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Mapping Trade-Offs in Teachers' Integration of Technology-Supported Inquiry in High School Science Classes[1]

William A. Sandoval[2,3] and Kenneth Daniszewski[2]

This paper explores how two teachers concurrently enacting the same technology-based inquiry unit on evolution structured activity and discourse in their classrooms to connect students' computer-based investigations to formal domain theories. Our analyses show that the teachers' interactions with their students during inquiry were quite similar, and each teacher used whole-class discussions as a major vehicle for connecting students' understanding to formal domain theories. Each teacher, however, structured the discourse in these discussions quite differently. We interpret these differences as each teacher navigating a set of trade-offs to balance, on the one hand, opportunities for students to actively develop their own ideas, and on the other, their concerns that students develop normative understandings. We identify several dimensions of trade-offs that emerge from our data, and suggest how teachers' choices on these dimensions shape students' opportunities for learning.

KEY WORDS: discourse analysis; teaching practice; science inquiry; evolution; Lamarckism.

INTRODUCTION

Inquiry-based science teaching demands a set of teaching practices quite different from typical didactic science instruction. Two of the central challenges in teaching science through inquiry are that (a) students' inquiry must productively engage them in exploration and reasoning about central questions in the domain; and (b) students need to be able to generalize specific inquiry experiences to broader, formal domain theories. These challenges reflect a tension in inquiry-based science learning between students' inquiry goals and instructional goals that students master formal domain concepts and theories (Hammer, 1997; Lampert, 1995). This paper examines the efforts of two teachers to address the challenge to connect students' inquiry experiences to broader concepts in the domain of evolutionary biology during a technology-supported unit. This unit focused on developing both students' understanding of evolution by natural selection and their abilities to construct and evaluate scientific explanations (Reiser *et al.*, 2001; Sandoval, 2003). A guiding premise of this work is that students' inquiry experiences must be woven into the regular fabric of classroom activity, by enabling teachers to transform classroom activities that they already use to teach evolution. The idea is to encourage teachers to create a culture of inquiry that permeates all of the activities in their classrooms. Our aim here is to explore how teachers navigate the general tension between open inquiry and content mastery, in terms of their choices for structuring activity and classroom discourse.

We focus our examination of these teachers' practice around three questions. First, what kinds of activities do these teachers use surrounding students' inquiry experiences to support their abstraction of a general understanding of the theory of evolution, and

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[2]Graduate School of Education & Information Studies, University of California – Los Angeles, Los Angeles, California.

[3]To whom correspondence should be addressed; e-mail: sandoval@gseis.ucla.edu

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of scientific argumentation? Second, how do teachers structure classroom discourse within these activities, and how do discourse patterns affect students' opportunities to learn? We are especially interested to identify specific discourse strategies (Gumperz, 1982) that teachers use to shape classroom conversations and document how teachers' discourse strategies affect how students participate and what they say. We argue that in striving to connect students' inquiry to formal science theories, teachers must negotiate a series of trade-offs regarding the kinds of activities they select to supplement inquiry (e.g., labs, discussions). These trade-offs include the way they structure these activities with respect to student participation and the content of the activity, and the extent to which their own discourse strategies support a stance of inquiry and active construction of scientific knowledge versus an orientation toward content mastery.

Below, we briefly explain our use of the terms *activity structure* and *discourse strategies* and their possible relationships to each other. We then review literature related to inquiry teaching practice and suggest that more attention needs to be paid to how teachers work to weave students' inquiry into the formal science curriculum. After describing the context of the study, we present analyses of the activity structures and discourse strategies two biology teachers used to enact the evolution unit in their classrooms. Our discussion maps out some specific dimensions of the trade-offs suggested above as evidenced by these two teachers. We conclude by raising several questions in need of further research.

Activity and Discourse

We use the term *activity structure* to refer to what Erickson (1982) describes as the relation between academic task structures and social participant structures. That is, the way that a particular kind of activity (or task), such as a science lab or a whole-class discussion, is organized sets up particular structures through which students and teachers can participate, both in terms of what students and teachers *do* during an activity and what they *say*. In classrooms, various activity structures afford particular kinds of action, interaction, discourse, and reasoning (Cazden, 1986; Lemke, 1990; Stodolsky, 1988). For example, students in a biology class interact with each other very differently during a lab than during a whole-class discussion, in part because the social arrangements for interaction are very different (i.e., working as a small group to conduct an experiment vs. sitting at desks interacting primarily with the teacher) and because the tasks demands of each activity are very different (conduct an experiment vs. listen and respond to questions from the teacher). As Erickson described, the participants in these activities have more or less understanding about the kinds of roles that they are expected to fulfill. As instruction shifts toward inquiry, teachers in particular may be expected to vary in terms of their ability to weave inquiry experiences into the broader stream of classroom activity and discourse.

Gumperz (1982) describes *discourse strategies* generally to refer to verbal strategies that people employ to understand each other within the context of a particular conversation. We use the term here specifically to connote that in pedagogical discourse teachers organize and shape discourse strategically according to their instructional goals. Teachers strategically ask particular kinds of questions or provide differential responses to students' talk according to their pedagogical focus during interaction (O'Connor and Michaels, 1996; Roth, 1993; van Zee and Minstrell, 1997). Further, teachers can use various repertoires of specific discourse strategies to construct and maintain patterns of discourse in the classroom, such as the typical call-response-evaluation pattern (Cazden, 1986; Lemke, 1990).

Activity structure and discourse strategies are deeply intertwined in that language organizes activity (Vygotsky, 1978), and activity affords and constrains particular patterns of discourse. The ways in which teachers organize both activity and discourse in their classrooms has profound effects on how students come to know and learn a subject (Stodolsky, 1988). In science classes, typical teacher discourse strategies tend to reinforce a view of science as authoritative fact, distancing students from being active constructors of legitimate scientific knowledge (Lemke, 1990). Also, activity structures can work against inquiry by promoting students' rote use of procedures without any particular inquiry goal (Schauble *et al.*, 1995). Thus, analyses of both activity structure and discourse are crucial to understanding how classrooms are constructed and how such constructions shape students' access to learning (Gutierrez, 1994).

Our interest here concerns how teachers use activities and discourse to shape students' understanding of and guide their participation in scientific inquiry. Indeed, learning to inquire as scientists is to learn to appropriate particular kinds of activities (e.g., empirical methods) and ways of talking about natural phenomena (see Kuhn, 1970, and his definition of paradigm). Analyses of discourse are thus fundamental to understanding how teachers support students' inquiry into and learning about science, and what students come to know about a particular science domain and inquiry into that domain.

