Teachers' Discourse Strategies for Supporting Learning Through Inquiry

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Abstract

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 issues in the domain; and b) students need to be able to generalize such 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. This paper explores how two teachers concurrently enacting the same inquiry-based unit on evolution structure activity and discourse in their classroom activities to connect students' computer-based inquiry experiences to formal domain theories. our analyses shows that each teacher uses whole-class discussions as a major vehicle for connecting students' understanding to formal domain theories. Each teacher, however, structures the discourse in their 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 understandings, and on the other, their concerns that students' develop normative understandings of the theory of natural selection. We identify several dimensions of trade-offs and suggest how each of these teachers' choices on these dimensions shapes discourse, and thus students' opportunities for learning, within their classrooms.

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 issues in the domain; and b) students need to be able to generalize such 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). Over the last few years, the BGuILE project has been developing software-based guided inquiry environments to productively engage high school students' explorations into key concepts of evolution by natural selection (Sandoval & Reiser, 1998; Tabak, Smith, Sandoval, & Reiser, 1996). These software learning environments guide students in productive investigation of key evolutionary principles.

This paper examines the efforts of two teachers to address the second challenge mentioned above, connecting students' inquiry experiences to broader concepts in the domain of evolutionary biology, when enacting a BGuILE unit on evolution. This unit is focused on developing both students' understanding of evolution by natural selection and their abilities to construct and evaluate scientific explanations (Sandoval & Reiser, 1997). 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 (Tabak & Reiser, 1997a). The idea is to encourage teachers to create a culture of inquiry that permeates all of the activities in their classrooms.

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 of scientific argumentation? More crucially, how are such activities structured to support these generalizations, and to sustain a "culture of inquiry" in the classroom? 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 discourse during classroom activities and document how teachers' discourse strategies affect how students participate and what they say. Our third broad question is to ask how activity structures and discourse strategies are related. How does the structure of a particular activity constrain or afford different discourse strategies? Alternatively, discourse strategies may be idiosyncratic to each teacher, across whatever activity structures they use in their classrooms.

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 present study, we present analyses of the activity structures and discourse strategies two biology teachers use to enact the BGuILE 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 the ways that a particular kind of activity, such as a science lab or a whole-class discussion, sets up particular participation structures for students and teachers, 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 vary 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).

Gumperz (1982) describes *discourse strategies* generally to refer to verbal strategies that people engaged in conversation 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 discussion. 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; what Lemke, 1990 calls triadic dialogue).

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 (Lemke, 1990; Stodolsky, 1988). With respect to inquiry, teachers' discourse strategies can reinforce a view of science as authoritative fact, distancing students' from being active constructors of legitimate scientific knowledge. Also, activity structures can work against inquiry by promoting students' rote use of procedures without any particular inquiry goal (Schauble, Glaser, Duschl, Schulze, & John, 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 and 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 in 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, Tippins, & Gallard, 1994; Welch, Klopfer, Aikenhead, & Robinson, 1981). Several 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 & Reiser, 1998); and modeling for students' effective strategies for interpreting data (Tabak & Reiser, 1997a). Much of this and similar work (e.g., Hammer, 1997; Krajcik, Blumenfeld, Marx, Bass, & Fredricks, 1998), 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; Tabak & Reiser, 1997b). Tabak & Reiser (1997b) have documented, for example, how teachers 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. 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 (Minstrell & Stimpson, 1996). These discussions, however, entail a trade-off between valuing students' ideas and guiding them towards an acceptable understanding of content (Hammer, 1997).

Tabak & Reiser (1997a; 1999) have begun to examine how teachers using BGuILE materials integrate computer-based investigation with other classroom activities such as labs and discussions to help their students articulate general understandings about evolution from their specific inquiry experiences. Here, we build on that work to explore how discourse strategies and activity structures in whole-class activities influence student participation in the discourse, what the discourse is about, especially whether it is focused on biology content or scientific argumentation practices, and what kinds of scientific explanations get constructed in the classroom.

Context of this Study

In the present 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 does each teacher use in their classroom to knit a coherent unit together around students' computer-based inquiry? Second, what discourse strategies does each teacher use during these activities to support student learning, both about science content and about 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 do different activity structures and discourse strategies affect the substance of discourse and student participation?

