J Sci Teacher Educ (2012) 23:745–768
DOI 10.1007/s10972-011-9235-2

Power Dynamics and Questioning in Elementary Science Classrooms

Lori A. Reinsvold · Kathryn F. Cochran

Published online: 6 May 2011

Abstract We describe the dynamic discourse interactions between a teacher and her students in a third-grade science classroom. We focused on how the teacher and students initiate, prompt, respond, and provide feedback; use questioning and power strategies; and how questions are associated with power dynamics. We relate the consequences of teacher use of power to the engagement of student with subject matter. Two classroom sessions were observed and teacher–student interactions audio recorded. Data were transcribed and a method was developed for analyzing teacher-student interactions, power dynamics, and types of questions asked. Results revealed that teacher talk was twice as frequent as students' talk; questions were primarily closed-ended and task-oriented; and students asked few questions. The teacher exercised power by keeping activities organized and conventional, and utilizing subject matter. The developed methods showed us the complexity of question and power dynamics in classroom discourse and have implications for professional development and research.

Keywords Discourse · Questioning · Power · Subject matter

Introduction

To improve science education, researchers are looking closely at how science classroom interactions, specifically discourse between teachers and students, provide opportunities to develop science reasoning and understanding (Candela

L. A. Reinsvold (✉)
Mathematics and Science Teaching (MAST) Institute, University of Northern Colorado, Greeley, CO 80639, USA
e-mail: lori.reinsvold@unco.edu

K. F. Cochran
School of Psychological Sciences, University of Northern Colorado, Greeley, CO 80639, USA

2005; Chin 2007; Cornelius and Herrenkohl 2004; Erdogan and Campbell 2008; Moje et al. 2001; Roth and Lucas 1997; Scott et al. 2006; van Zee et al. 2001). Researchers have been focused on *inquiry-based* science activities where students take the responsibility to collaborate on open-ended investigations and talk with their peers to solve problems (Cornelius and Herrenkohl 2004; Kelly and Brown 2003; Roychoudhury and Roth 1996). Duschl et al. (2006) suggest that in order for elementary students to become successful in building their science knowledge, they must have the opportunity to construct arguments, and organize and articulate evidence through reasoning. Students must be able to explain *how* and *why* they "know" something. For students to reach this high level of thinking, they need opportunities for interactions and engagement with content, peers, and teachers (Engle and Conant 2002).

We are interested in how elementary students build science knowledge in inquiry-based classrooms. Our purpose is to use discourse analysis to identify and describe elementary science classroom episodes and interactions where the teacher and her students use power and questioning strategies to discuss what they know about science. Specifically, we investigated the nature of the questions asked by the teacher and students, and how these questions are associated with classroom power dynamics. We relate the consequences of teacher use of power to the students' engagement of with subject matter content.

Lemke (1990) and Tobin (Tobin et al. 1990) take a socio-cultural perspective on learning, and thus it is through social interactions that students test their understanding and ideas during classroom discourse. Teachers shape the students' ideas by how they engage and respond to students (Wertsch 1998). Teachers direct students to complete established activities or guide them to take responsibility to develop an investigation with their peers. As the tasks unfold, discourse emerges among the teacher and the students, as does the power relations between students and teachers (Fairclough 1989; van Dijk 1996). The social and verbal interactions influence how students talk and act. It is through this participation that students construct their interpretation of what science is (Lave and Wenger 1991; Tobin and Tippins 1993; Vygotsky 1978).

Our discourse analysis is based on the understanding that teacher and students use forms of language to imply certain social purposes (Halliday 1978). Social power relationships exist as students and teachers interact in the science classroom. Van Dijk (1996) describes these classroom interactions as power relationships, "… teachers usually control communicative events, distributing speaking turns, and otherwise have special access to, and control over educational discourse" (p. 86). Critical discourse analysis is used to understand how verbal exchanges create, promote, facilitate, and resist power during classroom conversations (van Dijk 1996, 2003).

The most common dialog structure of interaction in classrooms explored in the literature is the teacher question/student answer/teacher evaluation sequence. This sequence is known as the I–R–E (*Initiation/Response/Evaluation*) framework (Cazden 2001; Mehan 1979). Generally, this framework is assumed to indicate the typical extent of teacher power in the traditional classroom, although Candela (1999) has shown that students have the opportunity to and do exercise power in the science classroom, even within the context of this traditional discourse format. Candela (1999) showed that students exercised power and influenced their teacher's discussion structure by (a) not participating in the discussion, (b) defending their explanations, (c) evaluating teacher and student explanations, (d) questioning the teacher's or other students' explanations, and/or (e) initiating topics for discussion. Teachers maintained classroom control by sustaining the activity task structure, initiating the discussion, and asking questions, but did not control how students responded.

Wells (1999) contended that the teacher *Evaluation* role in this framework can also provide a second, less dominating purpose. He claims, "… the third move [evaluation] functions much more as an opportunity to extend the student's answer, to draw out its significance, or to make connections with other parts of the students' total experience during the unit" (Wells 1999, p. 200). Wells explains that how teachers use the Evaluative role is dependent on the purpose and goals of the lesson. Based on Wells' (1999) perspective, Scott, Mortimer, and Aguiar (2006) expanded the I-R-E dialog to an *interaction chain* in the form of I-R-P-R-P-R-E or I-R-P-R-P-R. In this form, P represents *Prompts* by the teacher which is followed by a *Response* by the student. The dialog is extended as the teacher and students exchange what they know. The conversation could end with a teacher evaluation (E) or remain open without an evaluation. They used the interaction chain to describe shifts in authoritative and dialogic communicative approaches between teachers and students in science classrooms. Through this expanded dialog structure, Scott et al. (2006) found that teachers provided the students with the authority or power to collaborate in small groups to develop and conduct investigations, and share and defend their findings.