INQUIRY TEACHING PRACTICES

Although science education reform efforts have been calling for inquiry teaching approaches since the 1960s, such teaching remains rare across the nation's schools (Tobin *et al.*, 1994; Welch *et al.*, 1981). Recent studies of constructivist, inquiry-oriented science classrooms have examined teachers' discourse to understand how teachers support students during their inquiry. Specific strategies that teachers use can include asking questions to focus students' attention on problematic aspects of their inquiry, or expansion questions to push students to articulate their reasoning (Roth, 1993), asking students to elaborate on their rationales for experimental designs (Baumgartner and Reiser, 1998), and modeling for students effective strategies for interpreting data (Tabak and Reiser, 1997). Much of this and similar work (e.g., Hammer, 1997; Krajcik *et al.*, 1998; Polman and Pea, 2001), however, has focused on teacher–student interactions during small-group inquiry activities. There remains a need to examine more closely how teachers contribute to and shape discourse in other classroom activities to help students connect their inquiry experiences to formal domain concepts.

Teachers' discourse strategies can be quite different in whole-class discussions, for instance, than when they are engaged with a small group of students during inquiry (Roth, 1993). For example, teachers may guide students to make their individual findings public, to construct a shared understanding of a specific investigation. Such discussions can provide the basis for connecting those investigations to formal domain theories (Tabak *et al.*, 1998). Whole-class discussions can be an effective means to elicit students' ideas about phenomena and engage them in articulation and justification of their intuitive explanations (van Zee and Minstrell, 1997). These discussions, however, entail a trade-off between valuing students' ideas and guiding them toward an acceptable understanding of content (Hammer, 1997). Here, we explore how teachers use discourse strategies and activity structures to navigate this trade-off.

CONTEXT OF THIS STUDY

In this study we focus on three interrelated questions regarding two teachers' use of various activity structures and discourse strategies to integrate students' computer-based inquiry activities into a coherent unit on evolution. First, what kinds of activities did each teacher use in their classroom to knit a coherent unit together around students' computer-based inquiry? Second, what discourse strategies did each teacher use during these activities to support student learning, about both science content and scientific argumentation? Are these discourse strategies idiosyncratic to each teacher, or are they situational, such that particular activities lend themselves to particular discourse strategies? Finally, how did different activity structures and discourse strategies affect the substance of discourse and student participation?

Participants

Two biology teachers from the same mid-western suburban high school participated in this study, as part of their participation in the BGuILE project (Reiser *et al.*, 2001). Mr Gray, a teacher with 15 years experience, was in his 3rd year of collaboration with us on the project. (Throughout this paper we use pseudonyms to refer to teachers and students.) Mr Gray recruited Mr Brown, a teacher for 6 years, specifically for this study, at the request of the researchers. Each teacher reported during the planning of the unit that they understood and valued the explicit goals of the curriculum: to develop students' abilities to construct causal explanations from data, to promote inquiry process skills, and to use inquiry as a way to learn concepts more deeply.

At the time of the study, Gray and Brown taught in a high school with mostly Caucasian (85%) students in an affluent suburb (1% of students participated in school lunch programs). During this particular school year, Mr Gray was teaching two honors introductory biology classes and Mr Brown was teaching two regular-track introductory biology classes. There were a total of 87 students (44 boys and 43 girls) in the four classes. Students were accepted into the honors class on the basis of a writing assessment not related to biology. Thus, these students may not have known anything more about biology than the regular-track students, although they may potentially have been better writers. On the other hand, they may simply have been more motivated to attend honors classes. It is useful

Table I. Overview of Designed Evolution Unit

# Periods (42 min)	Activity
1	Introduction to Darwin and general theory of evolution
7	Computer-based investigation cycle (Galápagos Finches, GF)
7	Integrative lab and discussion activities, selected by teachers
7	Computer-based investigation cycle (Tuberculosis bacteria, TB)
2	Final discussions of unit

to bear in mind that most of the students in all of these classes were college-bound.

Unit Summary

The BGuILE software is described in some detail elsewhere (Reiser *et al.*, 2001). Table I provides a summary overview of the designed unit intended for this study. Notice from Table I that there was relatively little introduction either to general evolutionary theory or to strategies for conducting inquiry. The senior collaborating teacher, Mr Gray, felt that his prior experiences with this unit suggested that students would be able to jump into the finch investigation without much introduction. Instead, he felt that the time that in prior years had been spent on introductory lab activities could be better spent in discussion after students' investigations. We agreed that more class time for discussions would be important, and felt that given the time constraints faced by each teacher to cover large amounts of content in their courses that this was a reasonable decision.

Within this unit, students had two open-ended inquiry experiences during which they worked in small groups to explore computer-based investigation environments. The first investigation asked students to explain the cause of a catastrophic decline in a population of finches on a small Galápagos island (the GF problem). This is a classic case of documented natural selection (Grant, 1986). The second investigation asked students to explain how the bacteria that cause tuberculosis are able to develop resistance to antibiotics (the TB problem). The GF and TB investigations each occurred over seven class periods, or an entire week of class time. Each of these investigations was designed to follow a particular investigation cycle: framing of the problem and demonstration of software for roughly 1 period; 2 periods of investigation into the problem; 1 period of peer critiques of each group's work to that point; 2 more periods of investigation, geared toward generating and recording explanations for the questions; and 1 final period of peer critiques of each group's final explanations for the problem.

Of the activities planned for this unit, only the computer-based investigations were highly planned by the researchers. The researchers and teachers negotiated the most important goals for the unit, and the research team was very explicit with both teachers that we wanted them to feel that they could be flexible in their selection of activities to connect the computer-based investigations to their ongoing curriculum. Thus, it is inaccurate to conceive of this intervention as a fixed curriculum. It is, by design, underspecified for two reasons. One is that we felt this would make it easier for teachers to integrate into their classrooms, and the other is that we hoped that we could observe such efforts at integration.

Data Sources and Analytic Methods

The data for our comparisons of teaching are approximately 20 h of video recorded in one classroom from each teacher, or approximately 40 h of video overall. Observation classrooms were selected according to their schedule to permit each teacher to be observed. During the computer-based investigations, a single group in each class was recorded. Thus, detailed data of teacher support strategies during specific investigations are limited to each teacher's interaction with these particular groups. Because there were two such investigations in each of two classrooms, we have two cases to draw from for each teacher. When not recording the computer-based investigations, however, a single camera was used to record whole-class activities. These activities occurred mostly in the week between the computer-based investigations. During this intervening week, the teachers were often the locus of activity, or at least quite involved. Thus, during these activities each teacher was more naturally the focus of recording.

Our analyses were guided by Erickson's (1992) technique of microanalysis in which episodes of teacher discourse were identified and subsequently transcribed and analyzed. Our analyses were broadly framed by notions of cognitive apprenticeship (Collins *et al.*, 1989), which suggests modeling, coaching, and scaffolding roles for teachers. We expected, for example, that these teachers acted as coaches during inquiry to guide their students toward employing particular kinds of investigative strategies, or to suggest useful ways to interpret data, and so on. Therefore, the cognitive apprenticeship model was an initial guide to identifying episodes of discourse that might be of interest. That is, we began by asking what kind of modeling or coaching these teachers engaged in. Much of the classroom discourse that seemed interesting, however, did not neatly fall into categories of modeling, coaching, etc. Consequently, our analyses of discourse strategies have predominantly emerged from the data.

