Experiments, Contingencies, and Curriculum: Providing Opportunities for Learning through Improvisation in Science Teaching

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Received 4 September 1998; revised 1 September 1999; accepted 23 September 1999

ABSTRACT: In this article, we examine how, through discourse processes, a third grade teacher and her students come to situationally define science in their classroom. The teacher's use of particular discursive strategies promoted student talk, thus providing opportunities for students to learn about science through the exploration of a set of anomalous results in a life science experiment. Drawing from social studies of science, we used a discourse analytical approach to examine the classroom members' logic of experimentation, their explanations and scientific decisions, and their accounts of the events. These analyses allowed us to identify how particular teaching strategies afforded students opportunities to learn science concepts and about scientific processes. © 2000 John Wiley & Sons, Inc. *Sci Ed* **84:**624–657, 2000.

INTRODUCTION

Experimentation has played a central role in the construction of scientific knowledge. Perspectives as diverse as logical positivism (e.g., Ayer, 1952), scientific realism (e.g., Boyd, 1991), feminist studies of science (e.g., Longino, 1990), and social constructionism (e.g., Knorr-Cetina, 1995), among others, have identified the uses of empirical evidence

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Contract grant sponsors: UCSB Academic Committee on Research; National Academy of Education's Spencer Postdoctoral Fellowship Program

in the development of scientific theories. Nevertheless, sociological and anthropological studies of scientific knowledge and practices have demonstrated that connections between what a scientific community counts as a valid experiment and its relevance to what comes to be taken as (i.e., interactionally acknowledged as) scientific knowledge are established socially through conventionalized discourse practices (e.g., uses of speech and written genres for public presentation of candidates for knowledge, creation of peer-review texts, and standardization through textbook publishing) (Bazerman, 1988; Collins, 1985; Mukerji, 1989; Traweek, 1988). That is, across multiple disciplines studying scientific practices, there is a view that scientific knowledge is public, subject to debate, scrutiny, assessment, certification, or rejection by a relevant community (Duschl, 1990; Longino, 1990; Toulmin, 1982; for reviews see Kelly, 1997; Kelly & Chen, 1999; Kelly & Green, 1998). In a review of sociology of science from varying schools of thought, Zuckerman (1988) explained as follows, "Scientific knowledge is public, not private knowledge; contributions are not scientific until they are made public and subjected to evaluation by qualified experts" (p. 556). Zuckerman pointed to the production of scientific texts and scientists' discourse about texts as examples of the public review and critique of candidates for scientific knowledge. We use this as an as illustrative example of the perspective we bring to the study of school science.

Scientists produce texts that are subject to discussion in the processes of production and thereafter (Latour & Woolgar, 1986; Latour, 1987). Much of what comes to count as science is communicated through written discourse. The discourse practices embodied in written texts follow certain social conventions, conventions that can be characterized as a written genre[1] (Bazerman, 1988) and that change over time, subject to the evolving cultural practices of a relevant discourse community (Atkinson, 1999). For example, through a series of textual analyses, Bazerman (1988) examined the genre of the experimental research article and its role in the production of scientific knowledge. This analysis demonstrated the ways candidates for knowledge were entered into a community of scientists, and how, to be accepted as counting as science, evidence had to be presented following the evolving rhetorical demands of the scientific communities. In one example, Bazerman documented how the "Compton Effect" was written into the world of science and how this written text took on different meanings as it became incorporated into an evolving science (p. 203). For an example in social sciences, Bazerman (1988) reviewed the evolv-

[1] Our use of "convention" and "genre" does not suggest any form of epistemic relativism, nor undermine the instrumental reliability (Boyd, 1985, 1991) of scientific research. Our claim is that candidates for scientific knowledge are expressed following certain socially negotiated disciplinary practices (e.g., situating the proposed knowledge in ongoing conversations through citation, using common ways of presenting and representing data, using publicly recognized signs and symbols, etc.). Establishing a claim in science requires articulating evidence in particular ways, given a relevant audience of peers. The interpretation of the experimental article as a particular genre (Bazerman, 1988) does not undermine the epistemic status of the claims put forward in this rhetorical form. Indeed, how could evidence be marshalled if there were not common discourse practices for presentation of argument? Narrow interpretations of sociological aspects of knowledge construction pit reason and logical against social factors, creating a false dichotomy between cognitive, rational factors and social, causal ones. Our view is that argument and evidence are presented, recognized, and evaluated through social processes that define the "reason" of a discipline at a given time (Toulmin, 1972). Educators (Loving, 1997; Matthews, 1997; Slezak, 1994) may have identified aspects of sociological studies of science that need questioning and, where appropriate, debunking, but this hardly eliminates the value of interactional studies of science applied to educational issues (Kelly, Cunningham, & Carlsen, 1998; McGinn & Roth, 1999), nor does it suggest that analyses of social processes necessarily presuppose any sort of relativism.

ing restrictions of the American Psychological Association (APA) publication manual.[2] He concluded that the conventionalized discourse practices (e.g., use of increasingly statistical sophistication, diminution of research methods sections in length and complexity, and standardized headings) restricted the range and type of texts produced and reflected a commitment to behaviorist ideologies.

Thus, to become a member of a community (e.g., science classroom or research laboratory), who acts in socially appropriate ways (e.g., one who speaks and writes adhering to genre conventions), one must first understand the social practices of a community, that is, what counts as a valid description, explanation, inference, etc. For the third grade students in the study we present, this began with the oral discourses associated with the construction of discovery accounts. Through our analyses of classroom life, we illustrate the importance of considering the discursive work necessary to engage in experimental processes in science classrooms. We examine from an ethnographic perspective how an elementary school teacher and her students treat the anomalous data generated from a series of experimental life science activities. Through a discourse analysis of the students and teacher's talk and actions, we examine the opportunities for learning science afforded the students (Tuyay, Jennings, & Dixon, 1995), the potential lessons of the anomalous results, and the teacher's discourse strategies that both provided interactional spaces (Chen, 1997; Heras, 1993) for student participation and promoted student discourse of and about science. Even though the anomalous results rendered problematic the empirical evidence in support of the theory of photosynthesis, the educational value of uncertainty in science offered students unique learning opportunities. We present this case as an example of how the teacher and her students constructed contexts for learning science concepts and scientific processes.

SCIENCE AS INTERACTIONALLY ACCOMPLISHED IN MULTIPLE SETTINGS

Research over the last two decades has rendered problematic any straightforward account of the uses of experimentation in establishing scientific knowledge (e.g., see Brannigan, 1981; Collins, 1985; Pinch, 1986) and identified how the uses of empirical evidence are tied to activity systems of scientific communities, including the construction of persuasive texts (Bazerman, 1988). In an early study considering the relationship of social science research to epistemology,[3] Winch (1958) emphasized the importance of consid-

[2] Consider the relevance of this for the journal *Science Education.* As a community of science education researchers following the conventions of the APA manual, we shape written discourse about education in particular ways following particular conventions that reflect theoretical commitments. Each journal issue ends with "Information for Contributors" that details some of the conventionalized discourse practices of our research community beyond those of the APA manual. The social processes of peer review and editorial decisions demonstrate how these written discourse practices must be negotiated given particular situations. The community's values regarding the presentation of evidence and its relation to previous research are central epistemological commitments of this journal and others that use the APA manual as a basis for conventionalization. This is instantiated in the use of literature reviews, citations, and documentation of research methods, and to good ends in our minds.

[3] Although we describe studies primarily derived from research of science-in-action (sociological and anthropological studies of actual practice), our view is consistent with long-standing traditions in philosophy arguing against the Cartesian subject, described in detail in Habermas' (1987) *Philosophical Discourse of Modernity,* and applied to science by Toulmin (1972), Kuhn (1996), Fuller (1988), feminist philosophers such as Longino (1990) and Nelson (1993), and even consistent with certain articulations of scientific realism (see "science-as-social-practices constructivism" described by Boyd, 1992).

ering the uses of symbols (i.e., language) by scientific investigators. Winch identified how, in order to recognize an event as an "instance of," the investigator must have a concept referring to relevant characteristics and know the rules of use given a particular context (Wittgenstein, 1958). The symbolic use of a concept for a relevant group of investigators includes understanding the social practices of the group as well as "criteria according to which they make judgment of identity" (p. 84). Thus, for social science researchers to understand the activities of (other) scientists, Winch emphasized the need to consider two interconnected relationships: the relationship of the scientist to the relevant phenomenon and the relationship of this investigator with other scientists of the relevant community.