The National Science Education Standards suggests that "inquiry into authentic questions generated from student experiences is the central strategy for teaching science" (National Research Council 1996, p. 31). With this perspective, there are opportunities for a teacher's questions to support students to ask each other questions about what they know and why they know it. The inquiry science classroom includes transitions between student-centered and teacher-centered investigations as the teacher guides the student to question aspects of the science investigation (Chin 2007; Cornelius and Herrenkohl 2004; King 1994; Roth 1996; van Zee et al. 2001; van Zee and Minstrell 1997).

Researchers (Scott et al. 2006; van Zee and Minstrell 1997) show that high level reasoning and open-ended questioning allow students to engage with more than just facts and determine *how* and *why* they "know" something. A study by van Zee and Minstrell (1997) found that a physics teacher, Minstrell, used a questioning strategy identified as a *reflective toss*. Minstrell used this strategy to recognize a student's knowledge by inviting the student into a conversation with a reflective toss. A reflective toss is a statement that captures the student's comment and then asks the student to describe his or her thinking about the content. Minstrell believed that seeking clarification of the student's understanding within a respectful class discussion would refine the student's alternative conceptual understanding of a physics topic (Smith et al. 1993/1994; van Zee and Minstrell 1997). Minstrell used the reflective toss to accomplish three outcomes: engage students in thinking about a proposed method, refine the students' understanding of the method, and allow the students and teacher to discuss and evaluate the proposed method. Minstrell's questioning strategy, reflective toss, engaged students in the cognitive processes to build their understanding of science (Kelly 2007).

Power dynamics are influential in the classroom (Bianchini 1997; Scott et al. 2006; Shepardson and Britsch 2006). If a student's response does not support the "school science" point of view, teachers may exercise the power to reshape or ignore the student's ideas. Lemke (1990) states "Teachers and students have grossly unequal power in the classroom. The teacher is the representative of adult authority and backed up, at least in theory by the power of force as well as by the tradition of the schools. That difference in power extends to the control of dialog itself, both its form and its content, that is, both the activity structure and the thematic" (p. 44). Wang (2006) has shown that the nature of questions is related to power dynamics in adult discourse in non-school settings such as in institutional or formal dialogue and casual conversations. Some participants in institutional dialogues (e.g. doctor/patient; judge/lawyer; manager/cashier) have dominant roles, and they assign questions and control the overall structure of dialogue. There is unequal power and status within this dialogue. Even in casual conversations, a participant controls a temporary topic of the conversation by determining the type and sequence of the questions. When a person controls the conversation, he or she holds the central position of the conversation. Wang believed those in formal and casual dialog who used questions to control turn-taking and topic held power in the conversation.

Thus, teachers have the power to provide questioning strategies that allows student to evaluate their understanding, to provide evidence for their claims and ideas, to apply what they know to a novel topic, and in general, to reason at a higher level about what they know about science, but do they use it? How does this power relate to classroom questions? The questions addressed in this study focus on the relationships between the nature of classroom power dynamics, the types of questions asked, and the engagement of students and teachers with science subject matter.

Method

Participants and Classroom Setting

Purposeful sampling (Creswell 2007) was used to identify potential teacher participants using the following criteria: (a) the school district's science coordinator identified them as seeking effective science teaching strategies; (b) they taught science 2 to 3 days weekly; and (c) they volunteered. The first 2 teachers contacted met all criteria and were selected, one teaching first grade and one teaching third grade. Both were European–American.

The focus of this paper is on the third grade classroom. The classroom contained 21 students; 13 were European–Americans, and 8 were Latina/Latino students who were English Language Learners and who had attained the school district's literacy benchmarks before learning science. The students were studying magnetism and electricity from the Full Option Science System (FOSS) curriculum (The Regents of the University of California 2005). The FOSS system is designed as inquiry-based instruction, and the lesson format in the classroom followed the published FOSS materials. In the first class session students reviewed basic information about magnetism and performed an activity where they placed magnets within closed boxes and then attempted to locate them with other magnets, compasses, or small plastic bags containing iron filings. In the second classroom session, students were asked to complete an electrical circuit using a circuit board, a battery, a light bulb, wires, and a switch.

The teacher, Ms Creston (a pseudonym), taught at a new elementary school that had been open for 2 years. Like the school, the surrounding homes were new and occupied mainly by middle-class families. Ms Creston was an experienced elementary teacher of 26 years. She possessed a master's degree in elementary education and had participated in over 30 h of professional-development work in inquiry-based science education. She had collaborated with other teachers in her school in planning inquiry science lessons and worked with other teachers at a school-district level in planning science across all elementary schools. She had contributed significantly to the development of her new elementary school, and to science education within the school district.

Ms Creston revealed that the first classroom session observed in this study was the sixth science lesson for the eight English Language Learners (ELLs) in her class. They had attended school for 5 months, and prior to coming to her classroom, these students had been required to develop their literacy skills by attaining third-grade literacy benchmarks established by the school district administration. She indicated that these ELL students had few experiences in learning science; she noticed that they were shy, did not respond to her questions, and did not like to write during science lessons. However, she said that they appeared to enjoy manipulating science materials. In an interview, Ms Creston stated that she assigns roles to her students in order to engage them and gives them opportunities to explore activities. She said this practice comes from learning about the 5E instructional model from BSCS (Bybee et al. 2006), a model based on the inquiry perspective.

Data Collection and Preliminary Analyses

The results reported in this paper are based on observations and audio recordings of two complete 50-min science lessons conducted 2 weeks apart in the spring of 2007. An Apple iPod with a microphone was attached to the teacher's waist and used to record all teacher speech and all teacher-student interactions. After each observation a 30-min interview was conducted to explore the teacher's interpretation of what occurred during the science lesson. Field notes were also collected. The field notes and teacher interviews were used to understand the classroom context, the curriculum used, and the general nature of the students, and to assist with the coding process.