As we developed our analyses, we noticed two features of the teachers' talk during computer-based inquiry that significantly altered our analytic focus. First, each teacher seemed to spend very little time with our focal groups. We are unsure whether or not this was typical of their interactions with all groups; they may have avoided the student groups we were recording out of some sense that they would bias our data, we do not know. We only observed that they infrequently interacted with these groups, and each interaction was usually brief. The second aspect of these interactions that we noticed were that the teachers were rather similar in the ways in which they interacted with these groups during their inquiry. Both Mr Gray and Mr Brown commonly asked students to give general progress reports which were sometimes followed up with specific questions to show the teacher data or to more fully explain a claim. Their interactions with these groups were consistent with other research suggesting that teachers guide inquiry projects through refocusing students thinking or prompting them to expand upon their ideas (e.g., Polman and Pea, 2001; Roth, 1993). Therefore, we shifted our attention to Mr Gray's and Mr Brown's discursive strategies during the activities that surrounded these investigations. These are the analyses that we present below.

The identification of specific discursive moves was first coded by the second author, unfamiliar with the larger project of which these data are a part. These moves were iteratively refined in deliberation with the first author, through comparative analysis: as new discursive strategies were identified, previously analyzed events were examined again for evidence of the new strategy. Our aim through this analysis is to develop conjectures about the kinds of discursive strategies teachers use across different contexts to integrate inquiry experiences into the broader "curriculum story" (Gudmundsdottir, 1991).

FINDINGS

Table II summarizes each teacher's enactment of the unit. Because of our interest in these teachers' integration of students' inquiry experiences into the rest of the unit and the similarity of their interactions with students during inquiry, we focus on what each teacher did in their classes between the two computer-based investigations. We first describe differences in the activities each teacher used during this time. Following this description, we examine each teacher's predominant discourse strategies in detail.

Activity Structures

By design, this evolution unit was broken into four parts: (a) the GF investigation; (b) integrative classroom activities, designed by each teacher; (c) the TB investigation; and (d) summary discussions to relate the investigations to each other and to Darwinian theory. The first three phases were each expected to take roughly 1 week, 7 periods according to each class' blocked schedule. The final discussions occurred over the last two periods of the unit.

There is a striking difference between the two teachers' classrooms during the 2nd week of the unit (March 2–6; see Table II). Mr Brown's classes spent almost half of that week, 3 of 7 periods, completing work on the finch investigation. Two additional periods were spent in whole-class discussion. Mr Gray, on the other hand, used most of the 2nd week to engage his students in a variety of lab, small-group, and whole-class activities which he specifically designed to build on and further their explorations into natural selection begun in the finch investigation.

Part of this difference is that Mr Brown's use of intermediate critiques (February 27) interrupted his students' progress through the finch investigation, as designed. Also, Mr Brown was unable to schedule the computer lab for the next period (March 2) and so used that time to have a discussion with his class to review Lamarck's theory of evolution. We point this out to suggest that one of the reasons Brown may have relied so heavily on whole-class discussions during this week is that he had less time to use other kinds of activities, such as labs. Indeed, he had only a single double-period (March 5) in which he could have run any kind of a lab activity at all. Also, Mr Gray had had 2 years in which to refine his approach to this unit, which certainly guided his allocation of time during the three and one half weeks.

Table II. Evolution Units of Each Teacher

Date	Brown	Gray
February 23		GF intro & demo
		GF investigation
February 24	GF intro & demo	GF investigation
	GF investigation	
February 25	GF investigation	GF investigation
		GF investigation
February 26	GF investigation	GF investigation
	GF investigation	
February 27	Cross-group critiques	GF investigation
March 2	Whole-class discussion: Lamarck	Whole-class discussion: review of GF
		Natural selection lab: colored dots
March 3	GF investigation	Small group discussion: sexual selection
	GF investigation	
March 4	Cross-group critiques	Complete natural selection lab
		Labs: evidence for human evolution
March 5	Whole-class discussion: homework review	Animated evolution movie
	Finch migration seatwork	
March 6	TB movie: Brown's and Gray's classes met together	
March 10	TBLAB intro and demo	TBLAB intro and demo
	TBLAB investigation	
March 11	TBLAB investigation	TBLAB investigation
		TBLAB investigation
March 12	TBLAB investigation	Cross-group critiques
	Cross-group critiques	
March 13	TBLAB investigation	TBLAB investigation
March 16	Whole-class discussion: review of finch	Whole-class discussion: comparing problems
		Student panels on "Beak of the Finch"

Note. Most days included a double period for one or the other classroom. Each row represents a single 42-min period. Double periods lasted 85 min.

Our analyses of each class suggested that for both Brown and Gray whole-class discussions were a key vehicle for connecting students' inquiry work to formal domain theories. Indeed, they were the only means in either teacher's classes to develop a public understanding of the important theoretical principles of the unit. Comparisons of Gray's and Brown's whole-class discussions revealed striking differences between the two.

Brown's Discourse Strategies

Mr Brown's predominant connective activity in this unit was whole-class discussion. Of the 5 days in the unit not devoted to computer-based inquiry, 4 of these days included significant amounts of whole-class discussions, 3 of them occurring in the intervening week between computer investigations (March 2, 4, 5, and 16; Table II). Mr Brown initiated these whole-class discussions usually in a fairly didactic way, with the initial discourse resembling the triadic dialogue mentioned earlier: Brown asked a question of a particular student; the student responded; Brown evaluated the response. As Lemke (1990) and others have noted, this is a typical discourse in science classrooms.

During these discussions, however, Mr Brown repeatedly broke out of the typical triadic dialogue and entered into what we call *problematized explanation dialogues*. These were extended dialogues with a single student to construct an explanation for some evolutionary phenomenon. Sometimes these dialogues were related to the finch investigation and sometimes not. In the course of the four major discussions during this unit, two problematized explanation dialogues were explicitly about the finch investigation, and two were hypothetical problems Mr Brown posed to the class. There are several important features of these dialogues that we will discuss through an example momentarily. For now, we point out that once Brown and the class entered into problematized explanation dialogues, they persisted for several minutes, up to half an hour. Thus, within the time frame of this unit, such dialogues were a major vehicle for exploring science content in Mr Brown's classroom.

There may have been many possible events that triggered Brown's use of these dialogues in his classroom, although in our observations dialogues were introduced apparently to engage his students in the day's topic, as opposed, for instance, to any particular voiced misconception from students. For example, during a discussion of Lamarck's theory of evolution on March 2, Mr Brown began by asking the class, generally, to recall three principles of Lamarck's theory. One such principle is the idea of "use and disuse." Lamarck postulated that useful traits are passed on from generation to generation while traits that are not used eventually disappear from a population.

As an illustration of Lamarck's principle, Mr Brown mentioned the human appendix and the fact that it seems to serve no purpose other than to occasionally rupture and make people sick. Mentioning this, Brown posed the class a question.

Brown Now, the question is, if this is the case, we don't use it, most people have a finger shaped size, that's probably about three inches [holding up his pinky], Lamarck would say what would happen to the appendix?

Clark It would disappear.