Participants

Two biology teachers from the same Midwestern suburban high school participated in this study, as part of their participation in the BGuILE project. Mr. Goodson[1], a teacher with 15 years experience, was in his third year of collaboration with us on the project. Mr. Goodson recruited Mr. Burns, 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.

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[1] Throughout this paper we use pseudonyms to refer to teachers and students.

Goodson and Burns teach in a high school with mostly Caucasian (85%) students of high socioeconomic status (1% of students participate in school lunch programs). During this particular school year, Mr. Goodson was teaching two honors introductory biology classes and Mr. Burns was teaching two regular-track introductory biology classes. Each of these four classes had approximately 25 students enrolled at the start of this study. Students were accepted into the honors class on the basis of a writing assessment not related to biology. Thus, these students may not know anything more about biology than the regular-track students, although they may potentially be better writers. On the other hand, they may simply be more motivated to attend honors classes. It is also useful to bear in mind that most of the students in all of these classes are college-bound.

Unit Summary

We have previously described the BGuILE software in some detail (Sandoval & Reiser, 1997; Tabak, et al., 1996). Table 1 provides a summary overview of the designed unit intended for this study.

Table 1: Unit Overview

# Periods (42 min.)	Activity
1	Introduction to Darwin and general theory of evolution
7	Finch investigation cycle
7	Lab and discussion activities
7	TB investigation cycle
2	Final discussions of unit.

Notice from Table 1 that there was relatively little introduction either to general evolutionary theory or to strategies for conducting inquiry. The senior collaborating teacher, Mr. Goodson, 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 (for a somewhat different version of the BGuILE curriculum, see Tabak & Reiser, 1999).

The finch and TB investigations occurred over seven class periods, or an entire week of class time. Each of these investigations is 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 choosing and recording explanations for the questions; and 1 final period of peer critiques of each group's final explanations for the problem.

Method

These classroom trials were originally designed to understand how this unit, and especially software scaffolds, supported students' learning about evolution and scientific explanation, reported elsewhere (Sandoval & Reiser, in preparation). Our data for these comparisons of teaching are approximately twenty hours of video recorded in one classroom from each teacher, or approximately 40 hours of video overall. During the computer-based investigations, a single group in each class was recorded. Thus, our knowledge of teacher support strategies during specific investigations is 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 the otherwise 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. Consequently, most of the analyses we report below focus on this intervening week.

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 have been broadly framed by notions of cognitive apprenticeship (Collins, Brown, & Newman, 1989), which suggests modeling, coaching, and scaffolding roles for teachers. We consider, for example, that these teachers act as coaches during inquiry to guide their students towards 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 did these teachers engage 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. Analyses have been conducted primarily by the second author, unfamiliar with the larger project of which this data is a part, in collaboration with the first author, who observed these classrooms during the study. Transcripts have been jointly analyzed to attempt to categorize particular teacher utterances as instances of a particular discourse strategy. We use this term to convey that much of what teachers say in the classroom, both the questions that they ask and the evaluations or responses they make to student talk, have strategic, instructional purposes. Our analyses suggest that these teachers use sets of discourse strategies during particular episodes, similar to Lemke's (1990) *triadic dialogue* (teacher question, student response, teacher evaluation) and *joint construction*.

Central to our analysis then is that different discourse strategies are employed by teachers to achieve different goals. For our analyses, we are interested in two such broad goals. First, how do these teachers support their students' learning of important scientific conceptions, in this case pertaining to the theory of natural selection and its application to specific phenomena? Second, how do these teachers support their students' development of epistemological understanding of the construction and evaluation of scientific explanations? A related issue is that different activities lend themselves to different kinds of teacher roles, which may thus constrain discourse strategies in particular ways. Thus, one of the aims of our analysis here is to understand whether teachers employ different discourse strategies in different activity contexts, or if they instead have preferred discourse modes that they use consistently across activities. Indeed, if this were the case it may be that teachers organize activity in their classrooms to support their use of their preferred mode of discourse.

