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Opportunities to Talk Science in a High School Chemistry Classroom

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Abstract

The purpose of this study is to develop a better understanding of the discourse strategies employed by students and a chemistry teacher as they engaged in various activities in the classroom. More specifically, the paper examines how discourse supports or constrains opportunities to engage in experimentation and making sense of new experiences. Data, collected daily for four weeks in a high school chemistry classroom, included ethnographic field notes, video-recordings, and interview transcripts. Discourse analysis was combined with other data to produce a rich description of the classroom. We show that various discourse strategies were employed by the teacher in order to maintain control of the discourse, which was consistent with both his and his students' expectations and aims. The study argues that an understanding of the micro-discourse strategies that contribute to issues of control of talk and activities by the teacher in the classroom has important implications for learning science.

Key Words: chemistry teaching, classroom discourse, interactional sociolinguistics, social semiotics

There is a rapidly growing community of researchers addressing important educational questions through a variety of different theoretical frameworks (e.g., Engeström, 1987; Sewell, 1999) and associated methodologies (e.g., Roth & Tobin, 2002). Based on new understandings of the complex socio-communicative nature of teaching–learning processes, we believe that such efforts have the potential to improve the quality of science education. The most recent school-based approaches to research in science education involve people from diverse backgrounds, and assumes that, in part, their strength is due to the multiple perspectives illuminating field-based studies, examining questions about how people communicate and socially construct knowledge in educational settings (Gee & Green, 1998; Kelly & Green, 1998; Lemke, 2001).

The development of sub-disciplines such as social psychology, cognitive anthropology, sociology of knowledge, cultural sociology, ethnomethodology, conversation analysis, psycholinguistics, and sociolinguistics is evidence of a growing concern for the relationship between human cognition and social interaction. Educational research is now drawing on psychology, anthropology, sociology, communication, and other major disciplines and their subsumed sub-disciplines to help address growing concerns about what and how children should be learning in our nation's schools. Many educational psychologists are no longer content to ask questions about how an idealised learner learns in highly controlled laboratory conditions, but want to know how learning takes place in the social milieu of school classrooms. Likewise, educational sociologists and anthropologists are becoming more interested in exactly how individuals learn from interacting with others in social situations that include classrooms.

The theoretical perspectives incorporated in this study draw from the fields of social semiotics, cognitive science, and interactional sociolinguistics in order to explore the possibilities of expanding students' opportunities to learn to talk science, think scientifically, and communicate more effectively in science classrooms.

Classroom Discourse

The New London Group (1996) regards "discourse" as a sociocultural and political entity that subsumes ways of saying, writing, doing, being, valuing and believing. A discourse facilitates communication and establishes social identity within a community. Teaching and learning of science are considered to occur in evolving communities of practice in which the discursive practices (e.g., talk, writing, cognition, argumentation and representation) of participants are constantly changing. The catalysts for change are social interactions between participants and social structures such as conventions and norms (Moje, Callazo, Carrillo, & Marx, 2001; Roth, 1995).

Given the appropriate conditions in which particular interests in a group are supported, learning about science can lead students to develop an increasingly science-like discourse. An important criterion for progressing in this direction is the extent to which students use their discursive resources to make sense of their experience and support claims with evidence. According to Barton (1997, p. 155) "the experiences of everyone need to become part of the language of science if the experiences, beliefs, values and essence of all people are truly to be incorporated into science."

To avoid the methodological problems in discourse analysis identified by Klaasen and Lijnse (1996), we believe it is crucial to adopt well defined and trialed systems such as those used in interactional sociolinguistics (Gumperz, 1992) or social semiotics (Halliday & Hasan, 1989). Both Gumperz and Halliday's systems analyse the language used in social situations by breaking it down to basic units of communication that people use to make meaning through discourse in social interactions. Based on Halliday's methodology, Lemke (1990) carried out a study that was field-based, analysing field notes and recordings from 60 classes, involving 20 different teachers at the junior and high school levels in biology, chemistry, physics and earth science courses. Lemke described science dialogue in terms of two patterns: 1) organisational or activity structure in which people are interacting, move by move, strategically playing within some particular set of expectations about what will happen next; and 2) thematic pattern in which people construct complex meanings about a topic by combining words and other symbols. Using this theoretical framework, dialogue in a science classroom could be examined to ascertain the extent to which the organisational structure and thematic patterns were consistent with those evident in a field of science. This is the same problem area Shuell (1987) examined in an earlier study.

OPPORTUNITIES TO TALK SCIENCE

Shuell differentiated between the scientist's "science" and the teacher and students' "science" that they studied at school. Hence, if organisational patterns being constructed in classroom dialogue were similar to those of professional scientists or even to science textbooks, then we could say that the students and teacher are engaged in "talking science."