Brown It would disappear. Well, and we said that seems to make sense, doesn't it? You don't use it, why have it? [several students begin to speak at once, but Brown interrupts]

Brown Ok, I want you to turn to the person next to you and come up with a reason. Why do you still have it? Why don't you get rid of it? [Students begin talking to their neighbors.] Talk, talk, talk.

By posing this question, Brown "problematized" (Hiebert *et al.*, 1996) Lamarck's principle of use and disuse. Mr Brown made the issue concrete. His posing of this problem illustrates several features of his use of these dialogues. First, the question was open-ended and demanded that students generate their own explanation. There is no prescribed answer obvious from the question. Second, the question was posed really without warning, and, although this does not come through merely in the transcript, with a genuine sense of wonder. Why do we still have an appendix? A third crucial aspect of these dialogues was that after posing the question, Brown gave his students time to come up with an explanation before continuing the discussion.

From this posing of the question, Mr Brown then engaged in an extended dialogue with a single student to explain this question.

Brown Ok. Evan?

Evan Like, would be, in order for it to go away, there'd need to be a change in your DNA, and then that mutation has to be passed on, and since there are people now that have no appendix,

Brown umm hmm

Evan They probably have the DNA for no appendix, but in order for it like [inaudible] entire human population everybody has to [trails off]

Notice here that Evan conjectured a causal explanation for how an appendix might disappear from an individual, via mutation in that person's DNA to code for "no appendix," but he did not posit a mechanism for how that change might spread through the population. Brown's murmured assent to Evan's initial conjecture signals both that he was paying attention to Evan and also that Evan should continue. As Evan trailed off, Mr Brown prodded him to develop his explanation further.

Brown So you're saying eventually we'll get rid of it, because this DNA will just become in a lot more people, because those people that don't have appendixes actually reproduce, they have like thousands of kids. You don't have an appendix and you just go out and mate. Your like, "I have no appendix, I got to mate!" [in a louder and dramatic voice].

Evan No. But, like, some [laughs]

Brown I'm just wondering. I've got to watch out for those people. Steer clear. [chuckles in room]

Evan No, but like, more people will undergo that mutation.

Brown Huh?

Evan I think more people will undergo that mutation, like in the future.

Brown So the mutation is actually, that's a mutation that's going to happen more and more?

Evan Maybe.

Mr Brown rephrased Evan's initial claim and, in fact, asserts that Evan claims "eventually we'll get rid of" the appendix; a claim that Evan has not yet made. Evan's initial claim is consistent with a neo-Darwinian explanation that a genetic trait would have to be passed on, and he had not yet said how that might happen. Brown reframed the explanation directly in Lamarckian terms to problematize the issue of selective pressure. He then suggested an absurd causal mechanism to emphasize that Evan had yet to supply one himself. Brown's use of parody during these problematized dialogues was common, and parody appeared to be a technique to push students to think about and articulate causal mechanisms for their claims. Brown's use of these parodies was a way for him to communicate fairly clearly that there was a problem with the current explanation being offered without directly telling students that they were wrong. Brown here did not seem to be making fun of Evan, but of the idea that not having an appendix would dramatically increase a person's sex drive. The conceptual point is that a person's lack of an appendix is insufficient to lead to its disappearance from the human population.

Evan's response was to assert a vague idea of mutation dispersion. As an evolutionary explanation it lacks a key causal feature that there must be some pressure in the external environment that would somehow confer a reproductive advantage on people who did not have an appendix. Instead, he claimed that more people would undergo the mutation. There are two important aspects to Brown's responses to this. First, Brown simply asked "Huh?" to get Evan to repeat his claim. Second, Mr Brown rephrased Evan's claim to clarify that it is about the rate of mutation increasing. This revoicing (O'Connor and Michaels, 1996) is a way to make the "more mutation" conjecture the current topic of public discussion.

Mr Brown then asked Evan, and eventually the entire class, to explain how mutations occur. His goal was to contrast Evan's claim of "evolution through mutation" with the scientific idea that mutation is random. After clarifying that mutations are changes in the nucleotides of DNA, Mr Brown continues.

Brown [Let] me stick with Evan real quickly. So, can I control my mutations?

Evan No.

Brown I would like some serious good mutations. I would like webbed feet, personally. I don't know why. I think I could swim better. [laughter] Faster. And webbed hands. I'd be like aqua guy. [makes some swimming motions.] Cruising through the water.

Evan No.

Brown Now, why? You're saying that this is a mutation that's going to happen more and more and more and more. How do you account for that?

Evan Well, it's like, as people evolve too, cause, say we evolved from some other species, and they needed the appendix, And they needed the appendix. But now we don't.

Again, Brown used a parody to challenge Evan, and this time followed that up with a direct challenge to account for an increased rate of mutation. Brown's parody in this case was to make it clear to students that mutations do not happen purposefully, because of some choice. Brown's challenges, ironically, pushed Evan in this case to seek refuge in terminology, saying that it will just "evolve." At this point then, Mr Brown had seemingly pushed Evan to a limit: he knows that the number of people with DNA for "no appendix" has to increase in order for the presence of appendices in the population to eventually disappear, he suggests an increased rate of mutation as a cause for this, but cannot articulate a cause for that increased rate. Brown's challenges have served to show Evan, and the entire class, that there is a key aspect of the explanation missing: something that could cause a change in the proportion of people without appendices.

At this point in the discussion Mr Brown, without explicitly labeling it as such, introduced an environmental pressure into the discussion. He asked the class what would happen if a fatal appendix-attacking bacteria were to be introduced into the human population. Mr Brown then returns to a drawing on the board he had made earlier, a normal curve of appendix sizes where the low range represented no appendix. Brown explained how only those people at the end would survive such a bacteria, and through mating would spread the no-appendix gene through the population. Mr Brown then returned to Evan to summarize the discussion.

Brown So, Evan, coming back to your point, umm, what's going to happen to the appendix? You say, because we don't use it, generations will get rid of it. What did I just say?

Evan Your saying that through an outside cause it will become . . . it will like, people with that trait will die.

Brown People with that trait will die. People without that trait . . .

Evan Will live. So survival of the fittest.

Brown And that is called, what we talk about, what you guys all throw out there as [writes on overhead] natural selection. Those that have a beneficial trait are selected for.

Thus, at the end Brown led Evan, and by proxy the class, to an articulation of the accepted scientific view of evolution by natural selection. Brown used Evan's articulation of an explanation, and his subsequent confusion about mechanism, as a context for refuting the Lamarckian idea of use and disuse.

Summary

There are several discourse strategies Mr Brown used during these problematized explanation dialogues, as evidenced by the above example. We will briefly summarize them here and return to them in the discussion. First, Brown asked *open-ended questions* that required students to generate explanations in the moment. Second, Mr Brown responded to what students say, either by a *parody challenge* or by asking questions, similar to Roth's (1993) report of focus and elaboration questions. These responses affected the substance of the dialogue by pushing students to more clearly articulate their understanding. They also affected the overall pattern of discourse in the classroom by removing some of Brown's control of the direction of discussion. For example, mutation may not have come into the dialogue about the appendix at all if Evan had not mentioned it. On the other hand, once mentioned it became the focal point of the dialogue. Indeed, Brown's flip of Evan's initial claim is a way for him to maintain control of the topic by framing the problem with the principle of use and disuse. Another defining strategy of these dialogues is that Mr Brown stayed with a *single student* for an extended length of time and conversational turns. This engaged him, and by proxy the whole class, in the construction of an explanation in the terms of a single student. Together with his challenges and parodies, Brown's strategy of dialogue with a single student modeled publicly for the whole class that their knowledge was something to be critically inspected and pushed on to make sure that it makes sense.

