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ABSTRACT

This study brings an anthropological perspective informed by sociolinguistic discourse analysis to examine how teachers, students, and scientists constructed ways of investigating and knowing science. The teaching and learning processes for a group of third grade students and how, in the following academic year, these same students drew upon their prior experience to investigate animal behavior in a marine sciences observation tank is described. An ethnographic logic-of-inquiry was used to examine the ways in which cultural practices of science were interactionally constructed by the class members. Research findings include identification of specific instructional strategies used to model scientific inquiry; ways in which the student drew upon, appropriated, and reconstructed scientific practices; and opportunities afforded students when investigating inquiries into unknown science. The implications of this study for the teaching of science in elementary classrooms are discussed. (Contains 60 references and 6 figures.) (Author/NB)

Ways of knowing beyond facts and laws of science: An ethnographic investigation of student engagement in scientific practices

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Abstract

In this study, we bring an anthropological perspective informed by sociolinguistic discourse analysis to examine how teachers, students, and scientists constructed ways of investigating and knowing in science. We describe the teaching and learning processes for a group of third grade students and how in the following academic year these same students drew upon their prior experience to investigate animal behavior in a marine science observation tank. We describe an ethnographic logic-of-inquiry used to examine the ways cultural practices of science were interactionally constructed by the class members. Research findings include identification of specific instructional strategies used to model scientific inquiry; ways the students drew upon, appropriated, and reconstructed scientific practices; and opportunities afforded students when investigating inquiries into unknown science. We discuss the implications of this study for the teaching of science in elementary classrooms.

Ways of knowing beyond facts and laws of science: An ethnographic investigation of student engagement in scientific practices

Studies of student learning in science contexts are increasingly focused on discourse processes, and language more generally. Common among these studies is an understanding of the prominent role language use plays in many scientific practices for both practitioners and students (e.g., posing researchable questions, making observations of phenomena, articulating relevant interpretations, making decisions about collective actions, constructing arguments supporting particular positions, questioning experimental results). The rhetorical and discursive aspects of teaching and learning scientific concepts, practices, and ways of being a group member have led educators to define science as discourse (Roth, McGinn, & Bowen, 1996), to compare the learning of science to the learning of a new language with particular semantic, syntactic, and ideological implications (Lemke, 1990), and to consider the ways that language use is related to group affiliation (Moje, 1995, 1997).

The ways discourse processes used by elementary students, their teacher, and participating scientists contributed to the construction of classroom norms, interactional contexts, and ways of doing and talking science were of central concern for this study. To examine how this community of learners constructed ways of investigating and knowing in science, we drew from and applied anthropological and sociolinguistic theories of culture and language to an analysis of classroom discourse. Through this analysis of the teachers' and students' talk and actions, we describe the discursive processes used by third grade students to interpret a set of anomalous experimental results, and how in the following academic year, these same students drew upon these experiences to investigate animal behavior in a marine science observation tank. Our analysis of the concerted activities of the teacher and students provides the basis for a discussion of how opportunities for learning

(Tuyay, Jennings, & Dixon, 1995) ways of knowing and practicing science are constructed discursively among members of a classroom.

Science as discourse, the languages of learning science

Studies of discourse in science classrooms have identified a range of educational issues that impact student learning, student affiliation/alienation to the school science community, and ways disciplines of science are positioned through descriptions of knowledge and practice. Lemke's (1990) studies of the instantiation of the thematic content of science(s) (e.g., chemistry, physics) demonstrated that by using particular discourse practices (e.g., Initiation, Response, Evaluation--IRE) teachers controlled the nature and extent of the interpretative variability of the semantics of scientific terms. Lemke claims that successful science students are those that link semantic relationships across time and contexts and apply scientific terminology in flexible and useful ways. However, the thematic content of scientific concepts -- ways of talking about phenomena specific to a community -- was often not explicitly described by teachers to their students as a specialized way of talking. Because particular class and ethnic groups (i.e., male, white, middle class) have closer historical ties to the talk associated with school science, certain students were privileged in these science classrooms (Lemke, 1990). The difficulty for students in identifying the specific semantics of scientific terminology across multiple instances led to the social construction of portrayals of scientific disciplines as elitist and difficult to learn in classrooms.

Learning in science was also found to be greatly impacted by the language of scientific writing in texts used as the basis for classroom instruction. From his analyses of a range of scientific texts, Halliday (1993) found that this type of writing generally uses difficult technical terminology highly specialized and specific to the discipline of science. Furthermore, for students to be able to have a functional understanding of the vocabulary associated with scientific writing they must be able to define and use these words in terms of the complex relationships they have with one another rather than attempting to learn them in isolation. This level of learning requires an understanding of the grammatical structure in which these terms are embedded. Specifically, Halliday's analysis of the grammatical features of school textbooks, historical scientific texts, writing in popular science journals, and science lectures identified seven ways scientific discourse presents difficulties for students: interlocking definitions, technical taxonomies, special expressions, lexical density, syntactic ambiguity, grammatical metaphor and semantic discontinuity (p. 71). Students are faced with the difficulty of identifying and deconstructing the complex grammatical features characteristic of scientific writing. The process of sense making, given these grammatical complexities and in the absence of translation to more common sense expressions, mark science discourse as intellectually elite, forbidding, and obscure.

Consistent with the linguistic analyses of Lemke and Halliday, other studies of discourse processes emphasize how the language of science teaching signals what counts as science to students in particular classrooms. Issues of the status of authority in classroom discourse were examined by Russell (1983) through analysis of argumentation structures of science teaching. This study considered how teachers are "in authority" in their role of classroom manager, and "an authority" of science for their students. Russell argued that teachers can be scientific authorities when they provide evidential arguments for the claims they seek to establish, thus modeling for students the grammatical features of scientific discourse. Expanding beyond the uses of argument, Carlsen's (1991, 1992, 1993) sociolinguistic studies of the syntactic, semantic, and pragmatic features of classroom discourse demonstrated that teachers' discourse processes do more than teach science concepts and methods; they teach students about science as a process. His studies suggested that teachers' subject matter knowledge of the scientific discipline being taught influenced the extent to which they opened up classroom conversations, the range and type of questions posed to students, and their willingness to diverge from specific, redefined curriculum goals. Similarly, Moje's (1995, 1997) study of a teacher's talk *about* science identified how uses of particular discourse processes (e.g., first person plural, precision in language use, demarcating science from other disciplines) positioned science and science teachers as authority. These studies explored ways the discourse processes, practices, and genres of teachers and texts communicated and portrayed disciplinary knowledge. To study student appropriation of these discourse processes and views of science, educational studies need to examine how students use scientific language in multiple contexts, including experimental settings.

Concurrent with studies of discourse processes in science classrooms and of science texts was a new recognition of how the emerging field of science and technology studies (e.g., sociology, rhetoric, philosophy, among others) could contribute to educational theory (Kelly, Carlsen, & Cunningham, 1993; Roth, & McGinn, 1997). Studies of the mundane, everyday activities that constitute doing science in a range of contexts and disciplines were found to be particularly useful for educators concerned with how science was practiced and portrayed in schools. One implication of studies of scientific practice was that educators need to take into account more than the substantive content (i.e., propositional knowledge) of ready-made science and consider the importance of the social practices constituting science-in-the making, following Latour, 1987 (e.g., see Kelly, Chen, & Crawford, 1998). Analysis of science-in-the-making suggests that much of the work of constructing new knowledge is discursive, involving the appropriate use of texts, citation, and argument (Bazerman, 1988; Latour, 1987), as well as various rhetorical strategies to procure funding, personnel, and research space (Mukerji, 1989; Traweek, 1988; for review see Kelly & Chen, 1998).