The research suggests that in most classrooms students do not talk science in the sense that Lemke (1990) or Moje (1995) have described science talk. According to Hicks (1995), students do least well in school science when they are from social backgrounds where customarily used activity structures, preferred grammar, rhetorical patterns, and figures of speech are least like those used in science and the classroom. Giroux (1992) notes that when students can employ their own language resources, the language that they speak at home and in the streets, they are more likely to develop literacy skills that are the foundation for developing more canonical, mainstream discourses. There is a tendency for the primary discourses of children from homes of working class or unemployed not to connect well to a scientific discourse (Atwater, 1996). Accordingly, teachers enact the curriculum for such students to emphasise the learning of scientific facts and to de-emphasise conceptual learning, inquiry and scientific habits of mind (Anyon, 1981; Lemke, 1998).

Classroom discourse supporting such a fact-orientated curriculum often follows a familiar three-part I-R-E (I for initiation, R for response, E for evaluation) pattern known to educational researchers since the early sixties (e.g., Bellack, Kliebard, Hyman, & Smith, 1996). In general, this discourse pattern plays out when the teacher asks a question, the student responds, and the teacher evaluates the response. The same pattern was observed to be the dominant discourse structure in classroom discourse studies throughout the 1970s and 1980s, sometimes called I-R-F (F for feedback from the teacher) (e.g., Edwards & Mercer, 1987). Lemke (1990) renamed the IRE or IRF pattern as “triadic dialogue.” Use of the triadic dialogue tends to keep Lemke’s thematic pattern of the science content implicit and effectively hidden from many students, despite the best efforts and intentions of a good teacher. Just like learning a foreign language, fluency in science requires practice at speaking, thinking and writing (i.e., active use of language, grammar rules, language games). Yet, in most science classrooms, students mainly listen to and read the language of science but they talk very little science, write less, and are seldom given adequate time to think about answers to challenging problems (Tobin, 1987).

A useful framework to help examine some of these issues about classroom discourse is Gee’s distinction between “Discourse” (with a capital “D”) and “discourse” (with a lower case “d”) (Gee, 1990, 1991, 1996). Discourses with a capital “D” are ways of acting, interacting, speaking, listening, reading, and writing at appropriate times and places with appropriate objects so as to signal membership in a particular social group. Our identities as individuals and group members are a function of the Discourses in which we participate. Two broad types of Discourse exist: primary Discourses (learned in the home) and secondary Discourses (learned outside home in places such as school, workplace, or church).

Primary and secondary Discourses require us to communicate in patterned ways that provide a day-to-day continuity in our associations with others. How we actually get this accomplished, our use of language, involves learning several “discourses” (discourse with a lower case “d”). Lower case discourses are the language bits of Discourses. They are connected stretches of language that only make sense in specific situations (e.g., protocols for data input, reports, conversations, arguments, procedures, graphing conventions (Bowen, Roth, & McGinn, 1999)). It is primarily through this day-to-day use of language that classroom discourse takes on special meaning for students in a particular class. Whatever the learning goals may be, they are accomplished through this discourse. One of these goals that is of interest to many science educators, is to provide opportunities for students to learn to think scientifically.

Thinking Scientifically – Argument in Science Education

Kuhn's (1993) work connects everyday thinking and scientific thinking. She conceptualises both as forms of argument and explores the similarities from this perspective, based on empirical research evidence. Both everyday and scientific theories are built on argument and are subject to confirmation or disconfirmation on the weight of new evidence. In defending their theories, students begin to develop the discourse practices that scientists employ in their everyday work. The main task for a scientist is to convince colleagues that new evidence either confirms or disconfirms the theory in question in order to explain why certain phenomena are taking place (Pickering, 1992). As Driver, Newton, and Osborne (2000) conclude, "The major barrier in developing young people's skills of argument in science is the lack of opportunity offered for such activities within current pedagogical practices. If students are to be given greater opportunities to develop these skills, then this will require a radical change in the way science lessons are structured and conducted. " In other words, "students need to be given a greater voice in lessons" (p. 308). Hence, to provide opportunities for students to learn to develop logical scientific arguments, science education reforms to classroom pedagogy require attention to the socio-communicative nature of the classroom.

Theoretical Perspective

The way instruction engages students in science education influences access to scientific knowledge, and the opportunities that students have to talk science (Lemke, 1990) and to develop their scientific thinking skills. Based on this notion, the chemistry classroom, in which this present study was situated, was conceived in terms of socio-communicative aspects that bear upon the learning of science. The methodology of interactional sociolinguistics (Bleicher, 1994) was employed since it views teaching/learning processes as socio-communicative in nature (Collins & Green, 1992; Kelly & Chen, 1999). The essence of the perspective applied to this study is that as the teacher and students work together in the classroom over time, they develop patterned ways of doing things, common ways of talking about and conceptualising activities, and shared perceptions of interpretation and evaluation of activities. Their personal beliefs and images about who they are and what they can do in different situations influence the ways in which members of a classroom engage in activities. It is becoming increasingly clear that the ways in which teachers and students approach learning activities in classroom settings is very much affected by participants' personal beliefs and values (McRobbie & Tobin, 1995; Santa Barbara Classroom Discourse Group, 1992). While these personal beliefs and values differ between groups in specifics, the similarity remains that they are important referents for how participants interact and engage in activities in both science laboratories and science classrooms.