Below we consider more explicitly some of the implications of these strategies for what students might have been able to learn from these problematized explanation dialogues and how they helped students to connect their inquiry experiences to the broader conceptual themes of the unit. First, we examine Mr Gray's discourse.

Gray's Discourse Strategies

Mr Gray organized all of the activities in this unit in a format that we have dubbed "do and review." This format consisted of three major phases. The first entailed framing the upcoming activity for students. Framing included Gray setting the agenda for the activity, explicating his expectations for student work, and organizing students into work groups. Gray's discourse during these framing sessions was didactic, with little student commentary. Gray's directions for the finch activity, while explaining a rubric hand-out for that assignment, are typical (unlike our other excerpts, elision below indicates speech cut for brevity, and not pauses in speech):

Gray So, the second part of this . . . assignment is that you have to find the pieces, ok, in the explanation. All right. We've already done that. We just did that in this discussion a little bit. Ok, all right . . . . Who thinks they can do that? [students raise hands]

All right, uh, ok, let's look at this. The beak of the finch. Who remembers, ah, seeing the video . . . of Daphne [the island]? Who can picture that? You saw the whole island, the whole habitat . . . the Grants kept very careful track of all of these birds didn't they? . . . Did they measure their legs, and measure how wide their wings were? Did they keep track of when one got eaten by an owl? Ok, were they recording all this stuff? Ok, they were, detailed information of the lives of about a thousand finches that lived on that island.

Here Gray told his students what he wanted to see in their explanations, "all the pieces." He also gave them a lot of detail about the kind of data they would be able to look at in the GF investigation environment and related that to a video the class had watched earlier that showed the island of Daphne Major and described generally the scientists' work there. As we will see throughout our excerpts of Gray's discourse, these explicit connections to previous work were common. He also used a series of *assent questions* to remind students that they already know, to some extent, what data they can look at. This is one, fairly detailed, example of Gray's framing of activities in his class.

Following framing, students worked autonomously on the assigned activity. Again, this structure was common across all of the activities in this unit, including the computer-based investigations.

We focus here on the final phase of Gray's "do and review" structure, however, which were the whole-class discussions following each activity. As with Mr Brown, Mr Gray's whole-class discussions were the vehicle through which the class' public understanding of the content of the unit was articulated and shared. For Gray, all of the whole-class discussions we observed during this unit were grounded in the just-completed activity, so we term them *debriefing discussions*. A major focus for Gray seemed to be to use such discussions to make sure that students have "gotten" what he felt they should have understood from the activity. These whole-class debriefing discussions occurred on every day not devoted to computer investigation (March 2–5, 16; Table II).

Gray's discourse strategies during these debriefing discussions looked very much like Lemke's (1990) triadic dialogue in that Mr Gray was the primary speaker in the dialogue. We got the sense from these discussions that Gray began a discussion with a clear idea of where the discussion should go, and that the questions he asked of students were intended primarily to determine if they were following his path. His questions generally called for short "fill in the blank" answers, only occasionally followed by requests for more detailed explanations or definitions. The following exchange is typical, during a review of the GF investigation (March 2, Table II).

Gray Ok, ok, so ah, the very last thing is about distribution. Zach's already talked about that actually, he mentioned, ah, variation, ok, has shifted, ok, well, what do you call that?

Eric genetic drift [laughter in the room].

Gray Which is, did you hear what he said? Genetic drift, ok, I have a serious question about that, ok, what is genetic drift?

Eric it's where the, ah, basically it's when a gene pool of various traits shifts towards one way or another so//

Gray //randomly//

Eric //in this case it will shift towards the large beaks and therefore umm the next generation those birds are going to have relatively large beaks and the variance will start spreading, spreading out again as the conditions get favorable.

Gray Ok, well, ah, a couple things. Genetic drift is usually random. Was this random? There was selection pressure here, ok, so, it wasn't a random drift, it was a pressured, a drought driven change, ok, the Grants are saying that's evolution. Ok. That's natural selection occurring. All right.

First, notice that Gray asked simply for a label for the phenomenon that he identified as a shift in variation. Eric offered an answer that Gray doubted, he had a "serious question" about genetic drift being the appropriate explanation for what happened to the finches (it is also interesting that Eric's response generated laughter from the class; perhaps other students knew that was not the answer that Gray was looking for). Gray then asked Eric to define the term "genetic drift" and interjected a key notion into Eric's definition that genetic drift is random.

Interestingly, the latter part of Eric's definition of *genetic drift*, in which he suggested that the next generation of birds will have "relatively large beaks" and that the variance will again spread out as conditions become favorable, captures important aspects of the phenomenon of natural selection. Gray chose not to validate and emphasize these aspects, however, instead emphasizing the distinction that genetic drift is random and that natural selection involves an external pressure, in this case "a drought driven change."

Although this is just a brief example, it captures two important discourse strategies of Gray's. One is that his initial questions usually, albeit not always, asked for short-answer, label-like responses (e.g., the correct answer above would have been "natural selection"). Second, Gray sometimes, but definitely not always, asked students to explain a wrong answer. He seemed to do this most commonly when students used a formal term, like genetic drift, inaccurately.

As the above excerpt suggests, Mr Gray was the dominant speaker during debriefing discussions. He appeared to use these discussions to draw for students the connections they should have made with respect to material they have covered to that point. For instance, as the above discussion progressed, it became apparent that Gray wanted to extend the natural selection explanation for the finches' survival to an exploration of sexual selection, one of the key points being that for beneficial genes to survive in a population, individuals having those genes need to mate:

Gray Now, one thing, and this goes back to the guppy paper, we haven't talked about the guppy problem, ok, but this was something that almost everybody missed in the guppy problem, all right, so you have these 8 finches have survived. A few of them are males, a few females. Well now what? Ok, what happens, now? It rains the next year, now what? Ok, you were telling me guppies survive if they're camouflaged, guppies get to mate if they have big blue spots, so what? What happens now?

Gray explicitly connected the current discussion of the finches to a previous homework problem about camouflage and sexual selection in guppies. He told the class that most of them "missed" an important point about the guppy problem, and his questions asked them to now figure out what that was. When no student responded immediately, Mr Gray continued.

Gray What happens to those, those 8 finches that are flying around? What do they do as soon as it starts raining again? Do they just die and all the finches from Daphne Major become extinct?

Students No.

Gray . . . become extirpated?