Brannigan (1981) applied the perspective suggested by Winch to the study of scientific discovery. Consistent with other sociological studies of the Strong Program (Bloor, 1976), Brannigan sought to investigate the ways that "discoveries" were constructed as such, rather than identifying ways that social factors influenced the nature of the discoveries. These sociological studies of discovery concluded that the label "discovery" was an attribute awarded retrospectively for certain events meeting four criteria. The claimed achievement needed to be seen as substantively relevant, determined through scientific investigations, convincingly true, and unprecedented (p. 77). The retrospective naming of an event as a discovery entailed certain social processes, including public display of candidates for knowledge, critique, and debate among members of a relevant community. When disputes arise among scientists, sociologists of science have found that judgments of validity are determined through considerations of experimenter competence and credibility as much as experimental factors such as calibration or design of equipment (Collins, 1985). Thus, to understand what counted as a discovery or an experiment, sociologists needed to study the everyday practices of members of scientific communities.

Ethnomethodological studies, another sociological approach for the study of science, focus on the embodied practices scientists use to accomplish the everyday tasks of doing science. Lynch (1992) described ethnomethodological studies as concerned with the close study of particular sites of practical inquiry, where larger themes and constructs such as rationality, agency, or meaning are local achievements accomplished by actors through a day's work (pp. 239–240). For example, Lynch, Livingston, and Garfinkel (1983), using a university chemistry laboratory course as one site for the study of temporal order, studied how written materials, such as guides and instructions, were insufficient in providing descriptions of scientific procedures (i.e., procedures not worth talking about in the idiom of scientific method). They found these scientific texts pose questions as if they could be answered by a reader only through the use of the stated materials and by following the stated instructions. However, through the study of the embodied actions of the users of these scientific texts, Lynch et al. found that these particular readers could only make sense of the texts by moving beyond the stated instructions and engaging in physical actions and social negotiations. Thus, to accomplish the task at hand (i.e., the laboratory procedures), "something more" was required than could be written in even the most detailed lab guides or lab instructions (Lynch et al., 1983, p. 207).

Consideration of the interactionally accomplished nature of science in school has led to research examining what counts as science and how what counts is established by members of a group. In a study of the uses of evidence and its relationship to scientific knowledge in school settings, Millar (1989) identified the tension between views of science as personal inquiry vs. science as a body of consensually accepted knowledge. Millar showed how experiments in school science could be used as a basis for negotiation of meaning, but not as a means for theory testing (falsifying). He recommended that experiments be used in school science as a means of communicating abstract concepts through examples, demonstrating what counts as good (i.e., scientific) practices, and identifying approaches to problem solving. Millar's study identified a pattern found in other research in science classrooms, namely that the practices of school science often portray science in ways contrary to science studies scholarship (Cochran, 1997; Lemke, 1990; Moje, 1997).

In a review of implications of science studies for science education, Roth and McGinn (1997) analyzed the interplay between science and technology studies and science education. Through this review, Roth and McGinn summarized key features of studies of actual scientific practices, rather than those portrayed in published papers and textbooks. Science as practiced in laboratories and other scientific sites was characterized as contingent and dependent on local conditions:

> The reasoning of scientists is locally contingent, depending on the research context and the concrete research situation. The contingency and context of scientific action demonstrate that the products of science and technology are heterogeneous hybrids that are marked by indexical, context-dependent logic, political and economic relationships that contribute to their production and contributions by multiple actors. (Roth & McGinn, 1997, p. 7)

An example of the contingent nature of experimentation in school science can be found in a student discourse study around the interpretation of data inscriptions in a physics class. Kelly and Crawford (1997) found that through the use of microcomputer-based data acquisition technologies and associated computer representations, the use of real-time data by students led to the problematization of central constructs of Newtonian physics (e.g., velocity and acceleration). This was due to a number of experimental and social contingencies specific to the local conversations. The ethnographic data from this study provided the researchers with a means to assess how the students understood the local experimental procedures and results under these conditions and how particular experiences were tied to over-time practices established by the actors in the classroom (Kelly & Chen, 1999).

Other studies of classroom discourse show how common knowledge is accomplished through the embodied, everyday discursive work of members of a community (Edwards & Mercer, 1987; Green & Dixon, 1993; Kelly, Crawford, & Green, 1997; Kelly & Green, 1998). For the case of science teaching, the ways science is talked about in a classroom community becomes particularly important given concerns about an ideological mystique of science (Lemke, 1990)—a portrayal focused on the difficulty of acquiring scientific knowledge, rather than the social processes creating scientific knowledge. For example, Carlsen (1992) argued that discourse practices in classroom settings not only transmit what is known in science, they model science as a process. As science is more than substantive content (i.e., propositional knowledge, knowledge *that*), discourse processes in classrooms influence the opportunities students have to learn about the content, epistemology, and social practices characteristic of scientific communities. Carlsen's studies (1991, 1992) suggest that discourse processes be examined under a variety of conditions, considering the contextual nature of scientific knowledge and the ways different types of science and knowledge are negotiated through discourse.

Thus, across the studies by Carlsen (1991, 1992), Lemke (1990), and Moje (1995, 1997), a common theme emerges: Discourse analytical studies of classroom interaction found that science was often presented to students through whole-class conversations, controlled and dominated by teacher talk, and oriented toward the transmission of scientific facts. These authors argued that this presentation of science left students with ideological portrayals of scientific practices (i.e., a view that is both false and used for social control [Strike, 1989]). These views of science point to a more general concern of educators about missing elements of science instruction—namely, the importance and development of scientific theories (Duschl, 1990). Lemke (1990), in particular, pointed to problems of presenting the thematic content of science in the absence of evidential arguments and reasoning and proposed ways for creating educational contexts where students can "talk science." One such context is found in more recent studies that have examined student discourse in more open-ended student investigations (e.g., Bianchini, 1997; Finkel, 1996; Richmond & Striley, 1996). These studies noted the importance of group configuration, interaction styles, and social status constructed by students in small group contexts. However, few studies have examined how inquiry processes are constructed in whole class conversations, an issue we describe in the subsequent sections.

In this review, we demonstrated the importance of discourse and interpretative processes in the creation of scientific experiments and school activities. The literature suggests that there is a need to analyze ways that experiments "get talked and heard" in science classrooms, and, how under these conditions, disciplinary knowledge is accomplished through discourse within these activity structures; that is, contexts for deliberation concerning scientific phenomenon (Hicks, 1995; Klaassen & Lijnse, 1996). For the case that we describe in subsequent sections, a teacher's use of improvisation offered us a means for examining how experiments and social actions shaped ways that disciplinary knowledge and practices were constructed by students, teachers, scientists, and texts.

EDUCATIONAL SETTING

The setting for this study was a public elementary school of approximately 320 students in a small city in southern California. The student population in the school was comprised primarily of two ethnic groups, "Hispanic" (57%) and "white" (39%)—folk terms (Spradley, 1980) as defined by the school district. The study occurred over 2 academic years with the same teacher, first in her third grade and then her fourth/fifth grade class. Each of these classes had roughly equal numbers of Hispanic and white students, as well as, male and female students.

During the summer prior to the collection of our first academic year of ethnographic data, the participating teacher, Lori,[4] sought assistance from members of the University of California, Santa Barbara faculty, in education and in the sciences. Lori has almost 30 years teaching experience, has been identified as a mentor teacher, and is a fellow of the South Coast Writing Project and the South Coast Science Project—subject matter education programs for teachers. Despite her participation in the South Coast Science Project, Lori felt that her subject-matter knowledge of science was insufficient and that science was the subject she taught least well. Throughout the summer and the fall of the first academic year, Lori and members of the university community (see Table 1)—Greg (first author), Candice (third author), and Mary (marine scientist)—created a set of science activities for use in her third grade class. The data for this paper were collected over the course of the third grade year, the first academic year of the study.

RESEARCH METHODS AND ANALYSIS

Throughout the course of this 2-yr ethnographic study, we sought to get close to the activities of the people studied through participant observation (Spradley, 1980). Our ethnographic data consisted of videotape records, formal and informal interviews, field notes,

[4] Pseudonyms were used for the classroom teachers, students, and participating scientists respecting individuals' gender and ethnicity.