The data analyses were conducted in two phases. Phase 1 was the transcription of all classroom interaction audio recordings into a Microsoft Word table from mp3 files stored in iTunes. All names were changed to pseudonyms. The transcripts were initially organized into the Initiation-Response-Evaluation (I-R-E) framework from Cazden (2001) and Mehan (1979). However, as we began the transcription process we realized the limited nature of the original I-R-E framework. These limitations led us to add a Prompt role following Scott, Mortimer, and Aguiar (2006), and two additional Response roles, one each for the Prompt and Feedback roles. The Evaluation role was relabeled "Feedback" based on Wells (cited in Cazden 2001). We created a final six level framework that included the following Participation Roles categories; *Initiation*, *Response 1*, *Prompt*, *Response 2*, *Feedback*, and *Response 3*. Table 1 provides the definitions and examples of the six Participation Roles. The examples enclosed in double brackets are directly and temporally related.

Before coding the data, we trained ourselves by creating coding definitions and coded unrelated transcribed data sets from Lemke (1990). Then each researcher separately coded the data into a matrix and we assessed the coding for agreement. We also coded the data into three Participant categories, *Student* (S), *Students* (Ss) (meaning multiple student responses at the same time, sometimes in unison), and *Teacher* (T). Agreement on the coding of Participants and the Participation Roles ranged from 97 to 99%, and all differences were resolved through discussion. The

Table 1 Definitions and examples of participation roles

Participation role	Definitions	Examples
Initiation **(I)**	The teacher or student may ask a question or make a statement or comment that starts a sequence on a specific topic. Includes rhetorical questions, providing initial foundational information for a task, or setting the stage for a task.	[[T: Think about your graph… Did it go up? Did it go down?
Response 1 **(R1)**	The teacher or student may provide a question, statement, or comment that is related to or occurs as a result of an Initiation.	S:.. it went down.]]
Prompt **(P)**	The teacher or student may provide a question, statement, or comment that focuses on *continued engagement* on the topic and encourages or seeks conceptual understanding. This includes the facilitation of the student's verbal explanation or seeks elaboration or clarification of what is said. This also includes teacher questions or statements reminding students of appropriate behavior.	T: When was the force the strongest? S: So do we move them again?
Response 2 **(R2)**	The teacher or student may provide a question, statement, or comment that relates to or occurs as a result of a Prompt.	[[S: With just one spacer.
Feedback **(F)**	The teacher or student may provide a question, statement, or comment that conveys a level of correctness, appropriateness or usefulness of an idea, understanding, or an evaluation of student behavior.	T: With just one spacer.]] T: Yes
Response 3 **(R3)**	The teacher or student may provide a question, statement, or comment that relates to or occurs as a result of Feedback.	S: Ok

transcription conventions were mostly adapted from Adger (2003) and are included in "Appendix 1". An example of our final matrix is found in the "Results" (see Table 4).

During Phase 2 of the data analyses, we coded the data for power and questioning dimensions using QSR NVIVO 8 qualitative data analysis software (QSR International). These two dimensions were coded separately by each researcher and then cross-verified. For the power dimensions, six categories were developed to describe the nature of the power dimensions observed. These categories were adapted from the descriptions and characteristics of classroom power dynamics previously described (Gore 2002; Lemke 1989; Wang 2006). After the first coding of the power dimension, our coding consistency was approximately 75%. All differences were resolved entirely through discussion to reach 100% agreement, and the definitions of each category altered to reflect important distinctions between categories. Power categories, definitions, abbreviations and examples are found in Table 2.

For the analysis of classroom questions, we adopted Erdogan and Campbell's (2008) qualitative coding scheme for question characteristics, which was modified from Graesser and Person's (1994) original design. The main categories included *closed-ended questions*, *open-ended questions,* and *task-oriented questions*. In general, we defined closed-ended questions as requiring a brief word or phrase response, placing little cognitive demand on or subject matter engagement from the students. Open-ended questions required more extended answers, student reasoning, and student subject matter engagement. Task-oriented questions were used to clarify directions as students interacted with classroom activities.

Question types were also coded separately by each researcher and cross-validated. Initial coder agreement on the three major types of questions was approximately 80% and all differences were resolved via discussion and revision of the category definitions. The three categories of questions and their types are described in Table 3. We contend that open-ended question categories two through seven are consistent with inquiry and constructivist views of science teaching.

Results

We initially investigated the results from the two classroom observations separately; however, we found few differences across the two sets of data. As a result, the findings reported here are not differentiated by observation, but are combined across the two third-grade class sessions. We first report a few quantitative results to provide an overview, followed by qualitative descriptions of the relationships between power dynamics and questioning.

Total Utterances and Participant Roles

Teacher utterances were significantly more frequent than student utterances and thus dominated the classroom sessions, $X^2(1) = 102.5$, $p < .001$. More than two-thirds (68%) of the 796 total statements and questions recorded and coded were teacher utterances. Student utterances represented the remaining 32%. Also, the