The importance of science and technology studies for research in science education was manifest in a recent special issue of the journal Research in Science Education (Roth, 1998). The articles comprising this special issue considered educational phenomena from science studies perspectives and offered new ways of viewing the daily events of science classrooms. Two studies called for teaching and research informed by sociological theories of science. Costa, Hughes, and Pinch (1998), drawing from constructs in the sociology of scientific knowledge (SSK), proposed the pedagogical usefulness of controversy in science teaching. They argued that, regardless of the correctness of the students' theories, controversy (i.e., debates over the purported truths of science in particular historical contexts) could be used in teaching to show the untidy and human side of science, to demonstrate theory-dependence of observation, and to evince the excitement of scientific inquiry. Calabrese-Barton (1998) suggested that educators consider children's inventions and lived experiences to "challenge imposed definitions of science/technology" (p. 142). Based on feminist analysis of science and school, she suggested that teachers serve as resources of questions and guidance for student learning, rather than definitive sources of knowledge. Similarly, Cunningham and Helms (1998), drawing from sociology of scientific knowledge and feminist studies of science, proposed ways of making science more inclusive and authentic by showing the processes leading to the construction of scientific knowledge. They argue that teachers can situate students in the processes of scientific investigations, thus fostering more accurate understandings about science through personal experience.

Given research in the discourse of science in schools and elsewhere, and the possibilities offered by theoretical perspectives based in science and technology studies, two bodies of literature become relevant for studies of discourse processes in educational contexts. First, we review studies involving the use of experimentation, practical work, or student projects to teach science, as these pedagogical strategies were suggested by reviews of science and technology studies. Second, we review studies analyzing student-student and student-teacher discourse in a variety of settings, as these complement earlier works of teacher discourse.

Studies of uses of experiments and laboratory work in school contexts.

Studies of the uses of experimentation in school science suggest a number of problems and possibilities of this line of science teaching. 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 enquiry versus 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 testing scientific theory, a traditional pedagogical goal of uses of experiments in school science. This study anticipated critiques of science education by linguists who argued that theories advocating practical experience as a means for learning typically fail to consider the importance of scientific language, its history and conventions (Halliday & Martin, 1993; Sutton, 1996).

Fairbrother, Hackling, & Cowan (1997) discussed how pressures to get the correct answer through experiments in school science pushed teachers toward oversimplification and students toward fraudulent presentations of results. In the context of experimental investigations, students are faced with the dual roles of learning science and doing science, each with their respective responsibilities. With lack of experience conducting research, students are often left without the cultural resources (e.g., knowing how to investigate with integrity, to persuade peers, to understand the roles of uncertainty and error in experimentation) necessary to make scientific decisions and to direct their learning. The authors conclude by suggesting that these roles and responsibilities be clearly defined, and that students learn early in their school experience the different attitudes and behaviors necessary for the learning of science and doing of science.

Other studies similarly examined cases when practical experiences gave results at odds with expected results (often canonical science). Meyer & Carlisle (1996) argued that experimental work for small groups of student investigators offered opportunities for learning scientific phenomena, for learning processes of scientific inquiry, for developing positive attitudes toward science, and for appreciating the enjoyment of science. However, they found that limited student knowledge of how to conduct experiments and of scientific concepts constrained what could be accomplished. Most troublesome for the authors was the discovery that elementary students were likely to abandon experiments when the results were not as anticipated. They attributed this to students' experience in school science which reinforced the belief that correct answers can be achieved through linear algorithms. Nott and Hallam (1996) argued that unanticipated results create a "critical incident" which can be used as a way to teach the nature of science by showing how scientific theories are maintained and negated in complex interactions with experimental results. These critical incidents offer teachers ways to explain about science and scientists and offer educational researchers ways to learn about teachers' views of the nature of science.

Discourse processes in school science across contexts

A number of recent discourse oriented studies in science education focus on students and teachers working under more open-ended learning conditions than found in some earlier works (e.g., Lemke, 1990). Roth et al. (1996) advocate the use of open-ended laboratories to provide students with opportunities to view knowledge as socially constructed and personally meaningful. These authors considered the importance of the discursive and rhetorical dimensions of scientific practices, and in their teaching, position students to talk science with peers, teachers, and outsiders. By treating science as discourse (p. 462), Roth et al. (1996) examined how students change their ways of talking about phenomena through interpretation and sense-making activities. Because of the "interpretative flexibility" of the objects and tasks used in these studies, new ways of seeing and talking emerged as students increasingly included canonical scientific discourses (p. 472).

In a series of studies on language minority students learning science, Warren, Rosebery, & Conant (Warren & Rosebery, 1995; Warren, Rosebery, & Conant, 1994) worked with teachers to create conditions of authentic practice in classrooms. The teaching strategies in these studies emphasized questioning, theory building, and the development of scientific arguments. In one example, a teacher created conditions for students to present their ideas to their peers in the class (Warren & Rosebery, 1995). Through a sequence of challenges and rebuttals, a student investigator struggled to prove persuasively that his assertions were warranted in the face of questions from his peers. The class discussions about the student investigator's experiment provided opportunities for the whole class to learn about many important aspects of scientific discourse: use of data, argumentation strategies, the importance of norms of the "local" community, and the relationship of "facts" to arguments. Warren & Rosebery argued that the teacher played an important role by helping students develop the skills and strategies necessary to acquire this discourse of science.

Student discourse in small group learning contexts also has been shown to offer unique opportunities for students to talk science, although these opportunities were not without potential problems. Richmond & Striley (1996) conducted a study of high school students' as they worked together in laboratory groups during scientific investigations. Through an analysis of students' discursive practices this study examined how verbal interactions in small group contexts shaped students' developing ideas and ways of articulating scientific arguments. They found that the development of students' conceptual understanding of science was directly related to the social processes of the group (e.g., the social norms guiding group behavior, individual roles as contributing group members). They discuss the ways that group dynamics, particularly the interactional style of a group's leader, variously affect students' equity of access to the information necessary for building and articulating their scientific understandings. The authors conclude by suggesting that inclusive leadership and equitable participation be treated as a critical goal for teachers in their struggle to find ways of providing alternative pedagogical practices in science classrooms. The interaction of social dimensions in group processes was also evident in

Bianchini's (1997) study of middle school students learning human biology. In this class small group science activities based on the Complex Instruction Model were used to facilitate student learning in science. The study documented how students used discourse to accomplish a variety of goals from social positioning to learning science. This study described how status, an indicator of popularity and perceived academic excellence, influenced the social dimensions in learning. Differential status among student members in small groups was found to influence access to materials and to the ongoing conversations. Although status did not directly affect science achievement, high status students engaged in more on-task talk, the variable most strongly correlated with science learning.