This study builds on research we have undertaken previously using the same dataset (McRobbie & Tobin, 1995; Tobin & McRobbie, 1996). The earlier analyses examined student and teacher beliefs and goals that acted as referents for participant actions within the classroom. A major finding of these studies was that the congruence between teacher and student goals and beliefs must be taken into account before any intervention or reform can be expected in any meaningful change process. Just how was this congruence between student and teacher beliefs and goals accomplished? We hypothesised that the beliefs and goals of the students and teacher must have developed through the discourse practices established in the classroom over time as the school year progressed. To examine this hypothesis, the current study was designed to apply a micro-discourse analysis to the videotape record of classroom interactions.

Purpose

Our goal in this study is to develop a better understanding of the discourse strategies employed by students and a chemistry teacher as they participate in an enacted high school science curriculum. The study explores how teacher and student metaphors, beliefs, and images about the nature of science knowledge, teaching and learning, and authority, are translated into classroom discourse, and, in turn, how that evolving discourse shapes beliefs. The analysis focuses on how discourse supports or constrains opportunities to engage in experimentation and give meaning to new experiences. We argue that an understanding of the micro-discourse strategies that contribute to issues of control of talk and activities by the teacher in the classroom has implications for the opportunities of students to engage in science talk and scientific argument (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Tobin, 1993).

Method

Setting and Participants

The setting for the study was a public high school in Brisbane, Australia. The school was suburban and had an enrolment of about 1,000 students. The participants in this study were Mr. Jacobs, a 20-year veteran teacher, and his grade 11 chemistry class consisting of nine males and six females, from middle-class family backgrounds. These students were preparing to go to university for further study.

Design

The study design was a topic-oriented ethnography (Erickson, 1998, 1986) aligned with interactional sociolinguistics (Bleicher, 1996; Green & Bloome, 1997; Kelly & Crawford, 1996). The focus was on the socio-communicative interaction between teacher and the students involved in classroom activities. An effort was made to find out, from the perspectives of the participants, a chemistry teacher and his grade 11 class, what was happening and why the teacher and students acted as they did.

Data Sources

Two researchers visited the school daily for four weeks to observe one classroom during a unit on electrochemistry. Each lesson was videotaped. Data were derived from the following sources: field notes; interviews with Mr. Jacobs, the science teacher; interviews with six students; and videotaped lessons. Mr. Jacobs was interviewed on four occasions each of about one and half-hours duration and six students were each interviewed for approximately an hour. Procedures were undertaken to ensure that the study would yield outcomes that were credible, authentic, and robust. For example, the use of numerous data sources maximised the probability that emergent assertions were consistent with a variety of data. Member checks (Guba & Lincoln, 1989) allowed participants to review data and interpretations, agree or disagree with the assertions of the research, and suggest corrections, elaboration, and summary statements. The roles of the researchers were confined, to the extent possible, to research. Entry was negotiated to undertake a study that would provide a platform for changes to be considered by school faculty at a later time.

Sociolinguistic Analysis

The analysis involved transcribing video recordings of talk and breaking it down into discourse analytic units called message units that are smaller than whole sentences. The sociolinguistic theory (Gumperz, 1986, 1992) behind this analysis is premised on the notion that human communication occurs in ‘small chunks’ of both talk and non-verbal gestures as two or more people are interacting. These small chunks define the message unit. Thus, an emphasised word, change in intonation, increase in speed of delivery, or a nod could be significant signals from one speaker to another that communicate special and immediate meanings that become the basis for further talk and/or actions. In practice, message units are operationally defined by actually hearing or seeing the verbal and non-verbal communication cues (called conceptualisation cues in interactional sociolinguistic theory). Furthermore, the methodology has proven to be able to be performed with high inter-rater reliability (Green & Harker, 1988; Green, 1983).

The discourse analysis was combined with other data sources to construct robust interpretations from emerging patterns in the data. Various maps and summarisation tables were constructed in order to facilitate an analysis that incorporates micro- and macro-sociological perspectives. Transcripts and a summarisation table were used to support the assertions formulated for the paper. For a more complete explanation of this methodology and the theory underpinning it, see Bleicher (1998).

Results

Over the continuous four weeks of classroom observation, there were several types of activity structures evident in the day-to-day instruction. After reviewing the complete videotape record, we decided to apply discourse analysis to representative examples of each type of structure including lectures, homework feedback sessions, whole class discussions, group problem solving sessions, and demonstration lessons. Using the transcripts and summarisation tables from these initial analyses, we examined these for evidence of either supporting or constraining student opportunities to talk science or think scientifically. After several discussions, we agreed that one particular demonstration lesson stood out as a particularly telling example of what we were beginning to see in the discourse that shed light on our questions. Hence, we decided to make a closer analysis of this 50-minute lesson. The results of this analysis are presented to illustrate what we learned from our subsequent discussions.