RESULTS

Table 2 summarizes each teacher's enactment of the BGuILE unit. Because of our interest in these teachers' integration of students' inquiry experiences into the rest of the unit, our analyses in this section 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 three parts: a) the finch investigation; b) integrative classroom activities, designed by each teacher; and c) the TB investigation. Each component was expected to take roughly one week, 7 periods. Additionally, we expected that following the TB investigation there would be a few periods devoted to guiding students to relate all of their previous experiences in the unit to the broad theory of evolution by natural selection.

There is a striking difference between the two teachers' classrooms during the second week of the unit (March 2 – 6; see Table 2). Mr. Burns' 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. Goodson, on the other hand, used most of the second 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. Burns' use of intermediate critiques (Feb. 27) interrupted his students' progress through the finch investigation, as designed. Also, Mr. Burns was unable to schedule the computer lab for the next period (Mar. 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 Burns' 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 (Mar.

5) in which he could have run any kind of a lab activity at all. Also, Mr. Goodson had had two 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 2: Evolution units of each teacher

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

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

Our analyses of Goodson's various activities during this unit revealed that all of them followed a similar structure, which might be dubbed "do and review". For each activity in the unit, including, in fact, the finch and TB investigations, Goodson began by framing the particular activity for students, including what he expected them to do, and what he wanted them to learn from the activity. This initial setup was followed by students working fairly autonomously on the particular task, usually in small groups but occasionally singly. This work was then followed by a review discussion.

Our analyses of whole-class activities in each class suggested that for both Burns and Goodson whole-class discussions were a key vehicle for connecting students' understandings to formal domain theories. Comparisons of Goodson's "review" discussions with the whole-class discussions in Burns' class revealed striking differences between the two. Therefore, the remainder of our analyses focus on these whole-class discussions and the discourse strategies Burns and Goodson employ during them. Another reason for focusing closely on these discussions is that they are the only vehicle in either class for the development of public understanding of the important theoretical principles of the unit.

Burns' discourse strategies

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

During these discussions, however, Mr. Burns repeatedly breaks out of the typical triadic dialogue and enters into what we call *problematized explanation dialogues*. These are extended dialogues with a single student to construct an explanation for some evolutionary phenomenon. Sometimes these dialogues are 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. Burns 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 Burns and the class entered into problematized explanation dialogues, they persisted for several minutes, up to a half an hour. Thus, within the timeframe of this unit, such dialogues were a major vehicle for exploring science content in Mr. Burns' classroom.

We did not observe Mr. Burns to start a class discussion with a problematized explanation dialogue. Instead, whole class discussions would begin in the typical triadic mode, with Mr. Burns setting the agenda for the discussion. In each discussion we observed, however, Burns very shortly entered into problematized dialogue. There may be many possible events that trigger Burns' use of these dialogues in his classroom, although in our observations dialogues are 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. Burns 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. Burns mentions the human appendix and the fact that it seems to serve no purpose, other than to occasionally rupture and make people sick. Mentioning this, Burns poses the class a question:

Burns	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, Lamarck would say what would happen to the appendix?
Clark	It would disappear.
Burns	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 Burns interrupts]
Burns	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, Burns has "problematized" (Hiebert, Carpenter, Fennema, Fuson, Human, Murray, et al., 1996; Roth, 1993) Lamarck's principle of use and disuse. Mr. Burns has made the issue concrete. His posing of this problem illustrates several features of his use of these dialogues. First, the question is open-ended and demands that students generate their own explanation. There is no prescribed answer obvious from the question. Secondly, the question is 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 is that after posing the question, Burns gives his students time to come up with an explanation before continuing the discussion.

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

Burns	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,
Burns	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 conjectures 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 does not posit a mechanism for how that change might spread through the population. Burns' murmured assent to Evan's initial conjecture signals both that he is paying attention to Evan and also that Evan should continue. As Evan trails off, Mr. Burns prods him to develop his explanation further:

Burns	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]
Burns	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.
Burns	Huh?
Evan	I think more people will undergo that mutation, like in the future
Burns	So the mutation is actually, that's a mutation that's going to happen more and more?
Evan	Maybe.