Notice here that Gray's question carried with it an implied answer. Do all the finches on Daphne Major become extinct? No. He and the students all knew that. These kinds of leading questions were common in Gray's discourse and suggest that he was trying to guide students step by step to a particular explanation. A student attempted to answer the lingering question of what happens to the finch population during the rainy season.

Lee Well, like a recessive trait may still come out when like smaller seeds are the only ones//

Gray //What do you mean it may come out?

Lee well//

Gray //In them? Those individuals, like, that finch's beak will get shorter? what do you mean?

Lee Like since the seeds, since it takes, ah, it may lower the birds metabolism, like for having, smaller body, so it doesn't need to eat as much, if it's going for smaller seeds doesn't need a body, doesn't need a large beak.

Gray challenged Lee directly, asking him repeatedly to explain what he meant. Notice also that Gray proposed one interpretation of Lee's claim that a recessive trait "may come out" by wondering if individual finches' beaks will shrink. In a way similar to Mr Brown, Gray makes the claim problematic through a concrete example. Lee responded by describing a particular trait that may "come out," but not directly answering Gray's question. Gray ignored the response.

Gray Well you said mate, why do you, what about that?

Lee Like, ah . . .

Gray Who believes these 8 birds might mate now that they've survived and it rains?

Students No.

Gray Who thinks they probably will? Or who thinks this has been so traumatic they're going to swear off sex, because that might weaken them for the next drought?

Students Yeah

Gray who thinks that probably what it is? [sighs] That's a possibility. Did the Grants collect any data on that? What about? Who thinks they're probably going to mate?
[most of the students raise their hands]

Not only did Mr Gray ignore Lee's response, but he in fact claimed that Lee mentioned mating, even though he did not. Thus, Gray refocused the discussion away from recessive traits and back to his original theme, mating. He also repeated his question about mating several times until he got assent from the class. Having finally established that mating is likely to happen, Gray continued.

Gray All right, who, now, what genes are being passed on to the next generation?

Students Big beaks.

Gray So if you go back two years later after the drought and you measure all the beaks what do you think you are going to find? Do you think some variation might have reemerged, like some of these guys were talking about? Yes, ok, but, will the average be bigger than it was before the drought?

Students Probably.

Gray Probably, that's called natural selection, ok, that's called natural selection. What happens if there's another drought? Ok, on this one island, ok, you're going to see these finches have, over the 30 years that the Grants have been watching anyway they've seen changes, significant changes, statistically significant changes. Ok, that's evolution. That's natural selection.

Here Mr Gray constructed step by step, through his questions, the explanation he was trying to lead students toward. He began by reaffirming what students had found out during their finch investigations that the drought caused birds without relatively large beaks to die. He then led students through the idea that only those birds would mate, and therefore the genes that would get passed on to subsequent generations would be for larger beaks, and that if you came back to that island 2 years later you would see that the average beak size was higher than it had been before the drought, and that was natural selection. Throughout this discussion, students' contributions to the dialogue primarily served as foils against which Gray developed his own themes.

Another key to these discussions was that Gray's questions often contained their own answer, and merely required students' assent. The following exchange from the discussion of an animated video of evolution (March 5), was typical:

Gray Do each of those individuals have a different set of chromosomes [pointing to paused video on TV monitor], each of these, as a result of sexual reproduction?

Students Yes.

Gray Just like your brothers and sisters have a different set than you do? Is that a huge change in the amount of variation that's available compared to mitosis?

Students Yeah.

Gray In mitosis are there going to be some mistakes?

Students Yeah.

Gray Ok, once in a while, a new, you know, there's going to be some variation building up. That's going to be pretty slow, isn't it compared to this. So sexual reproduction was a big step, exchange of, ah, gametes, or exchange of DNA.

Mr Gray may have used these questions to ascertain students' current understanding, but it seemed instead that these questions were a means of emphasizing the key points or relationships that students should attend to. Again, students' contributions to the developing explanation were minimal. Gray essentially told students what they should take from these activities, and what connections between activities they should make.

A final prominent discourse strategy in Gray's repertoire during debriefing discussions was science content monologues. He appeared to use these primarily to extend discussion into topics beyond what students had worked on in their prior activities. For instance, near the end of the earlier discussion (March 2) of the relationship between natural selection and sexual selection, Gray eventually explained the key ideas.

Gray So this, sexual, in the case of the finches, this is a really interesting thing. Not all the males got to mate, even though they survived. The ones that did survive, however, they were the only ones who had the option of mating. OK. See, that's not the end of, that's natural selection, where these certain birds survive. Certain traits have survived. That's natural selection. But it's not evolution until that gene, those genes get passed on. Ok. So that's where, in a lot of species, especially the higher organisms, ok, including humans, I think, up until a few hundred years ago, ok, sexual selection is a really important consideration. All right. And that tends to sol to push natural selection in even different direction, or another direction. Because, let's say the really best beaked finch, with a really gigantic beak that could take a tribulus and just crush it, maybe it's an ugly finch, you know, it's an ugly finch, and it doesn't get to mate. So even though it's got the best genes, maybe those don't get passed on. Do you see that? Ok, so it's really, it's pretty complicated really.

Monologues such as this one served a key summative function in Gray's discourse. He could count on students in the class sharing a set of data, on which he imposed a normative explanation. For example, Gray knew that his students had already seen the data about finch survival in the finch investigation, and he could assume that they already knew that not all of the finches mated, as they had read and discussed that part of a book on the problem (Weiner, 1994). He thus succinctly laid out a key tension within evolution that students may not have yet considered, that natural and sexual selection often compete against each other, but that ultimately only genes that get passed from generation to generation influence evolutionary trends.

Summary

Several discourse strategies characterized Gray's debriefing discussions. First, Mr Gray asked primarily *fill-in-the-blank questions* or *assent questions*. These kinds of questions affected discourse in many ways. They did not lead students to articulate their own explanations for concepts under discussion. Rather, fill-in-the-blank questions invited students to provide formal domain terms (e.g., "genetic drift," "recessive trait") as responses, or to simply assent to the obvious answer implied by an assent question. (By the way, although we characterize these latter questions as assent, the implied answer can be no, but students still assent to Gray's implied answer). These kinds of questions served to maintain Mr Gray's control over the direction and substance of the discussion.

Another strategy Mr Gray used to direct discourse was to *directly challenge* inappropriate or inaccurate student responses to nonassent questions. Gray appeared to use these challenges primarily to elicit students' definitions of formal terms. He rarely pushed students very deeply, however, despite the example with Lee above. He either repaired an inaccurate definition himself (as with Eric, above) or called on another student (not shown in our example excerpts, but frequent in these discussions). It seemed to us, however, that the main purpose of Gray's challenges was not to understand and directly confront students' conceptions, but simply to use students' ideas as a foil against which to construct his normative explanation for the lesson's topic. Another strategy that Mr Gray used to control the direction and substance of the discourse during these discussions were *science content monologues*, in which he explicitly laid out for students the thematic ideas that they should take from an activity and the connections between activities that they should make.