Context of the Demonstration Lesson: Electrochemical Cells

The purpose of this lesson was to set up a copper-zinc wet electrochemical cell to illustrate all of the facets of electrochemical cells that had been covered in lectures, textbook readings, and homework problem assignments in the preceding fourth week of classes. The previous night's homework had been a problem requiring students to sketch the flow of electrons around the circuit in an electrochemical cell. The cell had already been assembled, and Mr. Jacobs' plan was to lead the students through a discussion of how the electrochemical cell works using the cell as a model. The actual cell was constructed with two 400 mL beakers, solid metal strips of zinc and copper, a salt bridge in a glass U-tube, and external wiring connected with alligator clamps to the electrodes. Figure 1 is a schematic representation of this cell.

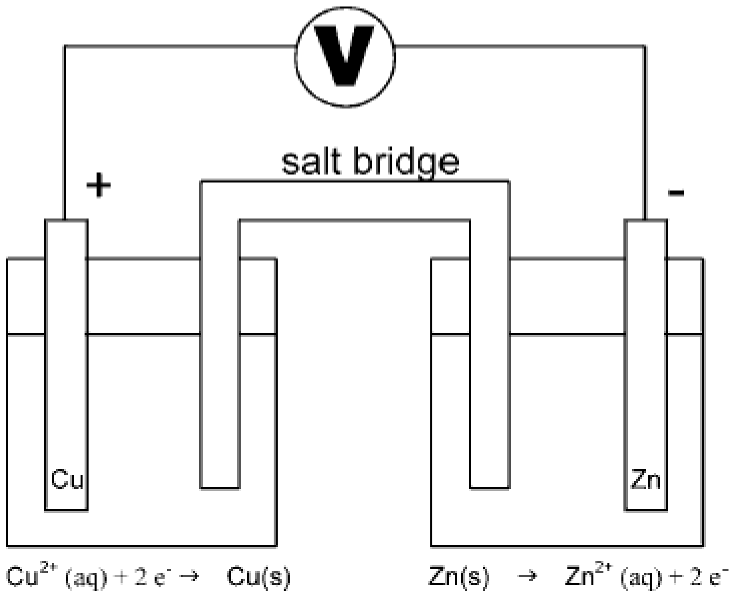

Figure 1: Copper-zinc electrochemical cell.

Sanger and Greenbowe (1999) replicated and extended earlier work by Garnett and Treagust (1992) that examined high school chemistry students' misconceptions about electrochemical cells. While this work had a different focus than our study, it did inform some of our discourse analysis. Sanger and Greenbowe (1999) found that students had difficulties in understanding several aspects of these cells.

Mr. Jacobs was particularly concerned about clearing up student misunderstandings on how the electrons flowed through the electrochemical cell. He felt that their naming of the different parts of the electrochemical cell was a necessary first step to understanding how it worked. This is not an unfounded tact to take with high school chemistry students. His concern and deliberateness in trying to get the students to understand how the cell worked is evident in the analysis.

ASSERTION 1. Classroom discourse reflected an emphasis on learning a basic toolkit of science terms with little evidence of making very many meaningful links between concepts.

Mr. Jacobs introduced at least 49 science terms frequently in the five lessons on electrochemical cells. These terms were repeatedly introduced and defined. Although some of them were introduced in earlier classroom lessons, all of these terms were used in the demonstration lesson. Indeed, this lesson was viewed as a culminating activity, a chance to employ the real life electrochemical cell as a model to guide and prove to students that they could understand how the electrochemical cell worked.

Identification of the anode and cathode and associated other parts (salt bridge, external wires, voltmeter, and the electrolytic solutions) of the electrochemical cell were the initial starting point of Mr. Jacobs' teaching on electrochemistry. This included correctly identifying the characteristics of the zinc and copper electrodes as well as the solutions in which they were immersed.

Understanding the direction of current flow was the primary concern that guided Mr. Jacobs' endeavours to have students learn many of these science terms. This involved many components. First, the understanding that the solutions in the halfcells were composed of charged chemical species was developed. Writing balanced chemical equations and being able to sort out negative from positive species was another necessary component. Understanding the direction of flow of electrons was the third component.

Mr. Jacobs depended on the tried and true methods he had employed successfully in the past to reach his instructional goals. These involved careful explanations at the chalkboard. One of his strategies was creating special memory aides for his students. These were handy in helping them remember lists of facts or sorting out two terms that were opposites. This was then followed by homework assignments and going over the answers the next day. Although willing to try some student cooperative work, Mr. Jacobs was clearly more comfortable when he was directing the lesson. So were his students. There was no question in our minds that Mr. Jacobs made explanations very clear and set just the right amount of homework to help students learn the science facts he considered to be most salient to understanding electrochemical cells.