Our review of the literature suggests that current recommendations for creating more authentic scientific experiences in classrooms (Crawford, Chen, & Kelly, 1997) require changes in teaching practices, such as orchestrating student conversations, considering issues of equity in small group work, and balancing the tensions between students' ideas and disciplinary knowledge. Nevertheless, authentic practices in classrooms pose new challenges and problems. For example, pedagogies advocating authentic investigations may present equity of access issues for students who participate in groups where social pressures (e.g., differential status, dominating group members) limit the possibilities for science learning, or in groups that construct knowledge claims at odds with the conventions of legitimizing institutions (Kelly, Crawford, & Green, 1997). Another example concerns scientific discourse in texts and talk that have been shown to be conceptually opaque because of conventionalized practices such as use of nomination, interconnected thematic content, and particular argumentation strategies, among others (Halliday & Martin, 1993; Lemke, 1990). Pedagogies informed by science and technology studies may offer new contexts to talk science, however, the noted discourse features of science and the problems students have with them will remain even as students become members, even if only peripherally, of (school) science communities.

As a whole, this current research of discourse processes indicates a need for studies of science in various settings and interactional contexts to examine how disciplinary knowledge is accomplished through moment to moment interactions among students, teachers, texts, and other material resources (Hicks, 1995). To contribute to the ongoing conversation concerning discourse processes in science education, we describe in subsequent sections a study of elementary students learning of scientific practices that offers a number of unique features. First, the students were investigating unprecedented scientific phenomena (i.e., not known among students, teachers, and scientists in the classroom). Second, the student initiated investigation was conducted as a whole class of approximately thirty students, rather than in small groups. Third, the students drew from experiences in third grade science to appropriate and reconstruct science discourse to meet the needs of their investigations in fourth grade.

Educational Setting

The setting for this study was a classroom in a public elementary school in a small city in southern California. The student population in the school (n = 320) was comprised primarily of two ethnic groups defined by the school district as "Hispanic" (57%) and "White" (39%). The study was conducted over two academic years with the same teacher, first in her third grade class and then in her fourth/fifth combination class in the following year. Both classes consisted of roughly equal numbers of Hispanic and white students, as well as male and female students. The fourth grade students in the second academic year of this study (1996-1997) were third grade students in the first academic year (1995-1996); while the fifth grade students participated only in the second academic year of the study. The participating teacher, together with a university based team of educators and scientists, created a set of integrated science activities for her students. The lessons used an interdisciplinary approach incorporating physical, natural, and social sciences.

Methods for the analysis and presentation of classroom life: Investigating the discourses of learning science

Our methodological orientation is informed by educational ethnography (Zarharlick & Green, 1991; Green & Bloome, 1997). We examine the indigenous meanings within a particular community (Emerson, Fretz, & Shaw, 1995) and how these meanings are situationally defined and accomplished among members through discourse processes and practices (Kelly & Crawford, 1997). This form of analysis focuses on the ways cultural practices are interactionally constructed by members of a group over time through their moment to moment, day to day activities (Castanheira, Crawford, Dixon, & Green, 1998; Erickson, 1992; Mehan, 1979).

Through the analyses described in this section, we present our logic of inquiry (Gee & Green, 1998) developed for the purposes of this study. Concurrent with the description of our research methods, we present relevant theories informing our methodological decisions and substantive findings particular to this study. As suggested by ethnographers (Emerson et al., 1995), theory-method-findings distinctions are not easily disentangled, as initial findings may lead to the incorporation of particular methodological techniques, each grounded in a particular theoretical framework. Thus, rather than artificially separating our inquiry processes as method independent of findings (Kelly & Chen, 1998), we reconstruct the logic of our research methodology, presenting the procedures used to study the cultural artifacts, speech messages, and cultural actions of the participants (Spradley, 1980), and how these procedures were informed by previous analyses (Kelly, Crawford, & Brown, 1998).

This study was part of a larger ethnographic study. In order to identify the patterned activities of the participants, we collected data for a broad range of classroom activities (Edwards & Westgate, 1994; Lemke, 1998). We recorded video and audio taped records of classroom events over the course of two academic years (approximately 65 days, 216 hours). In addition, as a research team we took fieldnotes, collected artifacts, conducted formal and informal interviews, and created an ongoing log of events. These records formed the basis from which we constructed data sets in the form of transcriptions of classroom events and research interviews, and identified initial patterns leading to our purposeful sampling for further analyses.

Consistent with sociolinguistically-informed ethnographic research in education (Erickson, 1992; Green & Wallat, 1981; Lemke, 1990), we used contextual, non-lexical features (Gumperz, 1982, 1992) as well as thematic content of the participants' conversations to identify the interactionally marked episodes transcribed at various levels of specificity. To begin this process of analysis we constructed running records (Castanheira, et. al., 1998) of when-in-time particular chains of activity occurred. These records were created using the C-Video software program while viewing the video data. A time-stamp was made each time a change in activity was noted, as demarcated by the substance of the member(s') discourse: talk and other contextualization cues (Gumperz, 1992). A brief description of each activity was entered next to the time-stamp, offering a written chronological representation of the video recordings.

Throughout the analyses of this study, these written records served as a type of indexing system, providing a means for locating events and participants' actions, cross-referencing data (i.e., field notes, audiotapes, videotapes, artifacts), and for allowing us to return to the same moment in time on a videotape for subsequent analyses. These running records also served as the basis for the identification of events and sub-events that occurred in this classroom. By analyzing the ways that the chains of activity (members' talk and actions) linked together thematically, we were able to identify, and differentiate between, particular phases of activity. Further analysis of the ways these phases of activity tied together around a common task enabled us to identify and name bounded events and sub-events that constituted "class" for the participants involved.

The product of these analyses yielded a set of event maps showing the type and nature of classroom events. Decisions regarding the construction of event maps (i.e., what information should be shown and how it should be represented), were theoretically driven (Green & Meyer, 1991). Thus, event maps were variously constructed dependent on our logic of inquiry and the questions we were asking of our data at particular stages of analysis (Kelly et al., 1997). One type of event map constructed was in the form of timelines, such as the depiction of events for one afternoon of third grade science (Figure 1 represents a typical example). These timelines offered a graphic representation of what members constructed as events and phases, making visible how the participants structured time and activity within their classroom (Erickson & Shultz, 1981; Green & Meyer, 1991). The use of timelines in our analysis enabled us to look across-time at the range, sequence, and time distributions of activities constructed for each day recorded (Erickson, 1992). Through this process we were able to systematically sample those events involving the teaching and learning of science (Bloome & Egan-Robertson, 1993; Green & Wallat, 1981; Mehan, 1979).

An example of the use of transcripts at multiple levels to study the ways science was interactionally accomplished among these classroom members was provided in a previous study (Kelly et al., 1998). In that initial ethnographic study, we selected a phase of activity, labeled the "algae experiment," for detailed discourse analysis (Green & Wallat, 1981; Kelly & Crawford, 1996). A complete description of the theoretical decisions and an explanation of the research methodology can be found in an earlier paper (Kelly et al., 1998). However, we summarize the findings here to provide the information gleaned from that study relevant to our methodological decisions presented in this paper. Through the processes used in the analysis of the third grade data, we identified the scientific practices engaged in by the students during their third grade experience. These practices included ways of observing, ways of articulating their ideas, ways of presenting data, and ways of reaching consensus. For example, the "algae experiment" represented a "key event" (Gumperz & Cook-Gumperz, 1982) as it provided a set of activities, identified by the class members as significant, that allowed us to examine the social practices of the participants and the consequences of these practices for learning science. In this school science experiment investigating the effects of different light treatments on algae growth, a simple treatment-control group experimental design became a complex investigation as the expected (to expert) phenomena did not occur. The anomalous results led the teacher and students to a process of continual negotiation as they struggled to decide the "next step" in their science investigation. Taken as a whole the activities offered unique opportunities for students to learn science. Doing science in this case meant making and using observations, proposing interpretations, knowing hypotheses, recognizing unexpected results, making decisions based on evidence under uncertain conditions, learning that results may not be definitive, and drawing on and using expertise (of person and of knowledge).