Mr. Burns rephrases Evan's initial claim, and then suggests an absurd causal mechanism to emphasize that Evan has yet to supply one himself. Burns' use of parody during these problematized dialogues is common, and parody appears to be a technique to push students to think about and articulate causal mechanisms for their claims. Burns' use of these parodies is a way for him to communicate fairly clearly that there is a problem with the current explanation being offered without directly telling students that they are wrong. Burns here does 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 is to maintain this 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 claims that more people would undergo the mutation. There are two important aspects to Burns' responses to this. First, Burns simply asks "Huh?" to get Evan to repeat his claim. Second, Mr. Burns rephrases Evan's claim to clarify that it is about the rate of mutation increasing.

Mr. Burns then asks Evan, and eventually the entire class, to explain how mutations occur. His goal is 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. Burns continues:

Burns	[Let] me stick with Evan real quickly. So, can I control my mutations?
Evan	No.
Burns	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.
Burns	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, Burns uses a parody to challenge Evan, and this time follows that up with a direct challenge to account for an increased rate of mutation. Burn's parody in this case is to make clear to students that mutations do not happen purposefully, because of some choice. Burns' challenges, ironically, push Evan in this case to seek refuge in terminology, saying that it will just "evolve". At this point then, Mr. Burns has seemingly pushed Evan to a limit: he knows that the number of people with the 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. Burns' 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. Burns, without explicitly labeling it as such, introduces an environmental pressure into the discussion. He asks the class what would happen if a fatal appendix-attacking bacteria were to be introduced into the human population. Mr. Burns then returns to a drawing on the board he had made earlier, a normal curve of appendix sizes where the low range represents no appendix. Burns explains 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. Burns then returns to Evan to summarize the discussion:

Burns	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.
Burns	People with that trait will die. People without that trait…
Evan	Will live. So survival of the fittest.
Burns	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 Burns leads Evan, and by proxy the class, to an articulation of the accepted scientific view of evolution by natural selection. Burns uses 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. Burns uses 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, Burns asks *open-ended questions* that require students to generate explanations in the moment. Second, Mr. Burns responds to what students say, either by a *parody challenge* or by asking questions, similar to Roth's (1993) report of focusing and elaboration questions. These responses affect the substance of the dialogue by pushing students to more clearly articulate their understanding. They also affect the overall pattern of discourse in the classroom by removing some of Burns' 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.

Another defining strategy of these dialogues is that Mr. Burns stays with a *single student* for an extended length of time and conversational turns. This engages 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, Burns' strategy of dialogue with a single student models publicly for the whole class that their knowledge is 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 be able to learn from these problematized explanation dialogues and how they help students to connect their inquiry experiences to the broader conceptual themes of the unit. First, we examine Mr. Goodson's whole-class discussions.

Goodson's discourse strategies

As mentioned, Goodson organized all of the activities in this unit in a format that we have dubbed "do and review". This format consists of three major cycles. The first entails framing the upcoming activity for students. Framing includes Goodson setting the agenda for the activity, explicating his expectations for student work, and organizing students into work groups. Goodson's discourse during these framing sessions is didactic, with little student commentary. Goodson's directions for the finch activity, while explaining a rubric hand-out for that assignment, are typical[2]:

> Goodson 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 Goodson is telling his students what he wants to see in their explanations, "all the pieces." He is also giving them a lot of detail about the kind of data they will be able to look at in the finch investigation environment and relates 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 Goodson's discourse, these explicit connections to previous work are common. He also uses 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 Goodson's framing of activities in his class.

Following framing, students then work fairly autonomously on the assigned activity. Again, this structure is common across all of the activities in this unit, including the computer-based investigations. We wish to focus here on the final phase of Goodson's "do and review" structure, however, which are the whole-class discussions following each activity.

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[2] In most of our quotes of student and teacher talk here, ellipses represent pauses rather than elision. In this case, we make an exception and ellipses here reflect portions of talk omitted for brevity.