There was a noticeable change in confidence when it came to understanding the relationships between terms and concepts. No matter how well it seemed that the students were learning the basic science terms, linking concepts, such as is necessary in understanding the current flow seemed to frustrate both Mr. Jacobs and the students. The demonstration lesson illustrates this convincingly. Mr. Jacobs made repeated efforts to get students to explain how the charge flows in the electrochemical cell, but with very little success. In fact, in many instances he fell back on testing for understandings of science terms. If not understanding terms, then using equipment appropriately was often a technique used to elicit student responses to questions. For example, the voltmeter used to detect current flow from the electrochemical cell had two different scales that could be selected with a switch in order to measure volts or tens of volts. For several minutes, students were asked to explain this dual-scale feature and how to read the output indicated on the voltmeter. By the end of the demonstration lesson, it was clear that most students had very little understanding of how the charge flowed in the cell. They had, however, demonstrated a fair understanding of the science terms involved in naming the various parts of the cell.

Finally, it was clear to us that the time allocated for the electrochemical cell topic was running out and Mr. Jacobs wanted to administer a test and move on to the next chemistry topic. Thus, only a certain amount of time could be focused on building conceptual understanding. The discourse analysis revealed that few students were able to respond to teacher questions in ways that demonstrated deep conceptual understandings. Both the teacher and students accepted this pattern of involvement as normal practice. Chemistry was considered a hard subject to understand and only a few students were expected to demonstrate high levels of achievement beyond remembering the science terms and solving basic algorithmic problems.

ASSERTION 2. Classroom discourse constrained opportunities for students to talk science and think scientifically.

Mr. Jacobs and the students, as well as the researchers, agreed that the teacher maintained strong control of activities. Mr. Jacobs controlled the flow of classroom talk through the regular use of the following three discourse strategies: repetition; stress on key words and/or intonation; and interruption of a current speaker. All three are illustrated in the following two examples. The first is short in order to explain fine details of the discourse analysis, and the second is longer to explicate analyses that support Assertion 2.

EXAMPLE 1. In spoken discourse, the current speaker is said to be taking a "turn at talk" or to be "holding the conversational floor." In many classrooms, the teacher takes most of the turns at talk and generally holds the conversational floor, thereby, doing most of the talking. The following transcript excerpt illustrates this strategy. In this excerpt, the end of one message unit is indicated by a "/" mark.

> Mr. Jacobs: what is that (2.0)/oxidation or reduction/
> Diane: reduction
> Mr. Jacobs: reduction/okay/is that/consistent

Mr. Jacobs has finished saying, "what is that" with a rising intonation (characteristic of a question) and a two second pause (indicated by "(2.0)"). He was hoping for a student response at this point. Not receiving a response to this open question, he prompts the class with an easier option, a multiple-choice question: "oxidation or reduction?" Diane took up this easier option and chose "reduction." Diane said this with a clear voice, loud enough for the researchers in the back of the room to clearly understand it. Thus, Mr. Jacobs' repetition of her answer was not for clarification, but as a smoothing device for taking back control of the conversational floor. Another point brought up by this example is that it was typical of most of the types of questions asked by the teacher. If a response was not elicited fairly quickly, Mr. Jacobs followed up by giving a multiple-choice option. Mr. Jacobs did this quite intentionally in order to, as he put it, "get the right answer from the students" and "move on with the lesson." One further point is that if an answer was not what Mr. Jacobs was looking for, he would generally not repeat it, but do some re-explaining and then ask the same question, but this time electing a student (usually one of three he expected would know the answer) to answer it. These strategies were consistent with his belief that time was of the essence in order to cover the course content, even at the expense of giving students time to learn, as evidenced in this excerpt from an interview with Mr. Jacobs: “I have a sense of urgency making me try to help them advance more quickly. While learning is important, it is also very important to us to get the work covered according to the work program.”

EXAMPLE 2. This second example is taken from a transcript of the demonstration lesson. This segment is about 12 minutes into the discussion. Mr. Jacobs has finished with the zinc half-cell and is about to discuss the copper half-cell. In this 55- second sequence, the teacher begins to walk the students through what is happening chemically at the copper side of the electrochemical cell. Figure 1 illustrates the electrochemical cell that Mr. Jacobs was using in this lesson.

Table 1 contains a segment of the transcript of the demonstration lesson. Each line represents one message unit and begins with a line number that helps for reference purposes. The next column denotes the speaker (e.g., Line 220 is the teacher talking). The speaker is not indicated again until a change of speaker occurs as in Line 231.

Table 1
Segment of Transcript of Example 2.