Table 2 Definitions, abbreviations and examples of power categories

Category	Definitions	Forms	Examples
Conventionality Power	These indicate control supporting the conventions and rules (procedural and non-subject matter) in the classroom, including behavioral reminders, feedback, reinforcements, and punishments.	Teacher Conventionality Power **(TCON)**—Includes behavioral reminders Student Conventionality Power **(SCON)**—Indicates "buy in" to conventional classrooms rules and includes UNISON group responses	**TCON**—Marsha, Fred, and Jeff, you will be in this group.. **SCON**—Can I pass out the hand lenses?
Organizational Power	These indicate control of subject-matter procedures in the classroom activities or recall of a previous activity.	Teacher Organizational Power **(TOR)** Student Organizational Power **(SOR)**	**TOR**—We want to be scientists and make careful observations. **SOR** –We should write our conclusions so we don't forget.
Individual Voice Power	The use of I; or the indication of an individual having an opportunity to speak; or referring to a specific person's idea, conception or contribution.	Student Individual Voice **(SIV)** Teacher Individual Voice **(TIV)** Teacher Student Individual Voice **(TSIV)**—The teacher acknowledges a student's voice, usually by name or in the context of a specific conversation, including a small group. Does not include behavioral reminders. This power code only applies to the teacher's comments	**SIV**—I never thought of that. **TIV**—I need to look up the meaning of radioactive. **TSIV**—Mark what do you think? What did your group decide?
Group Power	Explicit or implicit use of a "we" perspective or acknowledges a group-level or consensus idea(s).	Teacher Group Power **(TGR)**-Includes classroom level responses Student Group Power **(SGR)**-Includes students' responses in unison	**TGR**—We looked at force on Friday **SGR**—Our group thinks so too
Subject Matter Power	Speakers use the discipline as a source of knowledge, to clarify or explain subject matter concepts, using the discipline vocabulary, and demonstrates owner-ship of subject matter ideas.	Teacher Subject Matter Power **(TSM)** Student Subject Matter Power **(SSM)**	**TSM**—When we make a prediction we are stating a hypothesis. **SSM**—The rock is red, so it must be an asteroid

distributions of teacher utterances and student utterances across the six Participation Roles of Initiation, Response 1, Prompt, Response 2, Feedback and Response 3 were significantly different, $X^2(5) = 347.3$, $p < .001$ (see "Appendix 2"). Overall

Table 3 Question categories and types, definitions, and examples

Question type	Definitions	Examples
Closed-ended questions		
1. Verification **(CEV)**	Requests a yes or no response.	Do we get them now?
2. Disjunction **(CED)**	Request a decision between two options.	Did it go up or down?
3. Concept completion **(CECC)**	Fills in the blank or completes a definition.	Magnetism is what kind of …..? This is called a what?
4. Feature specification **(CEF)**	Determines qualitative attributes of an object or situation.	What other categories can we use to categorize the types of rocks we have observed?
5. Quantification **(CEQ)**	Determines quantitative attributes of an object or situation.	How many categories can we use to sort our rocks?
Open-ended questions		
1. Definition **(OED)**	Ask for or determines meaning of a concept.	What is size?
2. Interpretation **(OEI)**	Seeks a description of what can be inferred from pattern of data. Often includes a "How do you know?" type of question.	How would we describe a size that is between small and big?
3. Causal antecedent **(OECA)**	Seeks an explanation of what state led to the current state.	What caused the motor to turn on?
4. Causal consequence **(OECC)**	Seeks an explanation of the consequence of an event.	What would happen to the layer of silt in the water if we shook the bottle?
5. Enablement **(OEE)**	Seeks an explanation of process that allows a person to perform an action. Can include referencing a learner by name.	How would you figure out where the magnets are inside the box?
6. Expectational **(OEEX)**	Seeks expectations or predictions.	Before you connect the wires to the motor, what will happen to the motor when you close the switch?
7. Judgmental **(OEJ)**	Seeks a value placed on idea, advice, or plan.	What do you think about their plan to find the magnet?
Task-oriented questions		
1. Monitoring **(TOM)**	Checking on progress of a task, seeks a plan. Not generally related to content.	I am going to put some circles over here on the board, okay?
2. Need clarification **(TONC)**	Seeks clarification of a statement or confirmation of previous statement. Not generally related to content.	I am sorry, I did not hear you. You said a compass is a magnet?
3. Requests/directive **(TORD)**	Request a specific action or a response. Includes calling on a student, either by name or implicitly. Not generally related to content.	Can you help her think of how size can be described? Look at this one

teacher control of verbal activity is revealed by high frequencies in Initiation, Prompt, Response 2, and Feedback categories.

Students' utterances occurred mostly in the Response 1 and Response 2 categories. The number of student Initiations and Prompts were also low and there were only six student utterances coded as Response 3. Finally, there were no student Feedback utterances at all. We interpret these data to show that students are responding to the classroom activities in a passive manner, rather than in the engaged, active mode expected in an inquiry classroom.

Power Categories

Next we compared the distributions of power categories across teachers and students, and found evidence for a high level of teacher control in the classroom despite the intended inquiry approach of the activity (see "Appendix 3"). Student and teacher power dynamics were substantially different from each other, $X^2(5) = 598.2$, $p < .001$. Moreover, the teacher used Organizational power and Subject Matter power the most, followed by Conventional power, showing that in spite of the inquiry focus of the curriculum, the teacher exercised power in very traditional ways. The following is an example of almost classic recitation where the teacher uses Organizational power to review magnetism concepts:

T {Initiation}: Ok are we going to be using this word anymore?
Ss {Response 1}: No {in unison, reading off board}
T {Feedback}: No=
T {Prompt}: = we are going to be using these two words, right?
Ss {Response 2}: yes
T {Prompt}: = we are going to be using these two words, right?
Ss {Response 2}: yes
T {Prompt}: And we know we are talking about what?
Ss {Response 2}: magnets
T {Feedback}: the force, right? {no wait time}

Student control tended to be primarily in terms of Student Individual Voice power (36%) and Student Subject Matter power (30%) showing that the students were indeed talking about science subject matter, which Lemke (1990) argues is crucial for the development of science understanding. This result is consistent with Candela's (1999) finding that students can and do exercise power in the classroom, even when the teacher creates a more traditional structure.