TABLE 1
Scientists Participating as Classroom Members (Adapted from Chen & Crawford, 1998)

Participating "Scientists"		
Official Title	Area(s) of Expertise	Involvement with Classroom Community
Research biologist at the UCSB Marine Science Institute and Adjunct Professor in Biological Sciences (pseudonym: Mary)	Marine biology	Assisted in curriculum development; supplied relevant materials; provided instruction in science; participated as an audience member during presentations/special events; served as on-call specialist.
University professor (Greg, first author)	Physics and science education	Conducted educational research; assisted in curriculum development; supplied relevant materials; provided instruction in science; participated as an audience member during presentations/special events; served as in-class resource.
Graduate student researcher (Candice, third author)	Environmental science and science education	Conducted educational research; assisted in curriculum development; supplied relevant materials; provided instruction in science; participated as an audience member during presentations/special events; served as in-class resource.
Director of Education at the Santa Barbara Botanical Gardens	Botany	Assisted in curriculum development; supplied relevant materials; participated as an audience member during presentations/special events; provided instruction in science and served as off-site resource during field trips.

and artifacts. Throughout the data collection, we used audio recorders and one or two video camcorders with remote microphones, depending on the research needs given the classroom events. As ethnographers, we interacted with the participants in the study to identify and understand and, through our participation, partially construct the "indigenous meanings" (Emerson, Fretz, & Shaw, 1995) or the "folk" definitions of the members of the classroom (Spradley, 1980). Our theoretical position, derived from anthropological perspectives, treats these indigenous meanings as situationally defined and accomplished interactionally among members through discourse processes within a particular community (Kelly & Green, 1998). Therefore, our ethnographic analysis relies heavily on, and is reinforced by, discourse analysis. This form of analysis focuses on the ways cultural practices are interactionally constructed and has been characterized as "ethnographic microanalysis of interaction" (Erickson, 1992), "constitutive ethnography" (Mehan, 1979), or "interactional ethnography" (Castanheira, Crawford, Dixon, & Green, 1998). Mehan (1979) described this approach as "the description of the social organization of routine, everyday events. . . . A description of the interactional work of participants that assembles the structure of these events is the goal of this style of research" (p. 8). Similarly, interactional ethnography has been described by Castanheira et al. (1998) as the study of "cultural actions, cultural knowledge, and cultural artifacts that members need to use, produce, predict, and interpret to participate in everyday life within a social group, for example, a classroom or a small group within a classroom" (Heath, 1982, p. 33). They noted that, through this approach, the ethnographer can identify cultural knowledge that members of a group use to interpret experience and generate behavior (Spradley, 1980).

Consistent with ethnographic approaches for the study of cultural practices (Emerson et al., 1995), we are hesitant to separate cleanly "methods" and "findings." Rather, we describe a "logic-of-inquiry" (Gee & Green, 1998) tracing our research methods and their relationships to a constructed account of the everyday life and key events in this classroom. As each set of analyses led to and influenced the next step in our overall analysis, we present our findings together with our methods as they were co-constructed through our ethnographic work.

While collecting our ethnographic data, including videotape records of classroom events, we kept a running record of major topics and activities for each day data were collected. Upon completing data collection, we began to create transcript representations of these classroom events at varying degrees of specificity (Crawford, Chen, & Kelly, 1997; Kelly & Chen, 1999; Kelly & Crawford, 1996, 1997).

First, we viewed the videotapes focusing on the whole-day's events (Erickson, 1992). Through this process, we created "event maps" (Green & Meyer, 1991) demarcating the phases constituting the activities of class members. A phase of activity represents concerted and coordinated action among participants, reflects a common focus of the group, and can be identified by the content of the actors' talk (Kelly et al., 1997). Often, phase units are redundantly marked by physical reorientation or by a shift in social arrangements (Erickson, 1992; Green & Wallat, 1981). Identifying phases of activity required a close viewing of the videotape, reviewing potential boundary markers, creating time-stamped records of the boundaries, and labeling each phase with a cover term (Kelly & Crawford, 1997). The cover term describing each phase was placed in a timeline to offer a visual comparison of the range of activities over time as well as the approximate length of each. A representative timeline showing the phase units of a day's activities can be seen in Figure 1.

Second, within each phase unit, there are more precise demarcations as participants structure the conversations and cue each other interactionally. These are labeled sequence units and may be identified as cohesive, thematically tied interactions or as potentially divergent (Green & Wallat, 1981; Kelly & Crawford, 1996; Kelly et al., 1997). For example, the event map in Figure 1 shows the sequence units for the phase of activity labeled "checking the plankton." By identifying the sequence units for each phase of activity, we can examine the ways that the activities are constituted by the actions of actors.

After constructing event maps for the entire videotape record of the data from the third grade academic year (~30 h), we reviewed the timelines, event maps, and field notes. This initial analysis identified the "algae experiment" as a key speech event (Gumperz & Cook-Gumperz, 1982), revealing important aspects of members' social practices in this classroom. The "algae experiment" was designed by the participating marine scientist (Mary) and educational consultant (Candice) to demonstrate the necessity of sunlight to plant growth. The experiment involved dividing a sample of algae, submitting each half to different treatments (sunlight and darkness), and observing the results. Through our analysis, we came to understand the activities surrounding the "algae experiment" as important

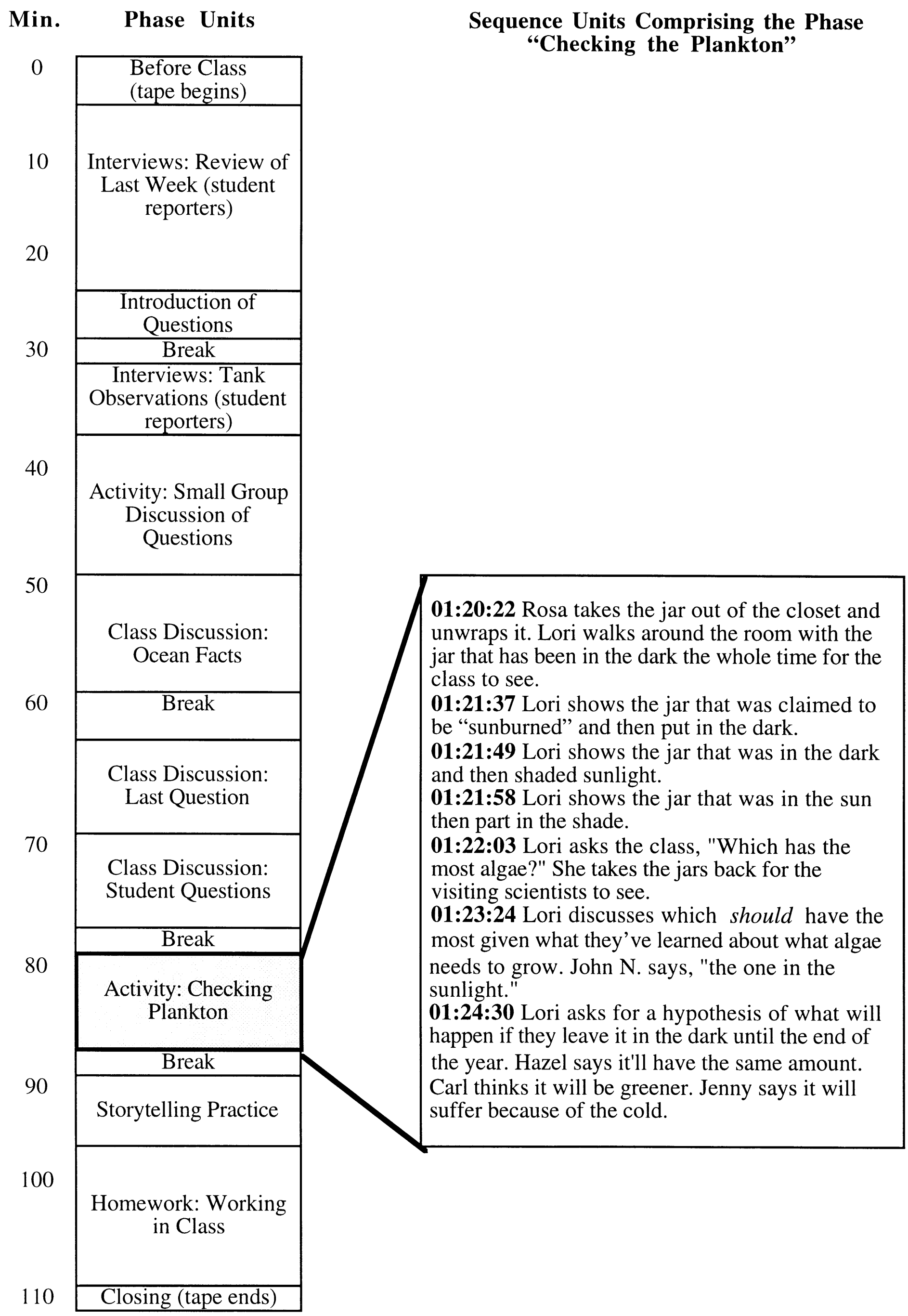

Figure 1. A representative timeline of a day's (2/8/95) activities separated by phase units, with expanded sequential analysis shown for "checking the plankton" phase.

for the members of the classroom—the teacher and students oriented to this ongoing activity, spoke of it often, and because of the anomalous results, requested participation of the marine scientist who was serving as a curriculum and scientific consultant. Furthermore, as we describe in subsequent sections, the experiment was interesting to us as researchers from a scientific point of view as well as from the perspective of science teaching. Therefore, this "key event" selected for microanalysis was both interactionally acknowledged among members as significant and was theoretically salient from a research point of view. This led us to examine in more detail these interactions through purposeful sampling procedures. (For a comparison with another science episode from the following academic year, see Crawford, Kelly, & Brown [2000].)