As with Mr. Burns, Mr. Goodson's whole-class discussions are the vehicle through which the class' public understanding of the content of the unit is articulated and shared. For Goodson, 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 Goodson seems to be to use such discussions to make sure that students have "gotten" what he feels they should have understood from the activity. These whole-class debriefing discussions occurred on every day not devoted to computer investigation (Mar. 2 – 5, 16; Table 2).

Goodson's discourse strategies during these debriefing discussions looks very much like Lemke's (1990) triadic dialogue, in that Mr. Goodson is the primary speaker in the dialogue. We get the sense from these discussions that Goodson begins a discussion with a clear idea of where the discussion should go, and that the questions he asks of students are intended primarily to determine if they are 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 finch investigation (Mar. 2, Table 2):

Goodson	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].
Goodson	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 were the, ah, basically it's when a gene pool of various traits shifts towards one way or another so //
Goodson	//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.
Goodson	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 Goodson asks simply for a label for the phenomenon that he has identified as a shift in variation. Eric offers an answer that Goodson doubts, he has a "serious question" about genetic drift being the appropriate explanation for what happened to the finches (it's also interesting that Eric's response generates laughter from the class; perhaps other students also know that's not the answer that Goodson is looking for). Goodson then asks Eric to define the term "genetic drift" and interjects 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 suggests 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. Goodson chooses 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 Goodson's. One is that his initial questions usually, albeit not always, ask for short answer, label-like responses (e.g., the correct answer above would have been "natural selection"). Second, Goodson sometimes, but definitely not always, will ask students to explain a wrong answer. He seems to do this most commonly when students use a formal term, like genetic drift, inaccurately.

As the above excerpt suggests, Mr. Goodson is the dominant speaker during debriefing discussions. He appears to use these discussions to draw for students the connections they should be making with respect to material they have covered to that point. For instance, as the above discussion progressed, it became apparent that Goodson 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:

Goodson	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?

Goodson explicitly connects the current discussion of the finches to a previous homework problem about camouflage and sexual selection in guppies. He tells the class that most of them have "missed" an important point about the guppy problem, and his questions ask them to now figure out what that was. When no student responds, Mr. Goodson continues:

Goodson	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.
Goodson	…become extirpated?

Notice here that Goodson's question carries with it an implied answer. Do all the finches on Daphne Major become extinct? No. He and the students all know that. These kinds of leading questions are common in Goodson's discourse, and suggest that he is trying to guide students step-by-step to a particular explanation. A student attempts 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//
Goodson	//What do you mean it may come out?
Lee	well//
Goodson	//In them? Those individuals, like, that finches' 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.

Goodson challenges Lee directly, asking him repeatedly to explain what he means. Notice also that Goodson proposes one interpretation of Lee's claim that a recessive trait "may come out" by wondering if individual finches' beaks will shrink. Lee responds by describing a particular trait that may "come out," but not directly answering Goodson's question. Goodson ignores the response:

Goodson	Well you said mate, why do you, what about that?
Lee	Like, ah…
Goodson	Who believes these 8 birds might mate now that they've survived and it rains?
Students	No.

Goodson	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
Goodson	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 does Mr. Goodson ignore Lee's response, but he in fact claims that Lee mentioned mating, even though he did not. Thus, Goodson refocuses the discussion away from recessive traits and back to his original theme, mating. Having finally established that mating is likely to happen, Goodson continues:

Goodson	All right, who, now, what genes are being passed on to the next generation?
Students	Big beaks.
Goodson	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?
Student	Probably.
Goodson	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. Goodson constructs step-by-step, through his questions, the explanation he is 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, in these excerpts, 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 two 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 have primarily served as foils against which Goodson develops his own themes.

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

Goodson	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.
Goodson	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.
Goodson	In mitosis are there going to be some mistakes?
Students	Yeah.
Goodson	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. Goodson may be using these questions to ascertain students' current understanding, but it seems instead that these questions are a means of emphasizing the key points or relationships that students should attend to. Again, students contributions to the developing explanation are minimal. Goodson is essentially telling students what they should be taking from these activities, and what connections between activities they should be making.