This initial analysis of the third grade data demonstrated that science for these students was constructed as a set of social practices that involved knowing scientific information, but more importantly, knowing how to engage in scientific investigations. This focus led us to examine ways that the teacher and students developed such practices in the subsequent academic year (grades 4/5, described below). Given this initial understanding and the event maps across both the third grade and the fourth/fifth grade academic years, we identified a particular pattern in the social practices of the teacher and students: the pedagogical strategies of this teacher provided opportunities for students to initiate scientific investigations, discussions, and other literate practices, such as reading and sharing with class members "what was learned" about science through reading, even during times not designated for learning science.

Evidence of this pattern was manifest throughout the two academic years. Such classroom patterns are typically constructed and established at the onset of the academic year as teachers and students interact, affiliate, and build common knowledge of how to be a student, teacher, and/or class member, and in particular, how to be a scientist, mathematician, historian or ethnographer, among other roles (for examples across disciplines, see Green & Dixon, 1993). Examples from the first three weeks of the 4/5 class showed how students took up teacher-provided opportunities, given a range of open-ended activities and topics, to engage in science. Figure 2 provides a description of activities -- grouped into categories "learning time" and "three-minute break" (folk terms, following Spradley, 1980) -- dates and number of instances of occurrence, and examples of how students drew from available resources to engage in science. These student-initiated activities, while often accomplished among diverse groupings of small numbers of students, became bases for the development of common knowledge through sharing of findings and further discussion with the entire class. Occasionally, these activities led to more in-depth whole class investigations. In this paper we provide an illustrative example of how a student-initiated observation of the behavior of a whelk snail and an anemone in the class's aquarium led to a whole class investigation. Through this process we document the opportunities afforded students for learning about science given the social practices constructed across the academic years.

Investigating unknown science: The story of the whelk and anemone

One of the patterned activities constructed by class members was the "three minute break" in which students were given free time to "take a break" from the official curriculum. During these times students were not required to engage in academic activities, however they often used these breaks to explore science resources available in the classroom. One such resource was an aquarium that housed live sea creatures (e.g., snails, crabs, anemone, urchins, sea stars). Our ethnographic records show that students frequently visited the aquarium during these three minute breaks, making observations and having discussions. Following these breaks students were often allotted time by the teacher to share their observations with the class. In the Fall of the fourth/fifth grade academic year a three minute break was called by the teacher during a mathematics lesson. During this break several students made observations at the aquarium. In this case, student reports of their observations were sufficiently intriguing to the teacher as to cause her to interrupt her planned return to the math lesson. Instead, she sought to understand the information being shared by the students. We present this case as an example of the educational opportunities afforded by the particulars of the phenomena at hand and as an example of how such opportunities were constructed as resources for learning through over-time, sustained social practices.

Noting the potential relevance of this particular key event and the opportunities it afforded students to practice science, we transcribed all discussions related to this event, including participants' talk, taking into consideration non-verbal actions (e.g., pitch, stress, intonation, pause structures, physical orientation, proxemic distance, and eye gaze) (Gumperz, 1992). From these transcripts and associated videotaped episodes we created a representation showing the reconstructed logic of the students' investigations that occurred as a result of the opportunities created by this particular three minute break. We illustrate our analyses of the opportunities constructed and the ways students engaged in the processes of science by tracing the logic of this investigation as shown in Figure 3.

After the three minute break during a math lesson, a student (Billy) called the teacher to the aquarium to show her what he considered evidence that a decorator crab was eating a brittle star. This sharing prompted the teacher to break from the math curriculum to conduct an experiment to validate Billy's hypothesis, which he then shared with the whole class. Although the experiment with the crab and the brittle star was never concluded on this day, this pedagogical shift created the onset of a "spontaneous" science event which afforded the opportunity for students to engage in the processes of doing and talking science (i.e., posing questions, making observations, constructing arguments using empirical evidence, making decisions).

This spontaneous event began when another student (Mark) shared with the class his observations of an unusual interaction between a whelk snail and a sea anemone that he and another student (Joe) had made during the three minute break. These students noticed that the whelk's foot was attached to the tank's glass and that the anemone seemed to be attached to the back of the whelk. They observed a "slimy" substance emanating from the animals. This sharing prompted a whole class scientific investigation in which many members of the class constructed various arguments about the ongoing episode. An analysis of student discourse during this investigation revealed that they engaged in scientific processes by drawing on particular referents and knowledge considerations to articulate claims they were making regarding the behavioral phenomenon they observed. For example, Mark claimed that "the anemone is thinking that that the big shell is a rock" and used his knowledge of anemone's actions to substantiate that claim stating, "cause anemones cling to rocks." Another student, Elizabeth, based her claim on observational evidence. Drawing on her knowledge of the physical characteristics of the snail (location of the mouth being near the antenna), she claimed that "the whelk is eating it [the anemone] because the um the little antenna are on it." Tom also used observational evidence and knowledge of physical characteristics to make a claim counter to that of Elizabeth. He claimed that, "I don't even think...the whelk is eating the anemone because um the last time I saw it the anemone wasn't even near its mouth it was like right in the center of its back." This discussion resulted in multiple interpretations being brought to the floor, prompting Joe to suggest calling a marine scientist, who had worked with the class for the two academic years, at her laboratory to elicit her expert advice.

Rather than using the expert as someone to give them an answer as to what to do next, the class engaged in a brainstorming session honing in on what kinds of information they needed (e.g., the location of the snails mouth, whether or not snails and anemone are "enemies," if human intervention would cause damage) so that they could draw their own conclusion and make a scientifically sound decision. The class then called the marine scientist on a speaker phone to ask their questions. Elizabeth and the teacher, acted as the class spokespeople by conducting the phone call for the class members. During the conversation Elizabeth asked a question regarding the class's proposed plan of action--to separate the snail and anemone. The scientist offered her opinion, stating that they could try the experiment (separate them) to see what would happen, or they could not try it (leave them together), but then they might never know if the snail was eating the anemone or not.

After the phone call, the teacher positioned the students as scientific authority by giving them the decision making power stating "what do you guys wanna do?" Rather than simply taking a vote, she requested that students state their recommendations for what course of action should be taken given the information obtained through questioning the marine scientist. An analysis of the students' discourse showed that they not only gave their opinions as to what to do, but extended their talk to include providing a rationale for their opinion. Figure 4 shows transcript segments of several students recommendations and rationales, along with an analysis column showing the referents drawn upon by the students and the knowledge considerations they used in articulating their arguments. As is often the case with practicing scientists (Michael & Birke, 1995), students considered both ethical concerns for the well-being of their animal subjects and scientific considerations such as completing an experiment and searching for the best evidence. For example, Tracy, states "I think that we like should like take them apart " justifying this by stating, "because then we'll never know if it was eating it." Tracy's recommendation and rationale shows an understanding that, as scientists, they can choose to take action to control the variables in an effort to find an answer to their question. Offering an alternative view, Josh's recommendation is to "...just leave it um leave it like it is" with the rationale that, "if we try to separate 'em [them] it will hurt the anemone and might kill it." In Josh's statement we see that although he understands they can try to find an answer by intervening and changing the conditions as suggested by Tracy, there are ethical considerations that should be taken into account.

