest in this section is to trace the role of these technologies in relation to the coordination or dissociation of data and model that we observed.

The students in the focal school used as a database system the Bank Street Filer as a recording device for their data relating to length of shadow, temperature, length of day, and time of midday. The students updated the files as they continued to collect data. After a significant amount of data was printed out, the students examined it to find the patterns of day length or midday time, etc. The discussions that resulted from examining the patterns in the data did not differ significantly from the discussion pattern that was typical of the classroom. Much like the example of Erica and Leah described in the first part of this paper, the patterns were noted and then the talk shifted to a discussion of the seasons or a presentation of seasons theories. We should note, however, that when the teachers were only using the blackboard and charts to display the data, the students struggled with trying to notice the patterns. The database ensured that all the data were collected in one place, making it easier to examine. The database technology serves the data side of the data-model coordination and, through graphing programs, can go as far as displaying patterns but does not support in any specific way the development of explanatory models.

The collection of real seasonal data has its own pace, determined by the slow real-time process. As we saw in the discussion of the curriculum sequence, the data collection for the most part followed a separate strand from the modeling activities. This was probably exacerbated by the fact that the data available at any particular time did not map onto the planned sequence of modeling activities. One might suggest giving up hands-on data in this domain, since data obtained from prepared databases and simulations like SunLab can be more easily integrated into the curriculum sequence. For example, a database available for the Bank Street Filer contains data on climate for more than a hundred cities around the world. Graphing the records by latitude and examining fields, such as average July temperature or lowest temperature recorded, illustrates some basic principles of climate zones and seasonal variation. Having such a database or a simulation like SunLab available might allow the teachers and students more spontaneously to answer questions that were not covered in the original hands-on data set. While these approaches may appear more efficient than gathering data on the real phenomenon, given a curriculum sequence built around the theoretical model as the objective, the more flexible access to data may actually give greater support for the model-based sequence. The hands-on experience, inefficient and disruptive as it may be, will help to support a focus on the phenomenon itself. We might expect that a combination of hands-on data and data from other sources, including data obtained via telecommunications, would be optimal.

Telecommunications is even more "inefficient" than local hands-on data collection since it involves coordinating the timing of instruction across different sites, not just within a single classroom. But this difficulty may not only be outweighed by potential advantages; the disruption of a tidy sequence of instruction may actually have positive aspects. The technology can put students in touch with other students and teachers in touch with other teachers in ways that break out of the usual sequence of instruction. The Boston area schools we were studying were not directly involved in telecommunications, although they received messages via paper copy. Two schools that were directly involved in exchanging shadow data (in New York City and Toyama, Japan) also exchanged a variety of other kinds of information. For example, the New York class began looking at the ratio of shadow length to the stick size, and the Toyama school devised a Logo program that simulated the fan data for a day. These exchanges open up creative possibilities that go beyond the unit as initially planned. Early in the planning for a telecommunications link in which data on day length would be exchanged, the teachers in our focal school illustrated the tension between the curriculum sequence and the imperatives that might require the modification of the sequence. The data format required a single quantity to represent length of day rather than hours and minutes. The school in New York was converting minutes to a decimal fraction of the hour. The teachers doubted that would work because the students would not have covered the necessary computation until much later in the year. Participation in the exchange may have afforded an opportunity to introduce the computation in a functional context, rather than subordinating the data collection to the established sequence.

In addition to forcing a breakdown of a strict curriculum sequence, the telecommunications link may result in greater cross-cultural understanding and may be very motivating. Obtaining interesting data from around the world, as well as these other beneficial results of telecommunications, do not, however, assure that the scientific process of sense making within the classroom will be en[illegible]d. The telecommunication link itself is well suited for exchanging data but not particularly well suited for exchanging, debating, and appropriating conjectures. The coordination of model and data remains a difficult problem.

The Sense-Making Community

We have argued that the common approach to curriculum design in which a topic or a theory is decomposed into categories of information that can be taught in sequence inhibits sense making because it moves the classroom discussion away from the objective of understanding the phenomena. Mastery of the model itself becomes the objective. In that system, the struggle to bring model and data into coordination becomes irrelevant. While technologies may provide support for alternative systems, they can also be easily appropriated to that system. In conclusion, we will review the features of sense making that are suggested by our analysis of classroom events and outline the major problems facing us and some of the solutions we are considering.