Questioning Categories

The overall frequencies of questioning between teachers and students and across the three major categories of questions were compared (see "Appendix 4"). There were high frequencies of teacher questions compared to student questions. Of the 383 questions coded, students only asked 25 questions (7%) in both class sessions combined, and the teacher asked 358 questions (93%). The differences between the three types of teacher questions showed *fewer* open-ended questions than any other type, $X^2(2) = 48.52$, $p < .001$ contrary to expectations based on the inquiry nature of the FOSS materials. The example of the magnetism review above also shows that the teacher is using closed-ended questioning. Only 17% of teacher questions were open-ended (see "Appendix 4"), with the majority of those being Interpretation and Enablement such as in the two unrelated examples below:

T {Prompt}: OK show me.. show me the electricity flow. If I could be a piece of electricity, how would I travel? {Enablement}

T {Prompt}: Now watch it,. it does something. Whoa, what did it do? {Interpretation}

Frequency differences across types student questions were not statistically compared due to small numbers of observations.

In addition, there were only *two* open-ended questions asked by students in *both* classroom sessions combined. One of these questions was regarding the definition of a word and was coded in the Definition category of open-ended questions. While technically this question is open-ended, it does not reveal a very high level of student subject matter involvement as shown in the teacher-student exchange below:

T {Initiation}: All right, here is your quartered paper. OK, I want you to [record…]

S {Initiation}: [What's record mean?]

The only other student generated open-ended question was found as a component of a more complex exchange between a student and the teacher and will be described in more detail below as we describe relationships between power and questioning dynamics.

Dynamic Relationships Between Power and Questioning

While these data contain much information about power and questioning, we elected to narrow our perspective for the current analyses. In order to explore the complex dynamic relationships between power and questioning, and since these lessons were intended as inquiry science instruction, we took the perspective that the teacher's use of power and questioning should facilitate and enhance the engagement of students with science subject matter. Thus, for the purposes of this study, we evaluated the contexts of students' use of Subject Matter power (SSM) by looking at the episodes where students engaged with subject matter. Then we looked at the relationships between those episodes and teacher power and questioning.

Open-ended Question Success

In the episode shown in Table 4, students are working in small groups building and testing an electrical circuit. The teacher required them to incorporate a switch into the circuit and she walked among the groups to monitor their progress. This episode is one where Student Subject Matter power (SSM) is quite dense and the students are obviously engaged. This is also an episode that shows a rare case of a student using Initiation. Moreover, the teacher uses Subject Matter power (TSM) and

Table 4 Coded episode showing the relationship between teacher power and student subject matter power **(SSM)**

Time	Initiation	Response 1	Prompt	Response 2	Feedback	Response 3
27:11	S: We got it with the switch. **(SSM/SIV)**					
27:16					T: Did you? **(TCON/CEV)**	
27:17			T: OK, open it. OK close it. Open. Close it. {motor going on & of} **(TOR/TSM)**			
			T: What do you guys think? **(TSIV)**			
					T: = Is that pretty cool? **(TCON/CEV)**	
27:33			T: OK show me… open the circuit.. {inaud} show me the electricity flow.. show me the electricity flow. how is the electricity is moving. **(TOR/TSM)**			
				S:{inaud} this one {inaud} then this goes through this {inaud} onto this because that's right there and it connects to {inaud}.. **(SSM)**		

Table 4 continued

Time	Initiation	Response 1	Prompt	Response 2	Feedback	Response 3
			T: OK so you are saying it starts here with the D cell, it follows this wire.. **(TSIV/TSM)**			
				S: yah, yah **(SIV)**		
			T: It makes the receiver what?… do something.. and then it comes out.. out of the receiver into the switch? **(TSIV/TOR/ CECC*/CEV/ TSM)**			
				S: uhuh, and then the switch needs to go over here and then it goes.. **(SSM)**		
28:23			T: OK why is this not connected? **(TOM/ TSIV/TSM)**			
				S: {inaud}		
			T: You need to have that connected…. OK close it.. **(TOR/ TSM)**			
					T: Cool. Alright, very good. **(TCON)**	

Table 4 continued

Time	Initiation	Response 1	Prompt	Response 2	Feedback	Response 3
28:55			T: OK show me.. show me the electricity flow. If I could be a piece of electricity, how would I travel? **(TOR/OEE*/TSIV/TSM)**			
				S: you would travel, you would.. {inaud} the battery..		
				S2: D cell **(SSM)**		
			T: what is this called?			
			(TOR/CEF/TSIV)			
				S: D cell **(SSM)**		
				S: and hook it up to all of these **(SSM)**		
			T: but which way.. what you think? How do you think it moves?			
			Use your fingers.			
			(TOR/OEI*/TSIV/TSM)			
29:21					T: There you go! **(TCON)**	

Table 4 continued

Time	Initiation	Response 1	Prompt	Response 2	Feedback	Response 3
				S: {inaud} most of the power will go around.. **(SSM)**		
			T: What does this do? **(TOR/CEF/OECC/TSIV)**			
				S: It turns it on and off **(SSM)**		

Abbreviations refer to power categories in Table 3

Asterisks represent open-ended teacher questions

Time indications represent the beginning of the utterances

Organizational power (TOR) during this activity, and she uses her Teacher-Student Voice power (TSIV) in a way that gives students opportunities to respond and express their understandings (Student Individual Voice power - SIV) of science. Finally this episode includes the teacher asking open-ended questions, specifically Enablement (OEE), Causal Consequence (OECC) and Interpretation (OEI) questions, as well as closed-ended questions, including Concept Completion (CECC), Feature Clarification (CEF) and Verification (CEV) questions (see "Appendix 4").

We have characterized this episode as a subject matter engagement opportunity for students and we see it as a context in which student–teacher discourse supports science subject matter learning. This is supported by the three open-ended questions embedded in this exchange, shown by the asterisks in the table, and by the continuous use of Student Subject Matter power (SSM).