We transcribed all discussions related to these activities at the level of message unit (Green & Wallat, 1981; Kelly & Crawford, 1996), totaling ~65 min over 3 days of activity. Message units are the smallest unit of sociolinguistic meaning, defined by boundaries of utterances or social action that are identified *post hoc* through cues to contextualization (e.g., pitch, stress, intonation, pause structures, physical orientation, proxemic distance, and eye gaze [Gumperz, 1992]). This was done first from an audio dub of the videotape record and then directly from the videotape, because the nonverbal cues are important for identifying the message units. Through the use of the data representations (transcripts) at multiple levels (timelines, event maps, and verbatim transcripts of talk), we were then ready to enter into microanalysis of the communicative actions constituting the "algae experiment," situating particular instances of discourse processes in relation to other activities (Lemke, 1998).

FOCUS ON THE DISCURSIVE NATURE OF THE "ALGAE EXPERIMENT"

In order to understand the concerted actions that came to define what counted as a scientific experiment for this class, we created a set of data analysis representations. Through review of the transcripts in conjunction with multiple viewings of the videotape records, we constructed three interconnected and mutually informing analysis charts. Figure 2 shows a reconstructed logic of the experimental procedures. Figure 3 shows a comparison of the experiments, denoting the research design, relevant variables, predictions, contingencies, and actions taken. Table 2 represents a log of the various accounts of different experiments constructed through student and teacher discourse. Included in this analysis is the identification of the teacher's strategies used to promote student discourse.

Reconstructing the Logic of the Experiment

The three analyses represented in Figures 2 and 3 and Table 2 were constructed concurrently as, for example, students' accounts of experimental procedures and results weighed heavily in our reconstruction of the experiments and logic of experimentation. We begin our description of the events by tracing the logic of the experimental investigations (Fig. 2). Next, we describe how we considered the science of the experiments (Fig. 3) and, finally, we describe the accounts of the events as voiced by the class participants (Table 2). The purpose of these analyses was to identify ways scientific knowledge, uses of empirical evidence, consideration of alternative procedures, evaluative weight of anomalous data, and roles of theory and expertise in decision making, among others, play into the construction of pedagogically inventive science.

The reconstruction of the logic of experimentation can be traced through Figures 2 and 3. Following a procedure guidesheet created by the participating marine scientist, the

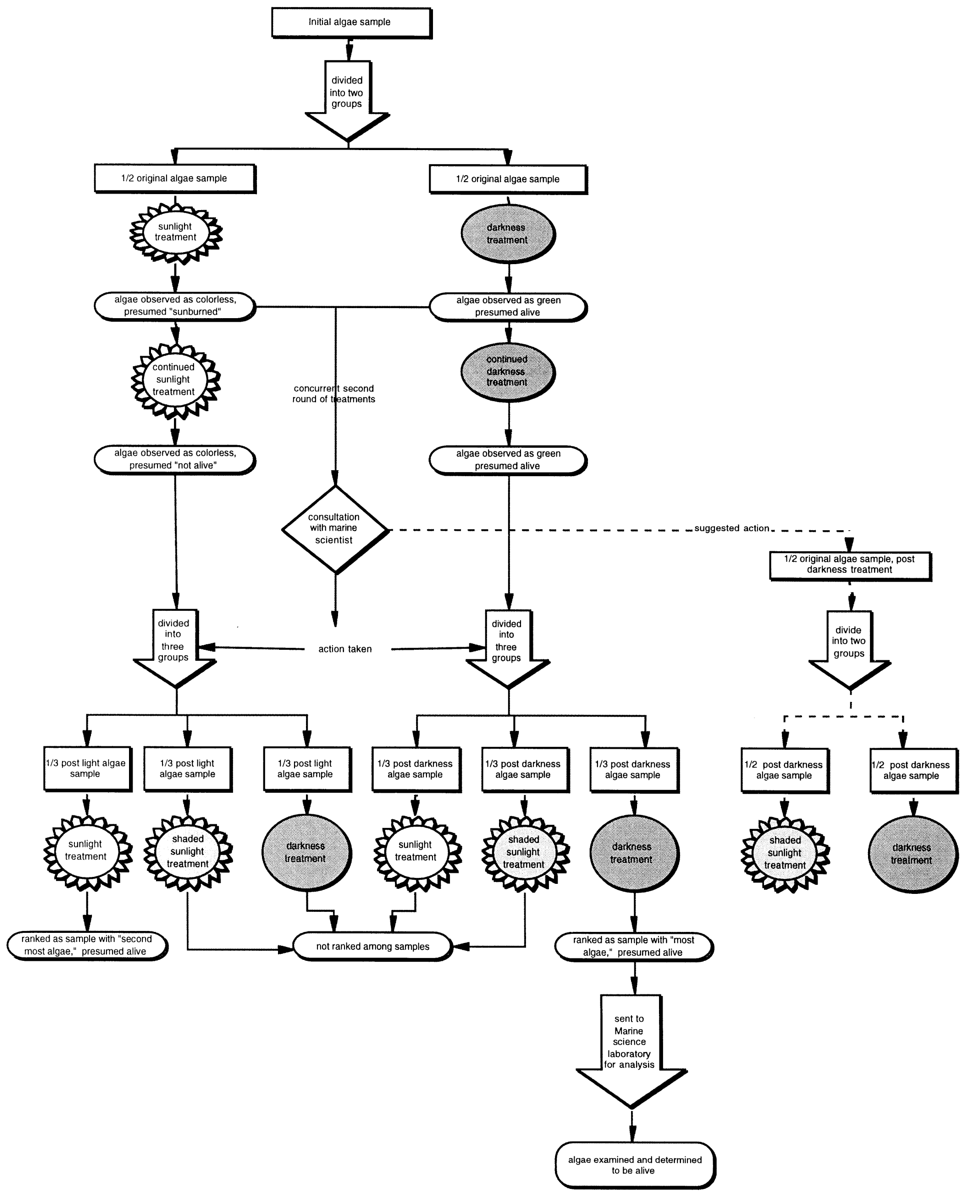

Figure 2. Reconstructed logic of the experimental procedures.

classroom teacher (Lori) and the students proceeded to follow the suggested action: They divided a sample of algae donated to them by the marine scientist into two jars. One half of the sample was given a "sunlight treatment" [x (s)] and the other half given a "darkness treatment" [x (d)]. The experimental design involved an initial observation for each sample [O1] and then subsequent observations [O2, O3, O4, etc.] to take place over a number of days or weeks. The analytic breakdown of the research design and predictions and outcomes is presented in Figure 3 as Experiment 1: "guidesheet—two jars."

The presumed intended curriculum involved the use of experimentation to demonstrate the importance of sunlight to life. The importance of sunlight to plant growth and photosynthesis as a teaching goal was developed in subsequent weeks. However, the experimental results led not to this conclusion regarding sunlight but rather to a series of unexpected and anomalous results: The algae in the "darkness treatment" condition for a period of 14 days survived, but the "sunlight treatment" condition led to the apparent death of the algae (Experiment 2a in Fig. 3). This experimental consequence led to a series of curricular changes beginning with a shift in focus for the students and teacher: The propositional knowledge of "sunlight as a source of energy" became a secondary interest to the processes of deciding "what to do next."

The results of this initial treatment led the members of the classroom to two actions. They first returned the two samples to their respective locations and again waited a number of days (~8 days) before the subsequent observation (shown as Experiment 2b in Fig. 3). They then contacted the participating marine scientist (Mary) by telephone soliciting her advice about what might have occurred and what actions should be taken. As shown in Figure 2, the marine scientist, in the absence of direct observations on her part and based on the teacher and children's explanation of the anomalous results, suggested that the algae, presumed alive (i.e., the algae that had been in the "darkness treatment"), be divided into two new treatment groups: one group would continue to be the "darkness treatment" [x (dd)], while the second would now be "shaded sunlight treatment" [x (dshs)]. She suspected that the previous "sunlight treatment" may have actually killed the algae through overexposure. From a research design point of view, this was an extension of the procedures the class had used in Experiments 2a and 2b as shown in Figure 3.