On the basis of our observations of Erica working closely with her teacher, we suggested four features of sense making. There is a question that the student is able to ask; data and a model, considered as artifacts, are coordinated in the context of understanding some real phenomena; an expert provides a challenge by setting up a framework; and the whole process is grounded in, but goes beyond, the student's common-sense experience of the phenomena. Sense making in this view is very much a socially interactive process. Lampert (1990) discusses the difference between the usual classroom process and one that does sense making as a cultural difference. The process of preparing a group of students for sense making is considered enculturation. In most classrooms, students do not expect instruction to make sense. Michaels & Bruce (1989) describe the approach of students in a fourth grade class:

> ...we found that classroom reading, writing, and problem-solving were constrained by several key assumptions students held. Among these were the following:
>
> (1) It doesn't have to make sense;
>
> (2) "It doesn't have to be perfect—we're only in fourth grade";
> (a) A finished product is finished, even if it's not perfect;
> (b) Getting it done is more important than getting it done right;
>
> (3) The teacher (or, by extension, the textbook) is always right.

Lampert describes the process of changing this ingrained assumption as requiring several months. Like an apprenticeship, learning science in school requires more than mastering a set of facts, it is an enculturation into a practice.

Sense-making conversations in science concern natural phenomena. But engaging students in hands-on data collection or experimentation with natural phenomena, will not, by itself, serve the function of enculturation into scientific thinking and scientific discourse. Students will not spontaneously invent scientific thinking given a set of data. As Lansdown et al. argued, the integrative discussion or "colloquium" is a critical component of the classroom science investigation. Students must learn to move between the data and the model or theory that explains them. The conversation can move in either direction. Students might collect data first, examine it for patterns and then develop a model to account for it. Or the class might consider a situation in which several outcomes are possible, reason from their current models to a hypothetical outcome and finally test their models empirically. In either case, the purpose of obtaining data is to test or develop a model or theory. The process of developing the relation between the data and theory can be considered the fundamental object of science instruction. That is, the central lesson is an epistemology. As with the recent work on sense-making conversations in mathematics, we can see this classroom discourse as the central method of science teaching. Without at all reducing the importance of working with data about the real world, we can place hands-on experience and other data-gathering activities in the context of a classroom conversation that brings it into coordination with a model.

The community is the central component of this view of sense making. The questions that the class comes to struggle with are not necessarily the spontaneous questions that children ask about their commonsense experience. Likewise, the data and the model can be the products of collaborative work. A coordinated effort may result in a richer set of data. The classroom or group discussion may prove more fruitful than individual exploration with the confrontation of differing conjectures. But the teachers' role is crucial and the framework they create largely determines how the conversation will proceed. While each individual student will have to have ownership of the question and will bring their own experience of the phenomena to the discussion, the community is the forum for the creation of the data and model artifacts that are the basis for the individual understanding of the phenomena. The community is also the forum for the coordination of data and model that gives students the essential epistemology of scientific work.

The creation of a working community in the classroom is no small accomplishment. The function of what appeared to an outsider as a somewhat obsessive concentration on collecting data in our focal classrooms was to get all the students intensely involved in the project. The classrooms were enormously successful in this community building, although they were less successful in consistently appropriating that spirit for sense-making discussions. In the classroom serving the much more heterogeneous population, a community sense was much more difficult to achieve. The science discussions were seen as the domain of the middle-class students. The minority students seldom spoke up in class or participated actively in the small group discussions. In one context, however, the researchers contrived to create a classroom drama scenario that engaged a group of minority girls intensely in explaining to a drama teacher/researcher why spring happened. This one event provided at least an initial insight that the problem for their earlier lack of participation was not an issue of the subject matter. Creating a community that will sustain sense making for all the students is the central problem facing us.

Technology may provide some useful tools for creating this community. Telecommunications links to other cultures may help in providing contexts in which the minority cultures in the classroom have specific values for the local community. We can also consider the function of local communication systems via local area networks in the school. Projects such as CSILE (Scardamalia, Bereiter, McLean, Swallow, & Woodruff, 1989) and Earth Lab (Newman, Goldman, Brienne, Jackson, & Magzamen, 1989) are showing how the communication and data sharing functions of local networks can help to create the local scientific community in the school. As we consider the design of database systems and simulation modeling systems, the ways that data and models will be shared and collaborated on can be built in from the start. Likewise the communication links to classrooms and other resources outside the school can be integrated with the local system for sharing, giving the local community additional resources for sense making.

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