Of the 61 total teacher open-ended questions in these two classroom sessions, the majority occurred as Prompts in the discourse; showing that these questions were asked in a discussion-oriented context, which is often considered a component of inquiry instruction (van Zee et al. 2001). Only two teacher open-ended questions occurred as Initiations, showing that the dynamic of open-ended questions and Student Subject Matter power is more obvious in the small group setting where students are conducting science investigations. This finding is consistent with expectations in an inquiry setting.

Interestingly however, only about half of the teacher's open-ended questions contain science subject matter, showing that teachers can encourage SSM in multiple ways. Often the teacher Prompts the students by non-subject matter questions such as "What did your group decide?," "What does it do?," and "What do you guys think?" These open-ended questions often resulted in students exercising their Individual Voice Power (SIV) to share their subject matter understanding, a finding supporting the contention that student engagement is enhanced through higher level questioning. This evidence is consistent with the position (Erdogan and Campbell 2008; Redfield and Rousseau 1981; Scott et al. 2006; van Zee and Minstrell 1997) that these questioning practices enhance student meaningful learning and exploration of ideas within classroom discourse.

The Episode of Jane: Open-ended Question Failure

In contrast to the episode above, another episode when the students were studying magnetism also shows the teacher using open-ended questions. However, in this episode, the questions were followed by virtual silence and lack of student engagement. The goal of the magnetism activity was to have the students use a compass and a small plastic bag of iron filings to find magnets hidden inside a small closed box. First, the teacher had the students practice by observing and discussing the effects of a magnet on the compass and filings. This initial exploration is followed by having small groups of students hide two magnets inside closed boxes for another group of students to find. She starts this component of the lesson with nearly 2 min of specific instructions which, although she does include some subject matter, consists mainly of Teacher Conventionality Power, Teacher Organizational

Power, and Task Oriented (Monitoring and Requests/Directive) questions. Her comments include the following examples:

T {Feedback}: Bridget put it down… (Time: 25:30)
T {Initiation}: You may not exchange these boxes until I tell you to. I'm going to give you… oh.. about a minute… two minutes to detect 'em. And I am going to say give me 10 and we'll rotate 'em. Alright? Any questions?… know exactly what you're going to do? (Time: 26:34)
T {Feedback}: ok, wait. Not yet Ted… I just told you. OK. (Time: 26:49)

Without any teacher prompting, one student, Jane (a pseudonym), responds with an open-ended question by raising her hand and after the teacher calls on her, Jane asks how to indicate the location of the magnets in the closed box:

Jane {Response 2}: Well, if you put one of the magnets on the bottom of the box and one on the top to separate them for magnets far apart, how will you be able to write that other magnet when… this paper… (Time: 26:56)
T {Feedback}: {interrupting} OK,.. that is a good question.
T {Prompt}: She said what if one's on the back? OK? And Lucy's going to help me with this one.
T {Prompt}: OK, Jane's right, there might be one on the back. There might be one on the side.

No responses from students followed (including Jane and Lucy), and the ensuing teacher talk sequence covered about 30 s:

T {Prompt}: How would you label that? How would you label that? It'd be very easy I think. How would you label that?… Say for instance this one's on the back. What would I do? Think about it. Would I just leave it at that? What would I do?… If someone looked at that and one of those magnets was on the back, how could I do something so when they looked at that they would say… "Oh, I can see that." How can they see that? What do you need to do? (Time: 27:27)

This attempt to engage students resulted in only whispers, so the teacher persists:

T {Prompt}: OK give your idea to somebody in your group. What would you do? Huddle and let's see. Huddle with your group… What could you do? (Time: 28:37)

More students' whispering occurs, and the teacher tries again:

T {Prompt}: Alright, alright, give me your attention. Each person… I am going to ask this group… what did you guys decide? How could you do this? (Time: 29:07)

Jane responds again by suggesting a method for indicating the magnet locations:

Jane {Response 2}: {inaudible} We could maybe even take and put a line and make one part the front and one part of the back.

The teacher restates Jane's suggestion as feedback and then asks another open-ended question of a different small group of students; one responds:

T {Prompt}: What did your group decide? (Time 29:45)
S {Response 2}: umm.. we could have put a B for back and an S for side.

Then the teacher switches to a series of closed ended questions and receives almost unison student responses in return. About 1 min later the teacher allows the students to actually begin the process of finding magnets inside the boxes:

T {Initiation}: Alright are you guys ready to exchange? When I count to three you may exchange your box with the other group. One. Two. Three. (Time: 31:05)

Teacher power and control is indicated here in many ways. First, more than 5 min elapsed from the beginning of this episode until the time that the students actually started the activity. Second, the teacher twice provided behavioral feedback to students requiring them to conform to the classroom conventions of sitting down and waiting. Third, after the teacher attempted to engage students and Jane responded with a well thought out inquiry about the activity, the teacher interrupted her. This episode is not intended as an evaluation of the teacher, but as an example of the integrated and *mutually dependent* nature of the relationships between teacher and students. These dynamics need to be more fully explored.

Closed-ended Questions and Student Subject Matter Power

Since a large portion of the teacher's questions were closed-ended, particularly Verification, Concept Completion, and Feature Specification questions (see "Appendix 4"), we investigated the episodes where these question types were related to Student Subject Matter power (SSM). First, the teacher's Verification questions (of which there were 94 total), are followed by SSM responses only about 25% of the time. These questions range from simple teacher comments like "OK?" or "Am I right?" to those that include more specific reference to science concepts such as "When magnets pull together we say they what?" On the other hand, we found that SSM responses were more common for teacher questions coded as Concept Completion or Feature Specification. This result implies that not all closed-ended questions are equally limited with respect to the extent to which they engage students in science. While students may more readily respond to close-ended questioning, the connections between teacher's questions and students' use of science subject matter are much more complicated than anticipated.