The members of the classroom heeded the marine scientist's advice, but extended it in interesting ways. First, they created the conditions for the two treatments suggested by the marine scientist: They divided the previous algae that had received the darkness treatment into a new "darkness treatment" [x (dd)] and a "shaded sunlight treatment" [x (dshs)]. However, they also added four other conditions. They created a third condition for the previous algae that had received the "darkness treatment": a "sunlight treatment" [x (ds)]. In addition, they continued the experiment for the "overexposed" algae that had received the "sunlight treatment," dividing it into the same three treatment groups as the previous "darkness treatment" (see Figs. 2 and 3, Experiment 3 "six jars"). The continued study of the overexposed algae may seem curious, after all, it was presumed dead. Nevertheless, the class continued their observations. This was one of the strategies the teacher used throughout this and other episodes in science: She let the children follow the logical consequence of their decisions regardless of whether or not the decisions were theoretically sound.

The students now had six treatments, three derived from the previous surviving "darkness treatment" and three from the presumed-dead direct "sunlight treatment." After more than 4 weeks in their respective locations, the six jars of algae were brought before the class for observation. The students were asked by the teacher to identify the jar that had "most algae or plant plankton growing in it." Two of the jars were ranked. The "darkness treatment" from the previous "darkness treatment" jar was ranked first. This result continued the anomaly: without light the algae survived. The jar ranked second for "most algae" was the "sunlight treatment" from the original "sunlight treatment." This, too, was an anomalous result: The algae exposed previously to direct sunlight were presumed dead, yet under the same conditions that presumably killed these algae, the same algae were observed as having grown and achieved the second ranking!

During the interim 4-week period, the students were taught about photosynthesis and thus they now recognized the survival of the "darkness treatment" algae as anomalous to their understanding of photosynthesis. The class decided to send the "darkness treatment"

Text continues on page 642

					Speakers are noted in predictions, observations, contingencies, and explanations columns as relevant				
Experiment #	Name	Design	Variables Identified	Brief Description	Predictions	Observations	Contingencies Identified	Explanation/ Interpretation(s)	Actions Taken
1	Guide sheet—two jars (intended)	01 × (s) 02, 03,04,05,06 01 × (d) 02, 03,04,05,06	sunlight (s), darkness (d)	Lesson focused on "energy sources." Suggested two treatments, sunlight and darkness, with multiple observations of each.	*Presumed: Seawater exposed to sunlight shows life observed as green color and algae growth.*			*Intended: Sunlight is a source of energy and necessary for life in seawater.*	Intended: Experimentation leads to evidence for knowledge that sunlight is a source of energy and necessary for life in seawater.
2a	Two jars *Recounted to researchers, completed days before*.	01 × (s) 02 01 × (d) 02	sunlight (s), darkness (d)	Algae sample separated into two jars, one exposed to full sunlight, and the other wrapped in foil and kept in darkness.		Kathryn: "Dark treatment" had more (algae?) [a1]. Rosa: Treatments looked the same [a2]. Lori: Treatments looked different [a2]. Tony: "Dark treatment" had more algae after experiment [a3].	Kathryn: accidentally put more algae in "dark treatment" [a1]. Tammy/Mary: the "light treatment" got less algae [a4].	Jenny/Mary: the "light treatment" was too light [a4] Steve/Mary: the "light treatment" got sunburned [a4].	Recognized anomaly. Decided to call Mary for explanation and advice, simultaneously repeating Experiment #2a (i.e., replace jars in same locations).
2b	Two jars revisited	01 × (s) 02 01 × (d) 02	sunlight (s), darkness (d)	Two treatments were replaced in the same locations—one in full sunlight, the other in darkness.	A majority of students predict the "dark treatment" will be more green than it was after experiment 2a.	Majority of students: The "dark treatment" is less green than after experiment 2a [a5].			Decided to do as scientist recommended and split the algae from "dark treatment" into two other jars, this time putting one in the dark and the other in less bright light. In addition they created four other conditions (see exp. design #3).

3	Six jars	03 × (dd) 04 03 × (dshs) 04 03 × (ds) 04 03 × (sd) 04 03 × (shs) 04 03 × (ss) 04	sunlight (s), darkness (d), shaded sunlight (shs)	Separated algae from the "darkness treatment" into three jars and "sunlight treatment" into three jars (see Fig. 2), each set receiving one of three new treatments: darkness, sunlight, shaded sunlight, leading to six experimental conditions.	Jenny and Lori predict the treatment in shaded sunlight may not get sunburned [a6].		Class: Six jars were available. Lori: Jar contamination might kill what's in there (algae?) Lori: Shake the original "dark treatment."		
				Comparison of five of the jars to see which had most algae. "03 × (ds) 04" not observed.	John: the one in the sunlight should have the most [a8].	Jill: Original "dark treatment" has most algae [a7]. Kathryn: The original full sun treatment has second most algae [a7]. Lori: Treatments are different colors [a7].			Recognized anomaly. Propose hypothetical experiment (see exp. design # 4).
4	One jar	04 × (dd) 05h (hypothetical)	darkness	Put the original "dark treatment" back in the dark until the end of the year.	Hazel: it will have the same amount as it does right now [a9]. Carl: It will get greener [a9]. Carl and Lori: It will grow more [a9]. Jenny: It will suffer from the (cold) water [a10].				Sample given to marine scientist to verify in scientific laboratory.
5	One jar	04 × (dd) 05	darkness	Put the original "dark treatment" algae in sunlight in marine scientists' laboratory.		Class: Consensus: algae grew, claimed to be alive.		Algae shown to be alive, students and teacher had no explanation as to why it stayed alive during dark treatment.	

Figure 3. Comparative analysis chart of across experiments associated with the algae growth investigation. Observations in research design are denoted as "O1, O2, . . . " etc.; experimental variables as "x ( )" with the following abbreviations: s = "sunlight treatment," d = "darkness treatment," shs = "shaded sunlight treatment." Speakers are noted in predictions, observations, contingencies, and explanations columns as relevant. Account numbers are labeled in brackets [a1, a2, a3, etc.] corresponding to those noted in Table 2.

TABLE 2
Summary Information of Experimental Accounts for the Algae Investigation

Day (Account #)	Video Time-Stamp and Line #s	Speaker(s)	Strategies for Promoting Student Discourse (see Fig. 4)	Experiment Name (see Fig. 3)	Short Description
1/11 (a1) (shown in detail in Fig. 5)	01:24:06; line #s: 1003–1013, 1035–1046, 1048–1092	Kathryn	• Positioning students as reporters and scientists • Framing and reframing questions • Orienting: referring to previous experiment; identifying audience • Questioning: description of events; specific information • Prompting: providing information; with question	Two jars (#2a)	Kathryn describes two-jar experiment, notes "accidentally put a little more" in "dark treatment" jar, claims one in the dark "had more."
1/11 (a2)	01:25:08; line #s: 1193–1119	Rosa and Lori	• Prompting: with question • Orienting: identifying audience • Inviting other speakers • Questioning: specific information; clarification • Responding: restating and extending student talk	Two jars (#2a)	Rosa claims that the two jars looked the same. When questioned by Lori, Rosa reaffirms her observation. Another student uses Lori's cue and Lori claims the jars were not the same.
1/11 (a3)	01:25:34; line #2: 1120–1136	Tony	• Inviting other speakers • Questioning: specific information	Two jars (#2a)	Tony notes the "odd" occurrence that the "dark" treatment had more algae than the sunlight treatment."