220	teacher	there's a gain of electrons here
221		we did say that before
222		reduction occurs over this side
223		okay Meggie
224		what is gaining the electrons (1.5)
225		there's the problem (2.0)
226		okay
227		well someone else will be able to answer that I'm sure (2.0)
228		what's your opinion Steve
229		what's going to gain the electrons
230		in this beaker
231	Steve	copper ((said very quietly))
232	teacher	sorry
233	Steve	copper
234	teacher	the copper
235	Steve	the solution
236	teacher	the copper solution
237		now be specific
238		in the copper solution
239		what (4.0)
240		Scott
241	Scott	copper ions in solution
242	teacher	copper ions
243		can you suggest a reason
244		that's plausible
245		why the copper ions
246		would (1.5)
247		gain electrons (4.5)
248	Scott	well not really
249	teacher	well I
250		I'd like to think you could
251		because your answer's right
252		okay
253		they will gain electrons
254		so let's work out why

For those accustomed to looking at transcripts of naturally occurring classroom talk, it is not surprising to note that the teacher is doing most of the talking. The second feature that is consistent across all the data is that the teacher more often than not elects which student is to answer a question. The third typical feature in this example is the teacher strategy of repeating the student's answer, as in Lines 234, 236, and 242. This serves the function of a positive evaluation by the teacher. The teacher and students are engaged in typical IRE cycle (Bellack et al., 1996), in which the teacher asks a question, the student answers (responds), and the teacher evaluates that answer. These discourse strategies are consistent with teacher's and students' personal beliefs and images on the topics of scientific knowledge, teaching and learning, and classroom authority, as expressed through interviews.

So far, we have examined the structure of the dialogue between the teacher and students. Now let's look more closely at the transcript for evidence of support or constraint to the opportunity for students to engage in talking science. The teacher restates the first question four times: Line 224, what is gaining the electrons?; Line 225, "there's the problem"; Line 227, "well someone else will be able to answer that I'm sure;" Line 228–30, "what's your opinion Steve? – what's going to gain the electrons in this beaker?" Now that a student has finally attempted an answer, the teacher goes on to get the answer that he really wants: Line 237–40, "now be specific, in the copper solution, what, Scott?" In Line 241, Scott supplies the answer "copper ions," which draws a positive evaluation from the teacher in the form of a repetition of the student's answer.

Up to this point, this example is very typical of the entire corpus of data collected, in which the teacher keeps the discourse moving linearly towards a preconceived goal to make a particular conceptual point on a specific topic. Throughout the discourse, Mr. Jacobs is very consistent in asking questions that seem to fall short as successful probes for student understanding. The questions are typical in that they almost always require merely a factual answer from the students. At Line 243, the teacher asks what appears to be a different kind of question: "can you suggest a reason, that's plausible, why the copper ions, would, gain electrons?" Though the grammatical form of this question appears to be asking for a suggestion, perhaps a hypothesis from students, it actually requires only further factual knowledge from the students. One explanation for this is that the reason was given in previous classroom work, and the students, rather than generating new knowledge, are really required to simply remember the reason as a fact. In this instance, a student claims to not be able to answer, which is a rare occurrence in this class. Usually the questions are designed to elicit quick, correct answers from students to help move the lesson along. From listening to the audiotapes, we infer that questions are not being asked so much to probe student understanding, as a rhetorical device employed by the teacher to make the lesson a little more lively, co-enacting the teacher-driven discourse through the second voice of various students. This is a case of apparent dialogue that is really a discourse strategy designed to allow the teacher to maintain control over the conversational flow.

Due to the discourse rules being imposed by the teacher, and his expertise in actuating them, the students do not have opportunities to engage in discourse that could be considered the result of scientific thinking. The metaphor of science as argument or students engaging in scientific thinking as argument is not a probable outcome in this teacher-centred activity.

ASSERTION 3. Intentional questioning strategies by the teacher can constrain the opportunities to talk science and think scientifically in the classroom.

The questioning patterns became a focus for one portion of the micro-discourse analysis. The comparison of types of responses included the differentiation between a voluntary response and a response from a student elected by the teacher to answer a particular question. Summary tables were constructed from the transcript analysis to give an overall perspective of who was answering questions, and whether they were selected or volunteered to participate.

Part of a typical table of data is illustrated in Table 2. This table summarises the results of a microanalysis of message units derived from 23 minutes of teacher–student discourse during a demonstration experiment carried out by Mr. Jacobs. (Telected responses = teacher elected that student to answer a particular question; MU = message unit).

Table 2

Who's Taking the Turns? Demonstration Instructional Phase.

Student	Voluntary responses	T-Elected responses	# MUs voluntary	# MUs elected
Rowena	4	7	5	12
Diane	5	5	5	7
Martin	2	6	2	10
Bob	4	0	4	0
5 more students	3	12	3	14
Totals	18	30	19	43

Voluntary responses are those in which students self-elect to answer the teacher's question, whereas T-Elected responses are those in which the teacher chooses a student to make a response to a question. #MUs stands for the number of Message Units that a student uses to make their response.

The focus in this microanalysis was on who was asking questions, in what context, and with what quality and frequency. For instance, Rowena answered 4 questions during this 23-minute segment voluntarily, while answering 7 more questions when Mr. Jacobs asked her by name to do so. In forming her 4 voluntary responses, Rowena employed 5 message units in total – therefore, her responses were short, one message unit answers, except for one. On the other hand, her 7 teacher-elected responses employed double the message units, on average two per response. Though we do not include it here, examination of the transcripts of the discourse analysed to produce Table 2, indicated that Rowena was more confident to extend her responses beyond simple one or two word constructions when the teacher asked her specifically to answer a question. The beginnings of her personal interpretations of explanations were evident. However, the teacher made no efforts to build on this by encouraging Rowena to engage in a discussion of her views with other students. Neither did he try to extend her thinking by further teacher–student discourse. The lack of such instances in the discourse has implications for the development of Rowena's depth of understanding. Theory suggests, however, that it would be a fruitful direction to encourage in the classroom discourse.