Task oriented Questions and Student Subject Matter Power

Finally, we looked at the relationships between Task Oriented teacher questions and SSM responses and found that few Task Oriented questions related to students' discourse of science. Less than half of the task oriented questions related to science subject matter at all. While keeping learners on task is certainly a crucial part of monitoring and conducting classroom activities, we conclude that this component of teacher questioning is not likely to be useful in enhancing student engagement in inquiry science and that focus on task monitoring might be overemphasized in many settings.

Conclusions and Implications

We found that while some of these classroom interactions did show teacher open-ended questions and enhanced student power considered to be the essence of inquiry instruction, some of these interactions did not. Thus, the implementation of inquiry teaching in order to enhance student higher-level reasoning may be much less common or straightforward than expected. The observed classroom discourse tended to be controlled by the teacher using traditional power strategies even though she was using inquiry materials, was familiar with those materials, and had experienced relevant professional development. The interactions in these classroom settings resulted in limited student subject matter discourse that seemed dependent on closed-ended questioning. Although the students were indeed “talking science” as Lemke (1990) would advocate, we do not see Lemke’s ideal fully implemented. The frequent advice given to teachers to ask more open-ended questions and to keep students engaged is clearly simplistic. It may be necessary and to help teachers with creating specific *types* of open-ended questions and the specific contexts in which those questions might be asked. In our experience, teachers are asking for this type of information, but it is not being provided. Moreover, even in the FOSS materials, we did not find the information about using questioning to be adequately explicit.

From a research perspective, we have yet to really understand what instigates and sustains students’ full engagement in inquiry discourse. We certainly need a more detailed analysis of teacher-student interactions if we expect teachers to meet students’ needs and to enhance science understanding for all learners. This study has shown us the complexity of these dynamics, and the methods developed here will allow more in-depth investigations into questions such as the following. Are teachers aware of these dynamics and what it takes to improve them? How could this particular teacher be supported to create classroom exchanges that would encourage more open-end exploration of subject matter ideas? How well do curriculum materials and professional development activities succeed in enhancing the abilities of teachers to engage students in science? How do students perceive these dynamics? How do these dynamics effect the engagement and achievement of students of color, girls, English Language Learners, and special education students?

Finally, the evidence presented here also relates to recent work that reveals teachers’ extensive use of labeling rather than interpretation to help students understand science concepts (Glen and Dotger 2009). We suspect that these labeling processes may be consistent with the categories of closed-ended questioning used in the current study, and there is a possibility that this focus on terminology is a side effect of literacy practices. Because literacy instructional practices were mandated by the district administration, the teacher in our study used a scripted reading curriculum. This recitation structure and practice may influence how the teacher interacts with the students in the inquiry science classroom. The students seemed to use the recitation exchange in the science classroom; they sometimes responded in unison to the teacher. We question whether the literacy learning experiences influence students' ability to respond to open-ended questions, and influence the teacher's use of more close-ended questions than open-ended questions when engaging the students in what they know about science. It may also be influencing other subject matter areas as well, such as mathematics.

This issue is also relevant for the way in which in-service activities are conducted. While it seems efficient to provide professional development sessions for different subject matter areas separately, we believe it is important to consider the effects of in-service in one area on the teaching of other subject matter areas. Given the integrated nature and complexity of teachers' daily activities, it may be unrealistic to expect even experienced teachers to be able to alter their teaching of different subject matter areas in different ways. Further, we need to be aware that some professional development activities might have unintended, even negative, consequences.

A few limitations of this study make our conclusions tentative. First, these data do not include specific indicators of student *learning*, either short term or long term. Verbal indications of Student Subject Matter power in the discourse show student engagement with science, but more study is necessary to determine the relationships between student learning and use of subject matter in various aspects of classroom activities. Second, our data do not include representations of *student-to-student* discourse dynamics, which also needs to be addressed from the perspective of interactions between power and questioning, particularly with respect to what forms of student-to-student discourse is allowed or encouraged by the teacher. Third, these data reveal only some of the dynamics in only two classroom sessions of only one teacher. We have begun the investigation of other teachers' classrooms and are finding wide diversity in these interactions that clearly need further analysis.

This study describes a method for the analysis of classroom science discourse that has potential for the investigation of the complexity of teacher-student interactions and relationships. This framework for describing classroom interactions holds promise for the in-depth investigation of inquiry processes, student engagement in subject matter content, and resulting student achievement. This approach may also be useful for enhancing pre-service, in-service, and professional settings to help teachers enhance their effective use of inquiry instruction, questioning strategies, and the wielding of classroom power and its consequences.

Appendix 1

See Table 5.

Table 5 Transcription conventions

Code	Meaning
T	Teacher
S	One student
Ss	Multiple students
.	Period, end of sentence
?	Question
.	One second pause
..	Two second pause, where each period is an additional pause
Line	An emphasis when speaking above the normal speech level
CAP	Extra emphasis when speaking at a shouting level
[]	Indicates overlapping speech between two or more people
=	Speaker's talk continues or second speaker's talk is latched onto first speaker's without noticeable pause
()	Nonlinguistic sounds, e.g. Laughing
↑	Rising intonation
↓	Falling intonation
{ }	Comments by transcriber

Appendix 2

See Table 6.

Table 6 Comparison of student and teacher utterances across the six participation roles

Participation roles	Students		Teachers	
	#	(%)	#	(%)
Initiation	11	(6)	197	(31)
Response 1	64	(38)	4	(>1)
Prompt	24	(14)	186	(30)
Response 2	64	(38)	98	(16)
Feedback	0		141	(22)
Response 3	6	(4)	1	(>1)
Total utterances	169	(100)	627	(100)

Appendix 3

See Table 7.