After hearing several student recommendations and explanations, the teacher took a class poll in which the students voted to take the whelk snail and sea anemone apart and conduct further observations in an effort to determine whether or not the anemone was being eaten. Two students volunteered to carry out the experiment, separating the two animals, while another student reported their actions to the other class members. Upon completing the separation by placing the snail and anemone at opposite ends of the tank, the entire class returned to the original math lesson.

Days later the students reported to the researcher that the anemone had died and offered observational evidence for this claim, stating that it had "curled up", "sat still", and "turned brown." Although questions of whether the whelk was eating the anemone or the separation of the two was responsible for the death of the anemone remained unresolved, the willingness of the teacher to shift from her intended curriculum to investigate the unknown phenomenon reported by students offered an opportunity for students to practice science in ways that went beyond the facts and laws of learned textbook knowledge (e.g., dietary habits of snails, habitat niches for anemone).

Our argument is centered on how the particular educational opportunities afforded by this event were tied to and made possible through the social and pedagogical practices of this classroom. These practices were established through sustaining group activities over the course of the academic years. In the next section we take our analysis across years to explore the similarities and differences in students' engagement with science in both episodes described previously--the complex algae experiment from the third grade year and the investigation of sea animal behaviors in the fourth/fifth grade year.

Comparative analyses:

Establishing classroom practices through concerted activities over time

The data set for this ethnographic study offered unique opportunities to us as researchers. Because the study was done over two years with the same teacher and some of the same students, we were able to look over time and across years to identify ways that the patterns of practice related to the teaching and learning of science remained the same or changed, in what ways, and with what outcomes. We chose to focus on two episodes previously discussed--the algae experiment from third grade and the whelk/anemone investigation in the fourth/fifth grade--for comparative analyses. The theoretical rationale for this choice is two-fold: First, the two episodes represented inquiries into atypical science for which the results were uncertain -- perhaps unprecedented in the case of the whelk/anemone investigation. In each case the participating marine scientist accorded the students' observations validity and helped them identify how the class observations differed from the standard scientific account. The two cases are linked a second way. In our analyses of the whelk/anemone episode we noted that the particular practices used by the teacher and students in this investigation followed from, drew upon, appropriated, and reconstructed particular scientific practices found in the third grade study. Our comparative analysis was conducted by examining the details of conversations at the discourse analytic level and comparing those details across instances within each episode. A summary of the similarities and differences between the algae experiment and the whelk/anemone investigation gleaned from this analysis is offered in Figure 5.

Both episodes demonstrated a whole class inquiry process, wherein students, teacher, and a participating scientist worked together to investigate particular phenomena through articulating their ideas, using evidence, reaching consensus, and making group decisions. Analysis of these episodes revealed particular kinds of work the teacher did, both in providing materials and using discursive strategies, to encourage student participation in the scientific investigations being undertaken in each case.
Although some of the strategies used by the teacher to provide the opportunities for student inquiry were similar across both cases, the differences between the two offered insight into the ways that knowledge attained from participating in third grade science affected the kinds of work done by the teacher and students in the following year (see Figure 5).

An examination of the differences between the two episodes shows a shift in the kinds of discursive strategies used by the teacher and the kinds of discursive participation by the students. Figure 6 presents a taxonomy of the discourse strategies used by the teacher to promote students "talking science" (Lemke, 1990) across both cases. To create this taxonomy we identified the strategies through a review of the transcripts of spoken discourse in conjunction with viewing the videotape over multiple iterations. An initial taxonomic analysis of the discourse in the third grade classroom and a discussion how the teacher promoted student participation can be found in an earlier paper (Kelly et al., 1998). For the purposes of this discussion we have reprinted that figure and added the new strategies found in our analysis of the whelk/anemone investigation. The strategies used by the teacher that were common across both instances are presented in regular print and those that are particular to the fourth/fifth grade investigation are printed in bold type. In addition, previous strategies identified, but not found in the second year of the study, are printed in italics.

This taxonomic analysis shows that the teacher utilized many of the same overall strategies across both years to create the interactional spaces (Heras, 1993) for students to speak; however there were significant differences in some areas. One reason for these differences can be attributed to the change in the teacher's role during the investigations. For example, in the algae experiment, there was an intended curriculum and an intended outcome, whereas the whelk/anemone investigation was a spontaneous event occurring with no intended curriculum or conclusion. As a result we see through the teacher's actions that during much of the inquiry process she takes up the role of fellow student, rather than an authority figure who was privy to knowledge leading to a particular conclusion (c.f., Russell, 1983). This shift is evident in the number of times she claims ignorance during this investigation (8 times in 26 minutes of classroom discourse), making statements as, "I don't get it," "I don't understand what's going on," "I can't figure this one out," as opposed to the times she claimed ignorance during the algae experiment (2 times in 23 minutes of classroom discourse).

Due to this shift in the teacher's role, we found that she positioned students as spokespersons in alternative ways. For example, students took on the role of "scientists" through the ways that the teacher referred to them as "Doctor," deferred to the students' suggestions regarding method, and offered them the possibility of giving the scientific accounts to outside observers (educational researchers). In addition to positioning students as scientists in these ways, her work during the whelk/anemone investigation also positioned students as teacher, providing them the opportunity to lead the discussion, ask questions of each other, the teacher, and the participating scientist, and make decisions regarding the next steps in the investigation. In these instances, her work to orient students to the scientific discussion at hand extended to orienting the audience (class members) to the student-speaking-as-teacher and to the topic of the discussion. Her role as fellow investigator was also evidenced in her use of questioning as a strategy to promote student talk. One difference found in this area was in requesting students' confirmation. In the first year she used the strategy of requesting students' confirmation of her understanding of their ideas. In the second year, this strategy of requesting student confirmation also included evaluation of her opinion regarding the events. Thus, the students-speaking-as-teacher were able to speak to <u>their</u> understanding of <u>her</u> ideas. This strategy served to position students in the role traditionally taken by the teacher, that of having the evaluative authority. This authority was often related to decision making regarding procedures and to the assessment of information and the validity of particular interpretations.