1/11 (a4)	01:26:52; line #s: 1172–1184, 1185–1191, 1192–1198	Tammy, Jenny, Steve, and Lori	• Questioning: specific information • Inviting other speakers • Responding: restating and confirming student talk • Prompting: providing information; with question • Offering personal point of view	Two jars (#2a)	Tammy states Mary's claim that the sunlight treatment jar may have had less algae put in. Jenny states Mary's claim that the sunlight treatment may have gotten too much light. Steve concurs with Jenny and uses Mary's claim that it may have gotten sunburned. Lori agrees with Steve and Jenny's account.
1/11 (a5)	01:27:31; line #s: 1207–1242	Lori and whole class	• Prompting: with question • Orienting: referring to previous experiment • Questioning: specific information • Offering personal point of view	Two jars (#2b)	Lori takes poll and then summarizes the children's and her own view about the relative greenness of the jars.
1/11 (a6)	01:32:22; line #s: 1412–1435	Jenny and Lori	• Orienting: providing rationale • Framing and reframing questions • Questioning: specific information • Questioning: extensions of students' talk • Responding: extending student talk	Six jars (#3)	Jenny suggests taking the "sunlight treatment" out of direct sunlight and putting it in part light/part shade. Lori concurs adding, "because it may not get sunburned."
2/8 (a7)	01:21:31; line #s: 2108–2050	Lori and Jill	• Orienting: referring to previous experiment and previous account • Questioning: specific information • Responding: restating and extending student talk	Six jars (#3)	Initial explanation of which jar received which treatment described by teacher. Jamie claims that the original "dark treatment" has the most algae of the four jars Lori points to for comparison (dd, sd, dssh, sssh).

Continued

TABLE 2
Summary Information of Experimental Accounts for the Algae Investigation *(Continued)*

Day (Account #)	Video Time-Stamp and Line #s	Speaker(s)	Strategies for Promoting Student Discourse (see Fig. 4)	Experiment Name (see Fig. 3)	Short Description
2/8 (a7)	01:22:17; line #s: 2051–2054	Lori and Kathryn	• Inviting other speakers • Questioning: specific information	Six jars (#3)	Initial explanation of treatment of jar described by teacher. Kathryn claims that the original “sunlight treatment” has the second most algae (she brings this treatment into the comparison by pointing to it).
2/8 (a7)	01:22:36; line #s: 2056–2068, 2074–2075	Lori	• Offering personal point of view • Claiming ignorance	Six jars (#3)	Lori notes that the “sunlight treatment” is a totally different color and states confusion as to how to measure algae growth “I don’t know if it’s (color) or (more or less).”
2/8 (a8)	01:23:24; line #s: 2078–2107	John and Lori	• Orienting: providing rationale • Framing and reframing questions • Responding: confirming student talk	Six jars (#3)	In response to question about what to expect, John states the anomaly that if everything was working as it should the one in the sunlight should have the most algae. Lori affirms the anomaly by claiming that the “dark treatment” is “all full of life.”

2/8 (a9)	01:24:30; line #s: 2121–2161, 2167–2176	Hazel, Carl, and Lori	• Orienting: referring to previous account • Claiming ignorance • Questioning: student predictions; clarification and extension of student talk • Responding: restating and extending student talk	One-jar "darkness treatment" whole year	Hazel makes a prediction that if they kept the original "dark treatment" in the dark until the end of the year the amount of algae would stay the same. Carl predicts it would get greener and might grow more. Lori supports Carl's prediction stating, "so maybe it's gonna grow more and more and more."
2/8 (a10)	01:24:47; line #s: 2162–2166	Jenny	• Claiming ignorance • Inviting other speakers • Questioning: specific information	One-jar darkness treatment, whole year	Jenny offers an alternative prediction stating that "it's gonna (suffer) from the cold water" suggesting it may not continue to grow.
4/18 (a11)	00:30:32; line #s: 4100–4128	Charlie	• Positioning students as scientific reporters and scientists	"Dark/sunlight treatment" for either two- or six-jar experiments	Charlie interviewed by Alice (student as scientific reporter). Charlie notes that experimental results were "not supposed to happen" because sunlight is needed in the cycle of photosynthesis. Recounts how algae in "darkness treatment" survived and the algae in sunlight died (or they "think" it did because of its color).

sample that was ranked first to the marine scientist's lab for verification that it was alive. The marine scientist verified that the "darkness–darkness treatment" algae were alive.[5]

Unpacking the Discursive Nature of Experimentation

The strange turn of events in this classroom led to a set of interesting science lessons. Through our analysis of the logic of experimentation, we focused closely on classroom discourse. For each of the experiments in the series, we identified the ways the students, teacher, and participating scientists spoke of the events. These accounts of the experiments formed a particular discourse genre (Gee, Michaels, & O'Connor, 1992) in which the students were positioned in the classroom as speakers, telling and listening to science stories. The stories about the experiments included identifying key features, people, and anomalies, as well as, the disciplining of the talk to achieve common knowledge of the events (Kelly & Green, 1998). To capture the relation of these accounts to the actions and how the telling shaped the nature of the experiments—in the research design, predictions, and subsequent explanations—we created a table of the accounts of the experiments (Table 2).

In the table of the experimental accounts, we included the day and time of the account, as well as, the transcript line numbers, the speaker(s), the experimental referent, and a short description. Through this process, we noticed that the students' accounts were the result of a number of strategies that the teacher used to promote students' discourse. She created spaces in the lessons and actively sought ways to get students involved in the telling about the science. We, therefore, added a column labeled "strategies for promoting student discourse." To identify the strategies shown in this column, we reviewed the transcript of spoken discourse in conjunction with viewing the videotape through multiple iterations. Throughout this process, we created a taxonomy of the strategies for promoting student discourse (Fig. 4). The taxonomy of strategies used by the teacher suggests that there was much work being accomplished in the process of creating interactional spaces for students to speak. In what follows, we provide a few illustrative examples from transcripts that show how these strategies led to opportunities for students to talk science (Lemke, 1990).

Among the strategies employed were orienting the class to the relevant set of events or phenomena. We identified four ways in which Lori accomplished this: by providing a rationale for the actions; by referring to a previous experiment; by referring to a previous account; and by identifying the audience as authentic, that is, not knowing (Crawford et al., 1997).

In addition to orienting the class, the teacher was able to use effectively the strategy of questioning to draw students into extended conversations about the experimental design, scientific knowledge, and anomalous results, among others. Her questioning strategies included requesting specific information, students' ideas, description of events, clarification of student talk, extension of student talk, students' confirmation, and student predictions either as a direct question or through polling of class opinions. The use of questioning in teacher talk does not always lead to greater student participation. For example, Carlsen (1991) found that teachers frequently used questioning to close down the conversation in arenas where their subject matter knowledge was weak. Yet, despite Lori's self-

[5] Mary's hypothesis was that the green algae survived the dark treatment much like they would have survived a seasonal dark period in nature (such as dark winter or being buried in soil).

Figure 4. Taxonomy of teacher strategies for promoting student discourse.

identified anxiety about science teaching, she was able to open classroom conversations through questioning.

A selected segment of the complete transcript of all phases of the "algae experiment" is offered in Figure 5. This is an example of some of the ways that Lori used orienting and questioning strategies to encourage student participation in the algae activity. On the day from which this transcript was created, there were two scientists visiting the classroom. This segment leads to and includes the first student account (summarized in Table 2) of the "algae experiment" as seen in the "analytic comments" column of Figure 5. The dotted lines in this column (lines 1003–1013 and 1035–1046) correspond to the discursive work Lori did to provide the opportunity for the first student account, represented by solid lined arrows in the "analytic comments" column (lines 1047–1092). The analysis of Lori's talk ("teacher(s) discourse" column), identifying the strategies she used to promote student discourse, is represented by brackets with the strategies labeled in italics.

Time	Line	Student(s) Discourse	Teacher(s) Discourse	Strategies for Promoting Discourse	Analytic Comments/Notes
01:23:20			**Lori:**		
	1001		okay		**Account 1**
	1002		and now		
	1003		there's one other thing that's happened	*orienting [referring to*	
	1004		in this room	*previous experiment]*	
	1005		that they don't know about		
	1006		an whi-		
	1007		which you started	*orienting [identifying*	
	1008		i-	*audience as authentic]*	
	1009		before the holidays		
	1010		and that's when we put things		
	1011		in the light	*questioning [requesting*	
	1012		and in the dark	*description of events]*	
	1013		would somebody relate what happened?		
			[students hands go up with "oohs"]		
	1014-1034		*Analytic summary of transcript lines 1014-1034: Teacher diverges to method for choosing students' participation. She explains why half of the students were more appropriate choices for recounting the previous experiment and observation (those that had less current knowledge of experiment due to their absence during the most recent observation).*		
	1035		so	*orienting [referring to*	
	1036		what happened	*previous experiment]*	
	1037		in		
	1038		the		
	1039		beginning?	*framing and re-framing*	
	1040		what did we do	*questions*	
	1041		before Christmas?		
	1042		kay?		
	1043		in other words		
	1044		when we made our two jars	*questioning[requesting*	
	1045		what did we do?	*specific information]*	
	1046		volunteers?		