In the 23-minute segment, the teacher and students employed a total of 690 message units. The teacher did most of the talking, as evidenced by his use of 628 message units (91% of the total), compared to the students' 62 message units (9% of the total). Nearly all of the student talk was in response to questions asked by the teacher. Of these, 19 message units were voluntary responses, while students who had been elected by name by the teacher to answer a particular question employed 43 message units.

In all cases, the teacher controlled the activity, choosing the next speaker either directly by electing students by name, or choosing among volunteers who had raised their hands to answer. Students tended to speak for longer periods of time when responding upon teacher election as compared to voluntary participation – an average of two MUs per response turn when elected compared to one MU per turn for voluntary.

Discussion

Our findings derived from our interest in exploring how the discourse in a chemistry classroom supported or constrained opportunities for students to talk science and think scientifically. The results of a tightly controlled discourse setting are apparent from casual observation from the back of a classroom. What is not so obvious is how both teacher and students come to establish such an environment.

Mr. Jacobs established a rigorous routine of activity structures such as question and answer discussions based on homework assignments, practical demonstrations, and lectures in preparation for upcoming examinations. This routine was driven by a common belief of both the teacher and students that it was necessary to cover a set of state-imposed curricular topics in order to pass the examinations that demonstrated accomplishment of learning the topics. The perceived press of time and the need to focus on just the information that would be examined drove the pace and structure of all activities. Thus, little time was provided for students to question, experiment, or ponder upon new ideas. The micro-discourse analysis revealed that the same strategies were being tacitly employed by participants in the flow of talk across different activities in order to "keep things moving." It was also consistent with Mr. Jacobs' beliefs about his goals as a teacher, illustrated in the following interview excerpt:

> I've got the responsibility to see that all the course objectives and content are covered. I feel that I need to push them (the students) along and stay on the timeline. I see myself as a transmitter of knowledge. I believe I have all the knowledge the students need for their course. Students should participate in the activities that we do and complete all the work that is set.

The students in this study agreed with Mr. Jacobs' views on teaching and learning. They felt that he was a very good teacher and trusted his leadership. They were in agreement that he should control the enacted curriculum, including the discourse. A typical student interview response expressing this view follows:

> Mr. Jacobs is the leader of the pack who looks after everybody else. He definitely has control of the classroom. I learn well from Mr. Jacobs. He has to give us the knowledge because we're not really going to get it anywhere else. There's not enough time. It was just in a rush to get it done.

Thus, Mr. Jacobs felt time was at a premium and this constrained his willingness to try new types of activity structures (e.g., student open inquiries). He felt obligated to cover important areas of the curriculum that counted for high stakes assessment of his students. For the students' part, they were 'on the same page' in their goals. Students supported the teacher's decisions to cover various parts of the curriculum in a timely fashion and keep things moving.

This was consistent with teacher and student personal beliefs and images on the topics of scientific knowledge, teaching and learning, and classroom authority (see Tobin & McRobbie, 1996). Students in this classroom, rather than generating new knowledge, were really required to simply remember an explanation as a fact. Usually teacher questions were designed to elicit quick, correct answers from students to help move the lesson along.

This type of traditional science curriculum has been documented as the more typical situation in most classrooms in Australia, the United States, and England (Edwards & Mercer, 1987;O'Loughlin, 1992; Tobin, 1987).One of the major driving forces for this control is the appeal to getting the material covered – getting through all the topics required on the curriculum. The even more compelling reason is that there is often a high-stakes examination to prepare for. If all topics are not covered in time, students are at risk of not being able to answer all the questions on the examination. This situation gives little motivation to teacher or students to experiment with the curriculum. Thus, the chemistry lessons, textbook, and curriculum in Mr. Jacobs' class differed very little from other chemistry classrooms we have observed. In fact it differed very little from the high school chemistry class some of us attended in the 1960s. This is not as surprising as it might sound when one considers the history of high school chemistry textbooks, publishing procedures, and textbook adoption practices of school systems.

This study presented an account of what occurred in the classroom discourse in a typical lesson sequence. But what is missing from the discourse? Students were not engaged in talking about science in a constructive manner. The teacher was developing the topic, with student participation being by invitation only, and then only as a technique for furthering the teacher's discourse. Students were not given opportunities to do more than passively listen to teacher talk, and occasionally deliver one or two message units of discourse, almost always supplying simple factual information to the on-going teacher discourse. Students were provided few opportunities to grapple with the factual knowledge and try to make conceptual connections. Nor were they provided opportunities to present alternative hypotheses to explain the phenomenon under discussion. The teacher was clearly controlling the discourse in a linear, unyielding one-dimensional push to reach a satisfactory conclusion to cover the topic of the day.