These strategies worked together to emphasize Mr Gray's role as a science expert in the classroom and limited student participation in discussions. It is clear by Gray's questions that there are right and wrong answers and that he has a normative view of the conceptual understanding students should gain from their activities. Although it is not fully shown in our excerpts here, a relatively large number of students were called on during a debriefing discussion, on the order of half of the class, and usually for a single turn. Students' self-directed work occurred during the assigned activities, and Gray used these debriefing discussions to explain what he believed students should take from these activities.

DISCUSSION

We have asked three questions in our analyses of these two teachers' practices during this unit. First, we wondered what activity structures each teacher used to weave a coherent unit of evolution around students' computer-based inquiries. We have seen that each teacher made different choices about the kinds of activities to use between the investigations. For both Brown and Gray, however, whole-class discussions played central roles in developing students' understanding of natural selection. Our second and third questions explore the discourse strategies each teacher used during these activities and the effects these strategies had on the substance of discourse and on student participation. In this discussion we articulate what we see as important similarities and differences between these two teachers' discussions, and how those affect students' opportunities to learn about evolution and about scientific argumentation.

We are sympathetic to Hammer's (1997) argument that in teaching through inquiry teachers must manage trade-offs between their goals for students' formal domain mastery and students' inquiry goals. Our analyses of these two teachers' discourse strategies begins to map out a space of trade-offs teachers navigate as they attempt to guide their students to connect their inquiry experiences to formal scientific theories. Our goal here is not to hold up one of Mr Brown or Mr Gray as an exemplar of good teaching at the expense of the other. Rather, we wish to try to understand how each teacher's decisions within a set of trade-offs shape the discourse that occurs in their respective classrooms, and how that discourse affects what students can learn from these discussions. We close by suggesting some implications for inquiry-based science teaching and questions in need of further study.

Mapping the Space of Trade-Offs

Much of the previous work into how science teachers manage the above trade-off in inquiry-based approaches has focused on inquiry activities, i.e., those times when students are actively engaged in self-directed inquiry (Baumgartner and Reiser, 1998; Hammer, 1997; Roth, 1993). Our analyses here extend that work by examining how these two teachers attempt to integrate such inquiry experiences into the rest of a curricular unit. If we view the general trade-off between student-directed inquiry and formal domain learning as bounding a general "problem space" for teachers' decision making (Lampert, 1995), then we have seen here specific trade-offs that Brown and

Table III. Dimensions of Trade-Offs in Orchestrating Class Discussions

	Mr Brown	Mr Gray
Purpose of discussion	Exploration	Review
Locus of ideas	Students	Formal
Locus of control	Student	Teacher
Teacher role	Guide	Authority
Student participation	Depth	Broadly superficial

Gray negotiate within that space. Specifically, Brown and Gray negotiate trade-offs along several dimensions summarized in Table III. Mr Brown's discursive strategies framed his discussions as explorations of students' ideas and were characterized by him guiding particular students' development of their ideas in depth. Mr Gray organized his discussions as reviews of target formal conceptions in which he maintained authoritative control and student participation was broad but superficial.

Exploration Vs. Review

One key difference between the discussions in Brown's and Gray's classes that may explain some of the differences in their discourse is the role that discussions seemed to play in developing content within the unit. Mr Brown's problematized dialogues appeared to be a means for developing new content in the unit. In the appendix dialogue, for example, although the discussion is in some ways a review of a previous lecture or textbook reading (we are not sure) of Lamarck's theory, the appendix problem itself is novel to these students. It provides a new context for them to develop explanations within the evolutionary framework that they have been working for the last week to understand. Because the problem is new, Brown may have more incentive to engage students in a more openly inquiry-oriented stance, because it provides his students with more opportunity to apply the theory of natural selection.

On the other hand, Gray's discussions are always grounded in and make frequent reference to the prior activities that students have conducted during the unit. In this unit, Gray's whole-class discussions always reviewed the immediately preceding activity. Gray may thus have good cause to expect that his students have already engaged in some active construction of their own understanding of the problem at hand, and see his role as providing them with his expert view. Gray's grounding of his debriefing discussions in prior activity provides him with concrete points of reference on which to hang a coherent conceptual framework for the domain. Thus, although his approach may be didactic, he explicitly tries to connect activities in the unit together, much more than does Brown.

Student Vs. Formal Ideas

Mr Brown used problematized dialogues to elicit student thinking about evolution and his discourse strategies during these dialogues pushed students to clarify their articulations of their own understanding. His open-ended questions demanded generative explanations from students, and the subsequent dialogue centered on developing a single idea in the terms offered by the student engaged. His discourse strategies lend credence to student thinking, simply by virtue of his willingness to devote large amounts of class time to their ideas. An advantage of these extended dialogues is that through them Brown can model for students how they can inspect their own knowledge and develop their ideas. A potential disadvantage, however, is that Brown's commitment to engaging individual students in extended dialogue sometimes prevented him from explicitly connecting their ideas to formal theory. Although in our example above he was able to move the class to an explanation of the hypothetical disappearance of the appendix in terms of natural selection, he sometimes ran out of time to provide such a normative recapitulation of the discussion.

Mr Gray on the other hand clearly used his debriefing discussions to try to ensure that students "get it." Where "it" is the normative (i.e., currently accepted) scientific account of evolution. His elicitation of student thinking generally consisted of checking that they were following the discussion, and his delivery of thematic content is, well, just that delivery. His apparent focus on ensuring that students understand the accepted scientific view may explain why he rarely directly responded to or validated what students said during the discussion (e.g., ignoring the part of Eric's definition of *genetic drift* that captured important aspects of natural selection).

Student Vs. Teacher-Directed Discussion

Much of the substance of discussions in Brown's class is generated by students, whereas this is not the case in Gray's class. Although our excerpts can only hint at this, Gray's discussions display a definite path and he controls the pace of how that path is traveled. Brown, on the other hand, really turns over most of the substantive talk to students, acting mostly as an evaluator of what students say and refocusing the discussion as appropriate. In Gray's class, students are not really substantive contributors to the discussion. Instead, they are asked simply to assent to Gray's explanation or to fill in the blanks of minor points and labels along the way.

Still, it is important to realize that both of these teachers are ultimately in control of these discussions. In Gray's case, it is clear how his discourse strategies support his control. In Brown's case it may not be so obvious. Regardless, as shown above, Brown is able to refocus problematized explanation dialogues by asking focus or elaboration questions or, as in the case of the appendix-eating bacteria, changing the terms of the problem under discussion. Both Brown and Gray freely rephrased student contributions to reflect a meaning that could move discussion toward their desired ends, even putting words into students' mouths. Brown's focus on a single student at a time may well contribute to his ability to manage the direction of the dialogue, rather than having to attend to and selectively respond to several students' ideas at once (cf. Hammer, 1995).

Teacher as Guide Vs. Authority

Given that Mr Gray was the primary voice of explanations in his discussions, it is clear that he was the scientific authority in his class. Mr Brown's authority was less overt, and he placed himself more in a role of guide or critic. Gray maintained his authority in several ways. First, as already noted, he did not ask students to substantively contribute to discussions. Second, when he did ask questions he rarely clearly validated a response. One way he made clear his disagreement with a student was to directly challenge their statement, or keep asking a question until he got the answer he wanted. Another way he signaled disapproval, which we have not shown but was common, is that he simply called on another student. Finally, Mr Gray was always the one to summarize the normative explanation, through one of his monologues.