A final prominent discourse strategy in Goodson's repertoire during debriefing discussions are science content monologues. He appears to use these primarily to extend discussion into topics beyond what students have 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, Goodson eventually explains the key ideas:

Goodson	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 serve a key summative function in Goodson's discourse. He can count on students in the class sharing a set of data, on which he imposes a normative explanation. For example, Goodson knows that his students have already seen the data about finch survival in the finch investigation, and he can assume that they already know that not all of the finches mated, as they have read and discussed that part of a book on the problem (Weiner, 1994). He thus succinctly lays 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 characterize Goodson's debriefing discussions. First, Mr. Goodson asks primarily *fill-in-the-blank questions* or *assent questions*. These kinds of questions affect discourse in many ways. They do not lead students to articulate their own explanations for concepts under discussion. Rather, fill-in-the-blank questions invite 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 Goodson's implied answer). These kinds of questions serve to maintain Mr. Goodson's control over the direction and substance of the discussion.

Another strategy Mr. Goodson uses to direct discourse is to *directly challenge* inappropriate or inaccurate student responses to non-assent questions. Goodson appears to use these challenges primarily to elicit students' definitions of formal terms. He rarely pushes students very deeply, however, despite the example with Lee above. He either repairs an inaccurate definition himself (as with Eric, above), or calls on another student (not shown in our example excerpts, but frequent in these discussions). It seems to us, however, that the main purpose of Goodson's challenges is 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. Goodson uses to control the direction and substance of the discourse during these discussions are *science content monologues*, in which he explicitly lays out for students the thematic ideas that they should take from an activity and the connections between activities that they should be making.

These strategies work together to emphasize Mr. Goodson's role as science expert in the classroom, and limit student participation in discussions. It is clear by Goodson'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 will be called on during a debriefing discussion, on the order of half of the class, and usually for a single turn. Students' self-directed work occurs during the assigned activities, and Goodson uses these debriefing discussions to explain what he believes 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 wonder what activity structures each teacher uses to weave a coherent unit of evolution around students' computer-based inquiries. We have seen that each teacher makes different choices about the kind of activities to use between the investigations. For both Burns and Goodson, however, whole-class discussions play central roles in developing students' understanding of natural selection. Our second and third questions explore the discourse strategies each teacher uses during these activities and the effects these strategies have 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. Burns or Mr. Goodson 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 shapes 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 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 & 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 Burns and Goodson negotiate within that space.

Specifically, Burns and Goodson negotiate trade-offs along several dimensions:

- Developing students' ideas vs. explaining formal theories.
- Exploration of content vs. review grounded in prior activity.
- Student vs. teacher-directed discussion.
- Teacher as authority vs. teacher as more expert guide.
- Few students participate in depth vs. many students participate briefly.

Student ideas vs. formal ideas

Mr. Burns' problematized dialogues are used to elicit student thinking about evolution, and his discourse strategies during these dialogues push students to clarify their articulations of their own understanding. His open-ended questions demand generative explanations from students, and the subsequent dialogue centers 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 Burns can model for students how they can inspect their own knowledge and develop their ideas. A potential disadvantage, however, is that Burns' commitment to engaging individual students in extended dialogue sometimes prevents 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. Goodson on the other hand clearly uses 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 consists of checking that they are 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 responds to or validates what students say during the discussion (e.g., ignoring the part of Eric's definition of genetic drift that captured important aspects of natural selection).

Exploration vs. grounded review

One key difference between the discussions in Burns' and Goodson's classes that may explain some of the differences in their discourse is the role that discussions seem to play in developing content within the unit. Mr. Burns' problematized dialogues appear 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, Burns 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, Goodson's discussions are always grounded in and make frequent reference to the prior activities that students have conducted during the unit. In this unit, Goodson's whole-class discussions are always reviewing the immediately preceding activity. Goodson 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 his expert view. Goodson'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 Burns.

Student vs. teacher-directed discussion

Much of the substance of discussions in Burns' class is generated by students, whereas this is not the case in Goodson's class. Although our excerpts can only hint at this, Goodson's discussions display a definite path and he controls the pace of how that path is traveled. Burns', 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 Goodson's class, students are not really substantive contributors to the discussion. Instead, they are asked simply to assent to Goodson's explanation, or to fill in the blanks of minor points and labels along the way.