The goal of providing wider opportunities for student learning was worthwhile. However, when we finished this study, there was something that didn't quite add up to our final feelings about it. It was clear that Mr. Jacobs' chemistry class was not the model for the envisioned inquiry science classroom of the new millennium. Yet, for these students (and their middle-class parents), the chemistry class was exactly what they wanted in order to be successful in getting into the best universities. We were initially frustrated. After all this research, we felt that we had little chance of convincing Mr. Jacobs to change his practice. Yet, from the outset of the study, Mr. Jacobs was very interested in participating so that he could improve his practice – such was his devotion to helping his students to the best of his ability as a teacher. The change he was willing to make had to fit into the goals and beliefs that he and his students held about what knowledge was worth learning in the chemistry class. The problem (for us) was that this change was trivial from our perspective of meaningful reform. Having taken inventory, we found an overwhelming congruence in the goals and beliefs of all stakeholders – the current state of affairs in Mr. Jacobs' classroom was defined as successful by the teacher, students, administrators, and parents. We think this outcome of our study raises significant questions about the purposes of studying science in high school. From many perspectives what happened in Mr. Jacobs' classroom is what ought to happen. Notwithstanding this consensus, what happened is not consistent with the recommendations for reform that have typified the last 40 years of science education, nor with our values that place a premium on students building a conceptual understanding of science and connecting it to their everyday life experience.

Conclusion

This study illustrates the usefulness of examining classroom discourse for instances of opportunities for students "talking science" and "thinking scientifically." These opportunities are created by a social co-construction between students and teacher of particular views of what it means to do science and be a classroom member (Crawford, Kelly, & Brown, 2000). In examining how students develop an understanding of science through classroom discourse, there is a need to understand how participants define what they mean by science and scientific knowledge. Once this is understood, then learning can be defined as taking up the patterned ways that local participants in the class know science, talk about science, and do science in that classroom.

Learning science can be considered as learning a new way to make sense of experience. Lemke argues that "instead of talking about meaning making as something that is done by minds, I prefer to talk about it as a social practice in a community. It is a kind of doing that is done in ways that are characteristic of a community, and its occurrence is part of what binds the community together and helps to constitute it as a community" (Lemke, 1995, p. 9). In a school science community one might expect to see students engage in ways such that, over a period of time, the discourse of a class would become more science-like. As has been advocated by Kuhn (1993), science could be regarded as a form of argument in which emerging conceptual understandings are related to evidence and the extent of the fit with canonical science.

If the essence of science is to examine the coherence of evidence and knowledge claims then one might expect a form of discourse in science classrooms that involves students routinely in arguments over the efficacy of the warrants for knowledge claims.

In summary, Lemke argues that students need to be given more opportunities to talk like scientists, not talk about science. Kuhn argues that students need to be given more opportunities to think scientifically, not talk about thinking. To implement either Lemke or Kuhn's suggestions in classrooms, more needs to be understood about how teachers and students engage in discourse in actual science classroom activities.

In a major review of science studies during the first half of the 1980s, Yager and Penick (1987) reported a major mismatch between the inquiry curricular approach and that found in the schools. They found that studentsweremostly engaged in learning a series of facts and rarely asked to suggest hypotheses or ways of testing these hypotheses with experimental evidence. This finding was generalised across schools of varying philosophy including those in which inquiry and discovery materials were utilised. Unfortunately a similar trend appears to persist at the present time (Driver, Newton, & Osborne, 2000).

In an elementary school study, Crawford, Kelly and Brown (2000) presented convincing arguments of the merits of providing students with opportunities to expand the range of traditional classroom discourse practices so that they could experience school science as a social practice. This type of science education reform is in agreement with many proponents (e.g., Norris, 1997; Hurd, 1994) who argue that classroom science lessons should provide opportunities for the teachers and students to expand spaces in the discourse in which students begin to practice talking science and thinking scientifically. In the case of a high school student, it is necessary to understand what level of expertise she brings to the classroom. It is also necessary to determine how the teacher and other students perceive all participants. In any classroom, the practices of students create opportunities for one another and the teacher to participate in the doing and learning of science (Moje et al., 2001). Just how students participate depends on many historical, social and cultural factors, including what participants expect to accomplish from their involvement. In circumstances in which there is such a solid coherence in the goals of participating in a chemistry course it is probably essential for the teacher and students to examine the contradictions between what they value, how they participate in class, and visions for science education that focus on inquiry. Through cogenerative dialogue discussions and activities (Roth & Tobin, 2002), it is possible that, over time, the teacher and students will change their values and associated practices. Such an approach to reform is consistent with activity theory (Engeström, 1987) in which the key to change is the identification and resolution of contradictions that exist, not only within a given activity system such as the chemistry class studied here, but between one activity system and another (ideal) form of activity. The resolution of the contradictions like those we have identified in this study point to a need to change the discourse practices that are well established in this particular classroom.

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