We now turn to the examination of the relationship of the practices established in the third grade and how these practices influenced the actions of the students and teacher in the subsequent academic year. One explanation for the additional discourse strategies used by the teacher to promote student discourse (Figure 6) can be attributed to the work she did as facilitator of the discussion in the previous year. During the third grade the anomalous results of a predesigned activity (algae experiment) created opportunities for the teacher to use particular discursive strategies to teach students some ways that scientific investigations are conducted, e.g., observing data, drawing on scientific knowledge to present arguments, basing claims and interpretations on evidence, and considering of the opinions of others in making decisions. In the second year we saw that students drew on this body of knowledge and as a result the teacher had to do less of this type of work. For example, she used the strategy of positioning students as scientists less often the second year as the students took up the position themselves in a number of ways. In this case the teacher had not intended to undertake a scientific investigation in which she planned to position students as scientists. Instead the students took the position of scientists of their own accord and initiated a scientific inquiry, by making observations during their own time and reporting them to the teacher and the rest of the class. Another significant example of students drawing on their knowledge.from their previous experience with science is evident in the fact that the teacher did not have to use the strategy of "prompting" during the whelk/anemone investigation (see Figure 6). In the previous year, she prompted students to extend their ideas, claims, and interpretations by offering additional information or asking specific questions. By the time the students reached the fourth/fifth grade, we found that student talk was self-extended, without prompting from the teacher. The students demonstrated their competence in talking science by providing evidence for ideas, claims, and interpretations based on scientific knowledge, observations, and ethical considerations (described earlier in this paper and as shown in Figure 4).

These analyses serve to show the importance of discursive strategies in creating the social practices that students draw upon to study science. Through these analyses we are able to see how the patterns of practice constructed through the talk and actions of members of this classroom over time served to form a particular discourse genre (Gee, Michaels, & O'Connor, 1992) for the teaching and learning of science. It is the common knowledge built through the use of the genre created in this community that students drew upon to act and talk in particular ways as speakers, and which shaped the nature of the experimentation or investigation processes they used in their research design, the predictions they made, and the explanations they offered.

Discussion

Our findings were derived from analyses of classroom members (students, teachers, guest scientists) actions and discourse during an investigation of animal behavior in the second year of this two-year study. We frame our discussion through a consideration of these events and how they may have been related to activities for the same teacher and students in a previous academic year. This cross-case comparison identifies three important issues concerning science education focused on explaining how: opportunities created for scientific inquiry, roles for the teacher in science discussions, and discourse processes affect what counts as science and what can be learned about science.

In the first year of this study, the teacher worked together with scientists as consultants and co-teachers to create opportunities for students to learn about science and scientists. In working with the scientists, she set up marine biology tank in her classroom for students to make observations and planned several lessons related to sea-life. In the second year of the study, we found that she drew on her first year experience and expanded possibilities for student engagement in science beyond assigning observational time at the sea-tank and initiating planned activities. In this second year she created an environment conducive to self-initiated exploration by surrounding students with science resources that included reading material, live plants and animals, and equipment for exploration, such as magnifying glasses and microscopes. Although it is not uncommon to use such materials in the teaching of science, the teacher made these materials a part of the classroom environment at all times (i.e., tools ready-at-hand, Roth, 1997), not only for use during structured science lessons. More importantly, she expanded opportunities for the study of science by allotting <u>time</u> for students to explore these materials outside of formal science instruction. Through providing time, tools, texts, and technologies for student exploration this teacher created opportunities for students to engage in scientific discussions with each other, foster their own interests related to science, and initiate opportunities for themselves, and the class as a whole, to participate in scientific inquiry beyond the traditional teacher-planned, teacher-led curriculum. The teacher's openness to allow exploration of student initiated interests provided conditions in which students were able to reshape the curriculum by bringing the results of their informal science experiences forward for consideration by the whole class, such as in the events describing the whelk/anemone investigation.

A second discussion issue for the teaching and learning of science derived from our analyses of these investigations concerns the roles a science teacher may choose to take. These examples demonstrated how the roles a science teacher takes in such instances and the discourse processes she uses serve to create conditions in which the teacher and students' work together to socially construct what comes to count as practicing science. Our analysis of this teachers' discursive practices make for interesting comparisons with other studies of teacher discourse. Russell (1983) described the role of teacher as that of being "in authority" as manager of the classroom and "an authority" of science (see also Carlsen, 1997). In our study, while we found the teacher to take up both roles, she did so in ways that promoted the sharing of these roles with other members of the classroom, including students. As the person "in authority" she modeled ways of drawing from others to share the role of being "an authority." For example she distributed scientific authority to outside experts, and she redistributed talk during science discussions by inviting students to give their ideas and interpretations even after an initial "answer" had been given. In these ways she modeled that what students have to say is important and worthy of listening to, and that weighing the contributions of others when making decisions is a viable scientific practice. In addition, she relinquished the typical teacher role as "an authority" and shared the role of being "in authority" by taking a more facilitative role, situating students as scientists and spokespersons in and for the class, as suggested in critical pedagogies advocated by Cunningham & Helms (1998) and Calabrese-Barton (1998). Through this process, the students were encouraged to articulate their ideas, explain their reasoning, and respect the ideas of their peers.

Some studies of teacher discourse relate these types of teaching strategies to teacher knowledge of and about science (Carlsen, 1991; Cunningham, 1997). In the cases of unknown science presented previously (algae and whelk investigations), the teacher did not feel she held a position as "an authority" of science, and perhaps as a result of this, she could not lead the class to a known conclusion. Operating from this self-identified position of "not knowing," she might have chosen to close down the conversation. Instead, we found that she used particular discursive strategies to orchestrate a conversation that kept the science task open, even though there was no known outcome. We are not arguing that it is not necessary for teachers to have a breadth of subject matter knowledge. We acknowledge the fact that having such knowledge may make classroom discussions, such as those described, more inclusive of science facts and theories, or even open up possibilities not otherwise available. However, we are arguing that through strategic use of particular discourse processes teachers can teach about science as a process and model ways for students to effectively "talk" and practice science (Chen & Crawford, 1998). For example, one of the discursive practices used by this teacher in the algae experiment during the first year of the study showed her prompting students to extend their talk in science discussions to include reasons and evidence for their claims when making arguments (a normative scientific practice). In the second year of the study we found the students, without prompting from the teacher, drew upon, appropriated, and reconstructed this practice, as well as others, in their discussion during the whelk/anemone investigation. The significance of this finding is that it demonstrates the usefulness of allowing students to explore ideas, even if they stray from known science and the propositional knowledge of science textbooks. In the case of the whelk/anemone investigation, the improvised curriculum offered the students in the class a way to consider the ethical implications for the use of animal subjects in science.

A third issue of importance is the value-added to the teaching and learning of science through effective use of whole class discussions. Science reform documents typically depict effective teaching strategies as those that are experiential in nature, often suggesting students, as individuals and in small groups, be offered opportunities to manipulate science to foster greater student involvement in discussions related to scientific processes (e.g., National Research Council, 1996). Interestingly, in the investigations described previously, the inquiry processes were conducted at the whole class level. Our analyses of these investigations revealed ways that whole class discussions can be a valuable pedagogical tool having the potential to add to the effectiveness of small group work. Teachers can use such formats to offer all students (even those that do not participate in the discussion) opportunities to hear the conversation and learn how to speak and listen to each other as members of a science community. For example, through her use of particular discourse strategies during the science discussions described in this study the teacher modeled for her students specific ways of talking science that included how to: articulate points of view, provide evidence for claims and recommendations, draw on knowledge of science when making choices about experimental procedures, consider the ideas of others, and achieve consensus. This type of modeling provided opportunities for students to gain the knowledge and practice of how to be a member of in an inquiry community. Such modeling may have direct influence on the participatory levels and the quality of discussions constructed by these students as they engage in small group work. This assertion indicates a need for future research to follow students into their work in small groups to explore how, and in what ways, participation in whole class discussions, and the modeling processes that occur through them, influence student participation and access to scientific knowledge and practice.