Indeed, it is important to realize that both of these teachers are ultimately in control of these discussions. In Goodson's case, it is clear how his discourse strategies support his control. In Burns' case it may not be so obvious. Regardless, as shown above, Burns is able to refocus problematized explanation dialogues by asking focusing or elaboration questions or, as in the case of the appendix-eating bacteria, changing the terms of the problem under discussion. Burns' 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 authority vs. guide

Given that Mr. Goodson is the primary voice of explanations in his discussions, it is clear that he is the scientific authority in his class. Mr. Burns' authority is less overt, and he places himself more in a role of guide or facilitator. Goodson maintains his authority in several ways. First, as already noted, he does not ask students to substantively contribute to discussions. Secondly, when he does ask questions he rarely clearly validates a response. One way he makes clear when he disagrees with a student is to directly challenge their statement, as we have seen. Another way he signals disapproval, which we have not shown but is common, is he simply calls on another student. Finally, Mr. Goodson is always the one to summarize the normative explanation, through one of his monologues.

Mr. Burns, just as clearly, is pushed into a less overt expertise role. He must be if he is to sustain students' engagement in dialogue. If he were to tell students they were clearly wrong then they would lose interest in the dialogue. Still, Burns is ultimately the authority of what counts as a good explanation. He ratifies good and bad explanations through his explicit validations and through his parody challenges. Burns also is the sole arbiter of when the dialogue is over, thus tacitly signaling when the right answer has been achieved.

We stress that being the science authority is not inherently a bad role for either teacher to assume. On the contrary, students rely on Burns and Goodson to represent the scientific community and its standards for acceptable knowledge and explanation. The dilemma for Burns and Goodson is that the ways in which they wield their authority potentially effect how their students see themselves in relation to science, as legitimate constructors of scientific knowledge. Arguably, Burns' discourse strategies are more likely than Goodson's to communicate to his students that their ideas are valuable scientific ideas.

In-depth vs. broad student participation

Mr. Burns' problematized dialogues engage few students in active discussion, but those that are involved participate in great depth. Mr. Goodson's debriefing discussions involve many students in the discussion, although perhaps minimally. On the face of it, broad and in-depth participation would be ideal, as seen in Hammer's (Hammer, 1995) inquiry-oriented physics discussion. On the other hand, as noted, Burns' engagement with a single student at a time allows 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 are more or less attentive than in the other. Certainly, in Goodson's class students have an incentive to pay attention as it is highly likely that they will be called on at some point. Students in Burns' class may not have this incentive. Indeed, it may be the case that some students in Burns' class are 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 only that they have different implications for the structure and substance of discourse in each of these classrooms. Burns and Goodson both appear to endeavor, through these discussions, to construct for their students a public understanding of what they see as the key conceptual elements in the theory of natural selection. Students in Burns' 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 Goodson'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. The trick is in supporting classroom discourse in such a way that both can be accommodated.

Limitations, implications, and open questions

We are careful to withhold judgments of the efficacy of either Burns' or Goodson's discourse strategies, or aspects of them, 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 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 their own abilities to engage in scientific inquiry. Another limitation to our analyses is that our student performance measures do not show any significant differences by teacher (Sandoval & Reiser, in preparation). Of course, it may simply be that our measures of students explanations do not capture aspects of students’ learning that are influenced by these discussions. It is also possible that the scaffolds for student performance in the BGuILE software environments outweighs any differences in each teacher’s discussions, at least with respect to our measures.

Regardless, our analyses suggest some implications for inquiry-based science teaching, and issues needing further research. Chief among these is that teachers may require additional support to effectively integrate novel inquiry environments into their regular classrooms. Certainly, there are models for effective inquiry-based curricula in some domains (e.g., White & Frederiksen, 1995). No doubt, appropriate curricular materials that can suggest activities, activity structures, and discourse strategies could be helpful to many teachers. 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 & Reiser, 1998; Hammer, 1995; Hammer, 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 contributed 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 our designs of learning environments that will support students' and teachers' learning. Also, this kind of research is necessary to develop models of effective inquiry teaching practice that will allow us to successfully educate prospective science teachers to be active inquirers with their students.

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