Mr Brown, just as clearly, was pushed into a less overt expertise role. He must be if he was to sustain students' engagement in dialogue. If he were to tell students they were clearly wrong, then they would lose interest in the dialogue. Why persist in generating ideas if they are routinely shot down? Still, Brown was ultimately the authority of what counted as a good explanation. He ratified good and bad explanations through his explicit validations and through his parody challenges. Brown also was the sole arbiter of when the dialogue was over, thus tacitly signaling when the right answer had been achieved.

We stress that being the science authority is not inherently a bad role for either teacher to assume. On the contrary, students relied on Brown and Gray to represent the scientific community and its standards for acceptable knowledge and explanation. The dilemma for Brown and Gray is that the ways in which they wield their authority potentially affect how their students see themselves in relation to science, as legitimate constructors of scientific knowledge. Arguably, Brown's discourse strategies are more likely than Gray's to communicate to his students that their ideas are valuable scientific ideas and that ideas are accepted through their ability to stand up to or respond to criticism, rather than because they are authoritatively ratified.

In-Depth Vs. Broad Student Participation

Mr Brown's problematized dialogues engaged few students in active discussion, but those that were involved participated in great depth. Mr Gray's debriefing discussions involved many students in the discussion, although minimally. On the face of it, broad and in-depth participation would be ideal, as seen in Hammer's (1995) inquiry-oriented physics discussion. On the other hand, Brown's engagement with a single student at a time allowed him to more closely manage the discussion while actively soliciting and developing student reasoning.

Of course, students may participate without being active discussants, simply by listening. Our data is inconclusive as to whether students in either teacher's class were more or less attentive than in the other. Certainly, in Gray's class students had an incentive to pay attention as it was highly likely that they would be called on at some point. Students in Brown's class may not have had this incentive. Indeed, it may be the case that some students in Brown's class were never engaged in problematized dialogue, although we cannot say from our data.

Our position is not that there is an a priori preference that either of these teachers be on one side of these dimensions or another. Also, it is certainly possible that there are other dimensions of trade-offs that we have not characterized here. With respect to these articulated trade-offs, however, we argue that they have different implications for the structure and substance of discourse in each of these classrooms. Brown and Gray both appear to endeavor, through these discussions, to help their students construct a public understanding of what they see as the key conceptual elements in the theory of natural selection. Students in Brown's class may find these dialogues more accessible as they are carried out in the terms of a peer, whose thinking they may largely share. Students in Gray's class, meanwhile, get an explicit, articulated formal conceptual framework with which to, potentially, make sense of their experiences during the unit. In our view, both of these aspects of discussion are valuable. With respect to what students learn about natural selection, these differences may not have much influence.

These differences in discursive strategies should have greater influence, however, in what students are likely to learn about the nature of scientific inquiry. Although our data are inconclusive on this point, Mr Brown's discourse strategies are more aligned than Mr Gray's with reform ideas about the role that students should play in scientific inquiry. Mr Gray's authoritative stance to formal disciplinary ideas seems to undercut students' inquiry experiences. That is, it is quite possible, and perhaps likely, that students in Mr Gray's classes would maintain beliefs that scientists have all the right answers, as embodied by Mr Gray, and their job as students is simply to figure those ideas out for themselves. As science education researchers examine teacher practices more closely, especially teachers' efforts to adopt inquiry-oriented teaching approaches, the trade-offs we have laid out here point to specific dimensions of classroom discourse that should be systematically investigated for the effects they have on students' learning of scientific ideas and their beliefs about the nature of science.

Limitations, Implications, and Open Questions

We are careful to withhold judgments of the efficacy of either Brown's or Gray's discourse strategies, because there are some important limitations to these data. Primary among these is that there are other sources of data that we would have wished to collect had this study been designed originally as a study of teaching practice, rather than student learning. We have only sparse anecdotal data concerning each teacher's goals for this unit, beliefs about their students, about science and science learning, and about biology. We have no data on their knowledge of biology or evolution, or their own abilities to engage in scientific inquiry. Future studies should include such data, as well as using video sources to prompt teachers to explicate their reasoning during specific instructional episodes. Another limitation to our analyses is that our student performance measures do not show any significant differences by teacher (Sandoval and Morrison, 2003; Sandoval and Reiser, 2004). Of course, it may simply be that our measures of students' explanations do not capture aspects of learning that are influenced by these discussions. It is also possible that the scaffolds for student performance in the BGuILE software environments outweigh any differences in each teacher's discussions, at least with respect to our measures.

On its face, the space of trade-offs we have mapped here seems generic to inquiry approaches and not particularly related to technology. Yet, projects such as this one develop technological supports for inquiry with tacitly embedded notions of the epistemology of inquiry (Chinn and Malhotra, 2002), and assumptions about appropriate pedagogy. As we discussed at the start of this paper, inquiry teaching is rare and it is likely that teachers could find the task of integrating inquiry technologies into their instruction difficult. It is also likely that teachers' pedagogic goals could be at odds with the tacit assumptions of technology designers. Indeed, we suggest that this might be the case with Mr Gray here.

Consequently, our analyses suggest implications for inquiry-based science teaching and technologies developed to support inquiry. Chief among these is that teachers may require additional support to effectively integrate novel inquiry environments into their regular classrooms. The loose structure of our curriculum here was inspired by a deep respect for teachers as experts, but may have underestimated the gap between a pedagogy of open inquiry and the teachers' views of pedagogy. No doubt, appropriate curricular materials that can suggest activities, activity structures, and discourse strategies could be helpful to many teachers (e.g., White and Frederiksen, 1995). Still, this will not relieve teachers from the fundamental demands of making decisions in the moment, in their classrooms, to negotiate the trade-offs that seem to inhere to inquiry-based teaching. What we need, researchers and teachers, are better models for characterizing effective decision making in a variety of inquiry contexts. This paper is an attempt to extend earlier work in that regard (Baumgartner and Reiser, 1998; Hammer, 1995, 1997).

Fundamental to any such models, however, is a connection between inquiry teaching practices and student learning that current work, including this one, lacks. In focusing on discourse, we and others have illuminated many aspects of how scientific inquiry is conducted in science classrooms and organized by science teachers. A missing piece of the puzzle, however, is how different activity structures and discourse strategies contribute to students' learning, as evidenced by something other than students' contributions to the discourses studied. This is not to devalue the study of classroom discourse, but simply to point out that there is a useful connection to be made between classroom discourse practices and student performance. This connection is especially apt in light of the fact that students and teachers are not assessed by what students say during class discussions but by how well students perform on assessments.

Ultimately, we argue that analyses such as ours here and others cited above should be springboards to research that integrates inquiry teaching practices directly to assessments of student learning and performance from inquiry. Only this kind of integrated research can inform designs of learning environments that will support students and teachers as active inquirers.

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