Conclusion

The events, as they are described in this study through the actions and practices of the members involved, showed that the learning of science was constructed as a social accomplishment. Through the social practices that came to define science for these classroom members, a particular intellectual community was created that afforded opportunities for student to access particular constructs found in scientific communities. While we do not advocate that all science teaching should be of the sort described here, by moving beyond the traditional focus on facts and laws of science, the students in this study were offered opportunities to use their knowledge in inquiry processes (e.g., posing questions, observing, offering interpretations) and associated social practices (e.g., group norms for speaking and listening, particular ways of formulating an explanation) to "talk science" (Lemke, 1990). For these students engaging in science required using the knowledge and expertise of others, living with uncertainty, articulating ideas in public forums, using evidence, reaching consensus, and making group decisions. The educational opportunities afforded under these conditions, unlike many of the experiences of school science concerned with the learning of science content (Cochran, 1997; Larochelle & Désautals, 1998; Lemke, 1990; Moje, 1995), offered students ways of seeing science as constructed through conventionalized social practices. Through the events constructed by the teacher and students, science was experienced as an inquiry process into unknown topics conducted by a community of knowers-- a perspective on science that is typically available only after a long apprenticeship in a scientific field (Kuhn, 1962/1996).

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Figure 1. Timeline depicting events for one afternoon of third grade science.

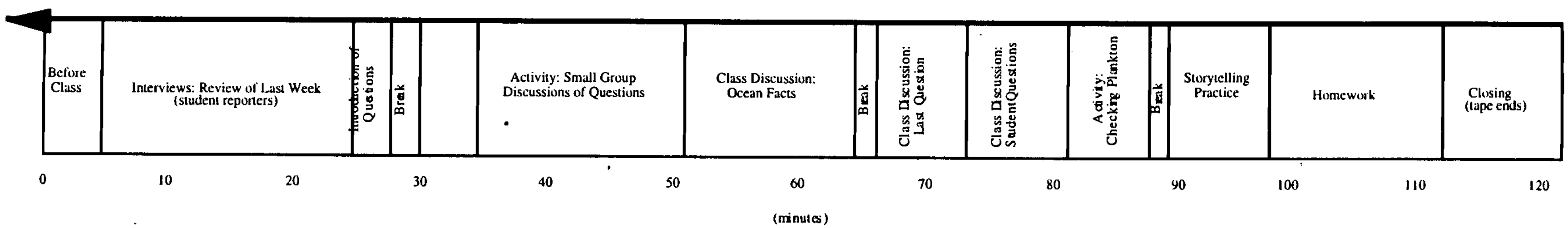

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Figure 2. Description of activities with dates and number of instances of occurrence, and examples of how students drew from available resources to engage in science.

Pedagogical Practice	Description of activity	Dates of Occurrence (# of times occurred)	Ways students use opportunity to learn about science
Learning Time	An activity occurring most often during transition times (e.g., after recess, before official starting of class) in which students read silently anything of their choosing. After time is called (5-10 minutes) by the teacher, individual students share orally with the class "what they have learned."	September 11 (1) 12 (2) 13 (2) 16 (1) 17 (2) 18 (1) 19 (2) 23 (1) 24 (1) 26 (1) 27 (1)	Self-selected reading of science text and trade books. Students sharing learning in science such as: •speed of light •sound barrier •hot air balloons •experiment: egg in bottle •experiment: growing beans •what bracket fungus is •rain gauges •clouds
Three-minute Break	An activity that occurs at various times during the day, usually after a "working" period of time. During this time students are free to get up from their desks and "take a break" from working. They may talk freely and use any resources available for exploration (e.g., internet, sea tank, books, plants)	September 9 (3) 10 (3) 11 (3) 12 (5) 13 (1) 16 (2) 17 (3) 18 (3) 19 (3) 20 (2) 23 (2) 24 (2) 26 (3) 27 (2)	Student-initiated exploration and discussion involving: • observing sea creatures in tank • caring for classroom plants • investigating science topics on the internet • working on science experiments • calling experts to answer science related questions (i.e., natural history museum, meteorologist, marine scientist)

Figure 3. Representation of the logical flow of ideas concerning the whelk/anemone investigation.

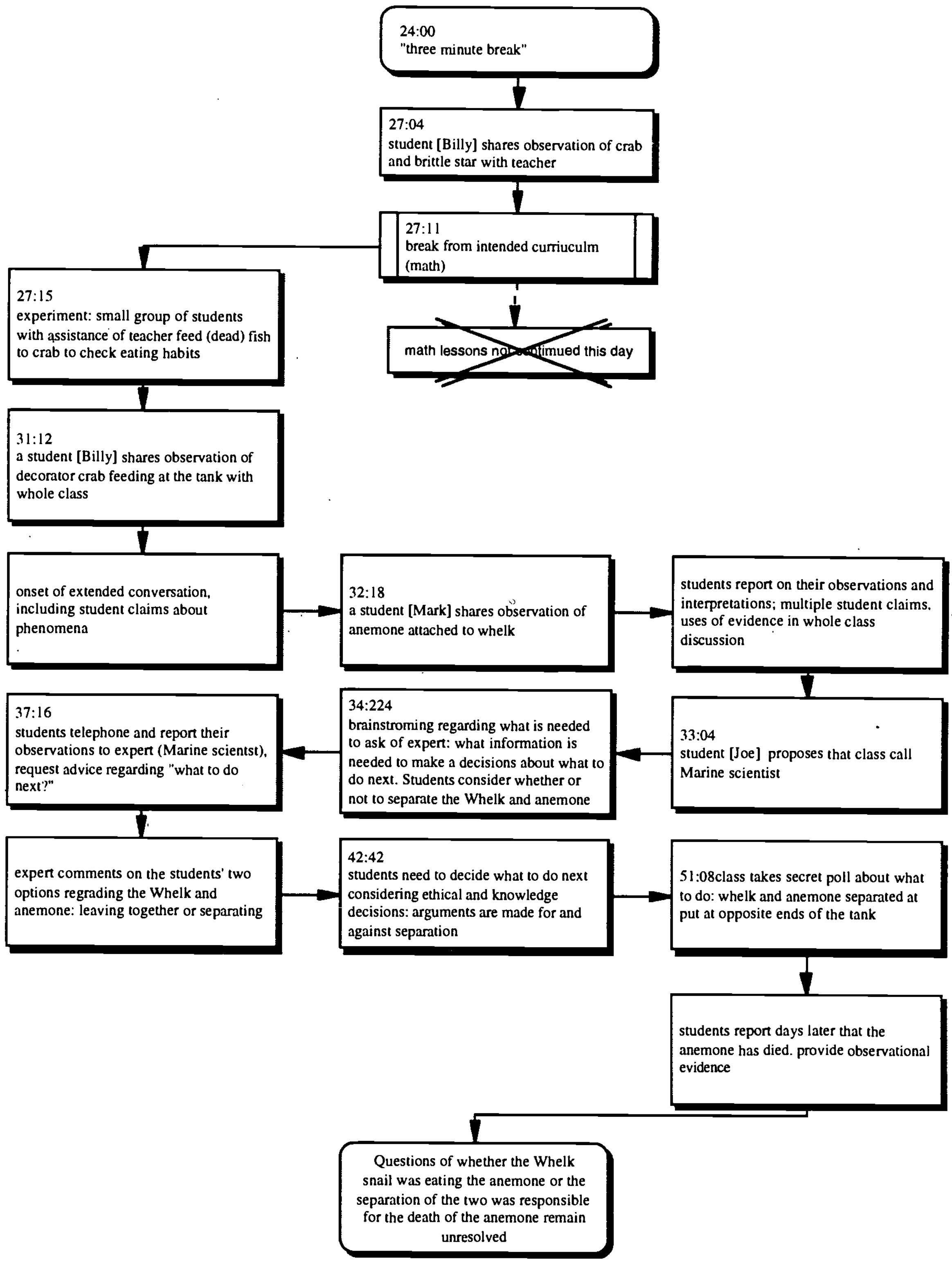

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Figure 4. Transcript segments of several students recommendations and rationales, along with an analysis column showing the referents drawn upon by the students and the knowledge considerations they used in articulating their arguments.