01:24:06	1047	**Kathryn:**		
	1048	umm		
	1049	we put		
	1050	umm [5 sec pause]		
	1051		**Dana:** you don't remember?	
	1052	I wa-	*(teacher's aide)*	
	1053	it was		
	1054	the stuff=		
			Lori:	
	1055		=oh	
	1056		you forgot what it's called?	*prompting*
	1057		algae	*[providing information]*
	1058	oh		
	1059	we put		
	1060	allergy		
	1061	in		
	1062	these cups [goes to the windowsill		
	1063	and points to a cup]		
	1064	and we let one		
	1065	we left one		
	1066	in the su-		
	1067	like		
	1068	out here in the sun		
	1069	and		
	1070	we accidently put a little more		
	1071	in		
	1072	the one where it's supposed to be dark		
	1073	and then		
	1074	uh		
	1075	on Monday		
	1076	I think		
	1077	it was Monday=		
	1078		=two weeks later	*prompting*
	1079	=yeah=	=cause= we went away for the holiday	*[providing information]*

Figure 5. Representative transcript of teacher strategies for promoting student discourse and student descriptive account of events.

Time	Line	Student(s) Discourse	Teacher(s) Discourse	Strategies for Promoting Discourse	Analytic Comments/Notes
	1080	two weeks later			
	1081	umm			
	1082	we got the one in the dark			
	1083	cause we put a little more in there			
	1084	and we got the one in the dark			
	1085	and			
	1086	compared it			
	1087	and the one in the dark had more			
	1088	than			
	1089	this one			
	1090		and how much more	*prompting*	
	1091		did it have?	*[with question]*	
01:24:57	1092	it had a lot more			

Figure 5. *Continued.*

At the onset of this segment (lines 1003–1004 and 1008–1012), Lori used an orienting strategy: "referring to previous experiment." Through analysis of subsequent actions, this strategy proved useful for positioning the students to recount what had happened on preceding days of the "algae experiment" by providing necessary background for this day's discussion. In addition, Lori provided a rationale for recounting the beginning of the experiment through the use of another orienting strategy: "identifying the audience as authentic." In line 1006, she states that "they don't know about" what had occurred previously, which served to position the audience (visiting scientists) as not knowing and, thus, provided a reason for students to restate what had happened up to this point in their experimentation process. After working to orient the students, Lori took herself out of the position of spokesperson and opened the floor for student speakers through the use of a questioning strategy: "requesting description of events" (line 1013). After a momentary divergence from the discussion (lines 1014–1034, summarized in transcript), Lori once again opened the floor through the use of "orienting" and "questioning" strategies (lines 1035–1045). In lines 1047–1092, we see a student, Kathryn, taking the opportunity provided and supplying a lengthy account of the original experiment. To encourage and assist Kathryn's efforts, Lori used a "prompting" strategy on occasions when Kathryn was searching for correct terminology (lines 1056–1058) and in need of additional information (lines 1078–1079). In a third "prompting" instance, Lori posed a question to extend Kathryn's descriptive comparison (lines 1090–1092). In her account, Kathryn was able to provide the class with an articulation of some key features of the experimental design (lines 1059–1068), the contingencies that that class had identified (lines 1070–1072 and 1083), the sequence of events (lines 1073–1080), the comparative process (lines 1082–1089), and the conclusion (lines 1087–1092). Through accounts such as this one given by Kathryn, the students in this class were able to engage in scientific processes such as expressing their position, identifying experimental factors, weighing evidence, considering alternatives, and making procedural decisions.

As a second example of how teaching strategies led to promoting student discourse, we offer the account co-constructed by Alice and Charlie. In this case, the teacher positioned Alice as a scientific reporter who questioned other students about the events comprising the "algae experiment" (lines 4060–4094 in Fig. 6). This account demonstrated how the series of discussions led to an understanding of the scientific concepts and how these concepts were related to the issues of theory and experimental results. In this instance, Charlie used first person plural (lines 4114, 4119, 4122, and 4127) identifying himself as acting as spokesperson for the class, rather than expressing merely his personal opinion. Alice's question (lines 4095–4099) hinted at the anomalous results that the class had observed and how these were in need of explanation. Charlie took this opportunity to build an argument for the uniqueness of the class's observations given scientific theory. He identified relevant variables (lines 4100 and 4108–4110) and observations (lines 4103 and 4128); described the anomalous conditions (lines 4103–4104 and 4114–4122), based on his understanding of scientific theory (lines 4106–4110 and 4123–4124); and offered the class's interpretation (line 4125). Much like Kathryn's first account, this account by Charlie is an instance of talking science (Lemke, 1990). While the initial account was appropriately descriptive, the last account included conceptual knowledge relevant to the phenomenon in question. In addition, the students (Alice and Charlie) were able to construct an account without prompting of the teacher. As the last account occurred 3 months after the initial one, the processes of learning to talk science can be interpreted as instantiated in the patterned practices of this classroom.

Through these and other examples (see Fig. 4), Lori found ways to get students involved in discussions about science. These examples show how, if properly organized, a set of

Time	Line	Student(s) Discourse	Teacher(s) Discourse	Strategies for Promoting Discourse	Analytic Comments/Notes
00:28:08	4060-4094		*Analytic summary of transcript: Lori initiates role play activity by introducing students as "famous visiting scientists that will be interviewing students in room 2." Introduces "Dr. Millar" (Alice) as scientific reporter. Alice questions several students about the process of photosynthesis, before asking Charlie specifically about the algae experiment.*	*positioning students as scientific reporters and scientists*	**Account 11**
		Alice: [to Charlie]			
	4095	I heard you are making scientific			
	4096	history			
	4097	in this room			
	4098	what happened to your algae that has			
	4099	been in the dark?			
00:30:32		**Charlie:**			
	4100	the algae that's been in the dark			
	4101	has			
	4102	um			
	4103	seemed to grown more			
	4104	and that's not supposed to happen			
	4105	because			
	4106	in the cycle of photosynthesis			
	4107	your supposed to have			
	4108	water			
	4109	sunlight			
	4110	and carbon dioxide			
	4111	has everthing else			
	4112	but sunlight			

4113	so
4114	we don't know why
4115	um
4116	it's
4117	growing
4118	cause
4119	we locked it up in the closet
4120	and
4121	where no light could get through it
4122	and plus we have tin foil over it
4123	and the one that's been in the light
4124	that's supposed to live
4125	has died
4126	or a-
4127	at least we think
4128	cause it's turned brown

Figure 6. Representative transcript of a student's account of events showing use of scientific knowledge.

whole-class discussions can lead to situations more often found in more experiential teaching approaches; that is, this whole-class discussion can be considered an inquiry approach to teaching without small group or individual manipulation of science materials. Although the activities were not directly hands-on for each student, the class's investigation into variables necessary for algae growth entailed active student participation in important scientific processes such as making choices about experimental procedures, listening and considering different points of view, achieving consensus from multiple perspectives, and taking action as a collective. The anomalous experimental results were used by the teacher as an opportunity to continue discussions and follow the suggestions of her students. Nevertheless, these examples demonstrate how this approach required the teacher to improvise and how much discursive work was needed for this set of actions to become opportunities for learning (Tuyay et al., 1995).

DISCUSSION

Our description of the events that constituted the "algae experiment" for this third grade class forms the basis for discussion of three science education issues: the contrast of the official and operational curriculum and what the contrast suggests for conceptualizing nature of science studies in schools; the relationship of teacher subject matter knowledge to discourse practices; and the consideration of the relevant community in deciding what might count as science and discovery. In addition, we discuss research avenues for students' use of anomalies in reasoning in relation to classroom discourse.

As is often the case in science teaching, the lesson started with an explicit goal of using experiments to arrive at a formulation of scientific knowledge. As was shown in this case, the propositional knowledge that sunlight is necessary for life became secondary to a set of important lessons about science, in particular about the nature of scientific investigation. Through improvisation and following a "what comes next" approach, the members of the classroom came to see experiments in science as surprising, inconclusive, sometimes in contradiction to theory, and subject to multiple interpretations. This improvisation led to a shift from the official curriculum to an operational curriculum (Posner, 1995) that included lessons about science not planned by the teacher. Much like the case described by Lynch et al. (1983), the teacher and students needed "something more" in their particular site of practical inquiry. Written instructions and the suggested experimental design underspecified the actions required to make sense of and accomplish the task of a science experiment.

Analysis of the operational curriculum treated the students and teachers' classroom practices as socially constructing what would count as science in this classroom. Providing students with opportunities to engage with science and in the practices of scientists revealed that the nature of science includes using expertise; identifying and acknowledging experimental variables and contingencies; making decisions in the absence of certainty; considering theoretical predictions; and creating new conditions to explore the consequences of various ideas. By considering the ways that this view of science was accomplished, we were able to identify the nature of school science as constructed through the actions of members of this community. From the point of view of educational research, the nature of science was a social accomplishment investigated by studying the moment-to-moment actions of members as they interacted with each other and the material world (Kelly, Chen, & Crawford, 1998).

Another interesting aspect of these classroom practices is the way that the teacher opened up the floor for participation from the students despite her acknowledged lack of subject matter knowledge. By using a large repertoire of strategies to promote student discourse, the classroom teacher created opportunities for students to learn how to observe, predict, interpret, explain, and speculate in a public interactional space. Through these discourse processes, the students gained experience articulating their views, considering the views of others, revoicing scientific knowledge, requesting assistance, making predictions, and designing and conducting experiments.

Lori's teaching practices make for interesting comparisons of other studies of teacher discourse that considered teacher subject matter knowledge. In a study of within-teacher variation of subject matter knowledge among novice secondary teachers, Carlsen (1991, 1992) found that, when teaching subjects of greater familiarity, teachers tended to encourage student participation, vary their curriculum to include instructional contexts that invited student discourse, and speak less of a percentage of class time. Carlsen (1991) cautioned against comparisons of discourse processes across teachers because of the confounding influences of teacher speech habits, average student ability across classes, and other school-setting variables. Therefore, the case of Lori, self-identified as unfamiliar with science, becomes theoretically interesting for the questions it poses for educational research, rather than for any inferences that could be related to her knowledge of and about science. Are there variations in discourse processes (e.g., asking questions, responding to students, and inviting talk) across subjects for elementary teachers who typically teach a variety of subject matters in a single day? Are there principles of practice that are domain-specific, while others can be effectively employed across subject matters? Are there central differences in the purposes and nature of science curriculum at the elementary level that make subject matter knowledge less important than it might be for secondary teachers?

The third aspect of the classroom events described in this study, which we now examine, is the science accomplished through the everyday activities of the members of the classroom. Given the level of doubt and equivocation among the members of the classroom and the deviance of the experimental results from putative theoretical considerations, to what extent can we consider the anomalous results a "discovery?" What was discovered and was this science? If we reexamine Brannigan's (1981) four criteria for scientific discoveries, we can consider how and for whom the growing algae were a discovery. The first criterion is that the claimed achievement be seen as substantively relevant. If we consider this classroom as constituting the community of practice and answer the question as substantively relevant for the students in the class, this criterion was clearly met. Following the same line of reasoning, we consider each of the next three criteria. Second, a discovery is supposed to be determined through scientific investigations. The interesting question here is who determines what counts as "scientific." The teacher and students followed a protocol of a marine scientist by accounting for relevant variables and setting up differing experimental conditions. Yet, many objections could be raised about the experimental procedures of the classroom. Indeed, the members themselves noted a number of contingencies (see Fig. 3). Third, a discovery is supposed to be convincingly true. The students and teacher right up to their last comment on the subject doubted the results of this experiment (although never ruled out as invalid). They decided to send their sample to the marine scientist for analysis because of their incredulity. However, the scientist found that the "darkness-treatment" algae were alive, consistent with the observational results, but in contradiction with the teacher and students' understandings about scientific theory. Finally, the discovered phenomenon (that algae survived and potentially grew in the dark) is supposed to be unprecedented. For this class, under these conditions, the growth of algae without sunlight was unprecedented. Arguably, given a slightly generous reading, the four criteria for scientific discovery were met by the classroom members. Nevertheless, theirs was not a scientific discovery outside their community of class members; that is, scientific theories of photosynthesis, plant growth, and energy transfer were never at stake in communities of botanists and marine scientists.

This example shows that the establishment of ideas as science is dependent on considerations of a relevant community. That is, what counts as science is socially decided and constructed. Therefore, to consider the science in these events, we needed to consider the audience to which the candidates for scientific knowledge were proposed. This audience acting as a relevant community decides whether such candidates will count as discoveries, experiments, artifacts, or errors. Toulmin's (1972) metaphor of intellectual ecology is helpful here. The classroom members acting as a community of scientists created a set of everyday practices established over-time through discourse and interpretative processes that selected among ideas, processes, techniques, and speech and written genres (Kelly & Green, 1998).

Finally, we turn to the relationship of classroom discourse and uses of anomalous data. Research on students' conceptions, conceptual change, and knowledge acquisition has identified the importance of anomalous data in science and science education (Chinn & Brewer, 1993; Posner, Strike, Hewson & Gertzog, 1982). In a extensive review of the uses of anomalous data for knowledge acquisition in science, Chinn and Brewer (1993) identified forms of psychological response by individuals to anomalous data and offered explanations for how their differential response to such data can be attributed to characteristics of these individuals. The research reviewed treated anomalies in the history of science as well as in education from a psychological point of view and Chinn and Brewer drew from this perspective to offer suggestions for science instruction. Building on their original taxonomy of responses to anomalous data in science, Chinn and Brewer (1998) identified the role of uncertainty about belief in science and called for the use of responses to data in classroom discourse as a means to develop an understanding of scientific rationality.

Conceptual change theories have similarly identified the roles of anomalies in scientific rationality and called for a social view of anomalous data. Strike and Posner (1992) explain as follows:

> . . . it seems obvious to the point of requiring no argument, that a great deal of inquiry involves much talk. Explaining, arguing, constructing metaphors, giving counter examples, and the like express the social character of rationality . . . (p. 170)

Strike and Posner continued arguing that students are initiated into "predominantly social constructions" and that "Almost every modern epistemology is likely to see scientific inquiry as involving a mix of observation and discourse" (p. 170). Explicit attention to the use of "anomalous data" as interactionally recognized, acknowledged, and accomplished in classroom discourse has yet to receive significant attention in educational research. Our argument here is that the particular uses of the anomalous data by the teacher and students led to opportunities for the students to learn about scientific processes and the uncertainties involved in empirical investigations. We did not investigate the changes in students' conceptions about photosynthesis nor the relationship of conceptual change to the uses of anomalous data in the classroom conversation. This would be an interesting extension for both psychological studies of knowledge acquisition and discourse-oriented studies of scientific content in classroom conversations. (For the case of analogies in classroom discourse, see Dagher [1995].) More generally, aspects of Toulmin's (1972) intellectual ecology (cf. "conceptual ecology," described in Strike & Posner [1992]), could be investigated in ways that follow the epistemic shift in studies of scientific cognition and practice "from knowing and reasoning by individual scientists or learners of science, to communities of scientists or groups of students" (Duschl & Hamilton, 1998, p. 1061).

CONCLUSION

Classroom members' actions in the events described in this study constructed a particular intellectual ecology that created opportunities for learning (Tuyay et al., 1995) about science (Cunningham & Helms, 1998; Moje, 1995) as well as for learning science concepts. In a recent review of educational implications of the sociology of science, Cunningham and Helms (1998) called for a sociologically informed approach to science teaching and identified a number of potential obstacles to achieving this goal. For example, rather than teaching from textbooks and through lecture formats, Cunningham and Helms (1998) called for "teachers to relinquish power and their role as science authority" (p. 495). Lori can be seen as overcoming the obstacle of textbook curriculum as she redistributed power by using discourse strategies that encouraged student participation and talk with and about science. These strategies allowed students to make key observations, offer interpretations, make suggestions for subsequent actions, and follow the logical consequences of their decisions. She was able to do this while she and eventually her students were grappling with the uncertainty of results that were in contradiction to their expectations and understandings of scientific theory.

In this case of ambiguous science, Lori can be seen as acting in a facilitative, rather than authoritative, role. Similarly, Lori was willing to teach science through ongoing, time-intensive, messy, open-ended activities as called for by Cunningham and Helms (1998, p. 495). By allowing for science to be taught with uncertainty and in an open-ended manner, the students in this class had more opportunities to learn about science and scientists (Chen & Crawford, 1998) than may have been afforded in traditionally structured science classrooms such as those found in other discourse-oriented studies of science teaching (Lemke, 1990; Moje, 1997).

The data presented, the statements made, and the views expressed are solely the responsibility of the authors. We thank Leslie Gravitz and her children in Room 2 for allowing us to be part of their classroom community and Miriam Polne-Fuller of the University of California, Santa Barbara Marine Science Institute, for her contributions to the collective project. We also thank Jenelle Ball, Julie Bianchini, William Carlsen, and Catherine Chen for their helpful comments on an earlier version of this manuscript.

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