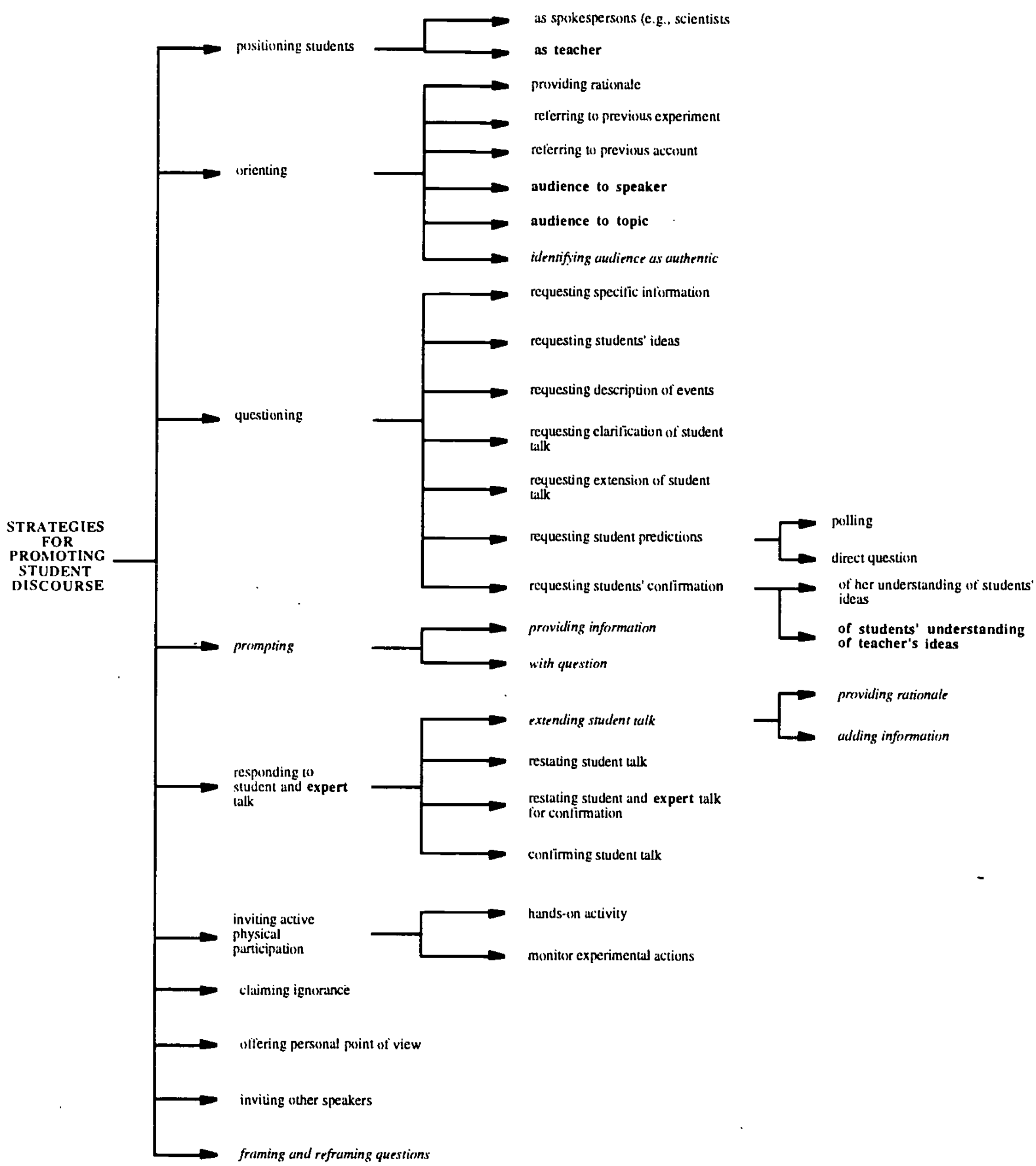
Student	Recommendation for experiment (student talk)	Rationale/reasons (student talk)	Referents, knowledge, considerations (researcher categories)
Tracy	I think that we like should like take them apart	because then we'll never know if it was eating it	knowledge consideration,
Josh	I think we should just leave it um leave it like it is	if we try to separate em it will hurt the anemone and might kill it	ethical consideration
Kathryn	I think we should [separate them] we could um keep them apart so they don't eat each other	because um it would (determine) if one of them was eating each other and so we know like if one of em was eating each other then we could um keep them apart so they don't eat each other	knowledge consideration ethical consideration (we need to act in behalf of another organism)
Tom	[leave them together]	I don't even think... the whelk is eating the anemone because um last time I saw it the anemone wasn't even near its mouth it was like right in the center	location of mouth on whelk in reference to where anemone was situated

		of its back... they stick together so hard you you probably might kill em kill it	ethical consideration
Joe	I think that we should um leave em like um leave em together	cause if we take em apart maybe both of them will die but if you um but if you you have a better chance of um (just maybe) only one of them will die	ethical consideration
Javier	I think um don't separate	em because (he should) get a chance to like um say like cause if one of em dies when we separate em it would be no fair cause it's just like two it's like they're kinda like us... because if one of em dies (and one doesn't) it wouldn't be fair	ethical consideration (we should not act to intervene in nature's ways)

Figure 5. A summary of the similarities and differences between the algae experiment and the whelk/anemone investigation

	Algae experiment (third grade)	Anemone episode (fourth/fifth grade)
Similarities	involved unprecedented science required student decisions about what to do next -- no clear cut steps to follow demonstrated whole class inquiry process drew upon and valued use of expert required work of teacher to make conversation possible evinced teacher's work to provide opportunities for student inquiry	
Differences	intended curriculum manifest in guidesheet	no known guidesheet or intended curriculum
	intended endpoint becomes one of several goals	no known conclusion as intended endpoint of lesson
	students learn and use body of knowledge about how to do investigations	students draw on and use body of knowledge concerning how to do science
	students make key decisions for class activity	students initiate activity for class inquiry
	teacher positions the students as spokespersons	teacher takes up role of student as class diverges from intended curriculum
	teacher uses strategies to promote student discourse	students make observations, make arguments, use evidence, building on social practices established in previous academic year
	Use of expert to request appropriate scientific actions	Use of expert to request knowledge to contribute to purposeful actions to learn about scientific phenomena

Figure 6. Taxonomy of the discourse strategies used by the teacher to promote students "talking science."



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