Table 7 Comparison of student and teacher power categories

Power categories	Students		Teachers	
	#	(%)	#	(%)
Conventional	30	(6)	176	(18)
Organizational	44	(10)	305	(32)
Individual voice	162	(36)	27	(3)
Teacher–student voice	0		119	(12)
Group	82	(18)	56	(6)
Subject matter	136	(30)	285	(29)
Total utterances	454	(100)	968	(100)

Utterances are often coded into more than one power category

Appendix 4

See Table 8.

Table 8 Comparison of student and teacher questioning categories

Question type	Students	Teacher
Closed ended total	14	167
Verification	13	94
Disjunction	1	5
Concept completion	0	40
Feature specification	0	28
Quantification	0	0
Open-ended total	2	61
Definition	1	6
Interpretation	0	25
Causal antecedent	0	0
Causal consequence	0	0
Enablement	1	2
Expectational	0	3
Judgmental	0	4
Task oriented total	10	130
Monitoring	9	73
Need clarification	0	3
Request/directive	1	54
Total questions	26	358

References

Adger, C. T. (2003). Discourse in educational settings. In D. Schiffrin, D. Tannen, & H. E. Hamilton (Eds.), *The handbook of discourse analysis*. Malden, MA: Blackwell.

Bianchini, J. A. (1997). Where knowledge construction, equity, and context intersect: Student learning of science in small groups. *Journal of Research in Science Teaching, 34*(10), 1039–1065.

Bybee, R. W., Taylor, J. A., Gardner, A., Scotter, P. V., Powell, J. C., Westbrook, A., et al. (2006). *The BSCS 5E instructional model: origins, effectiveness, and applications* (pp. 1–19). Colorado Springs: Biological Science Curriculum Studies.

Candela, A. (1999). Students' power in classroom discourse. *Linguistics and Education, 10*(2), 139–163.

Candela, A. (2005). Students' participation as co-authoring of school institutional practices. *Culture and Psychology, 11*(3), 321–337.

Cazden, C. (2001). *Classroom discourse: The language of teaching and learning* (2nd ed.). Portsmouth, NH: Heinemann.

Chin, C. (2007). Teacher questioning in science classrooms: Approaches that stimulate productive thinking. *Journal of Research in Science Teaching, 44*(6), 815–843.

Cornelius, L. L., & Herrenkohl, L. R. (2004). Power in the classroom: How the classroom environment shapes students' relationships with each other and with concepts. *Cognition and Instruction, 22*(4), 467–498.

Creswell, J. W. (Ed.). (2007). *Qualitative inquiry & research design, choosing among five approaches* (2nd ed.). Thousand Oaks, CA: Sage.

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (2006). *Taking science to school: Learning and teaching science in grades K-8*. Washington, DC: National Academies Press.

Engle, R. A., & Conant, F. T. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction, 20*, 399–484.

Erdogan, I., & Campbell, T. (2008). Teacher questioning and interaction patterns in classrooms facilitated with differing levels of constructivist teaching practices. *International Journal of Science Education, 30*(14), 1–24.

Fairclough, N. L. (1989). *Language and power*. London: Longman.

Glen, N., & Dotger, S. (2009). Elementary teachers' use of language to label and interpret science concepts. *Journal of Elementary Science Education, 21*(4), 71–83.

Gore, J. M. (2002). *Some certainties in the uncertain world of classroom practice: An outline of a theory of power relations in pedagogy*. Paper presented at the Annual Meeting of the Australian Association for Research in Education.

Graesser, A. C., & Person, N. (1994). Question asking during tutoring. *American Educational Research Journal, 31*, 104–137.

Halliday, M. (1978). *Language as social semiotic: The social interpretation of language and meaning*. London: Arnold.

Kelly, G. J. (2007). Discourse in science classrooms. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research in science education*. Mahwah, NJ: Lawrence Erlbaum Associates.

Kelly, G. J., & Brown, C. (2003). Communicative demands of learning science through technological design: Third grade students' construction of solar energy devices. *Linguistics and Education, 13*(4), 483–532.

King, A. (1994). Guiding knowledge construction in the classroom: Effects of teaching children how to question and how to explain. *American Educational Research Journal, 31*(2), 338–368.

Lave, J., & Wenger, W. (1991). *Situated learning: Legitimate peripheral participation*. New York: Cambridge University Press.

Lemke, J. L. (1989). Making text talk. *Theory into practice, 28*(2).

Lemke, J. L. (1990). *Talking science: Language learning, and values*. Westport, CN: Ablex Publishing.

Mehan, H. (1979). *Learning lessons*. Cambridge, MA: Harvard University Press.

Moje, E., Collazo, T., Carillo, R., & Marx, R. (2001). Maestro what is 'quality?': Language, literacy, and discourse in project-based science. *Journal of Research in Science Teaching, 38*, 469–498.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academies Press.

Redfield, D. L., & Rousseau, E. W. (1981). A meta-analysis of experimental research on teacher questioning behavior. *Review of Educational Research, 51*(2), 237–245.

Roth, W. M. (1996). Teacher questioning in an open-inquiry learning environment: Interactions of context, content, and student responses. *Journal of Research in Science Teaching, 33*(7), 709–736.

Roth, W. M., & Lucas, K. B. (1997). From "truth" to "invented reality": A discourse analysis of high school physics students' talk about scientific knowledge. *Journal of Research in Science Teaching, 34*(2), 145–179.

Roychoudhury, A., & Roth, W. M. (1996). Interactions in an open-inquiry physics laboratory. *International Journal of Science Education, 18*(4), 423–445.

Scott, P. H., Mortimer, E. F., & Aguiar, O. G. (2006). The tension between authoritative and dialogic discourse: A fundamental characteristic of meaning making interactions in high school science lessons. *Science Education, 90*(4), 605–631.

Shepardson, D. P., & Britsch, S. J. (2006). Zones of interaction: Differential access to elementary science discourse. *Journal of Research in Science Teaching, 43*(5), 443–466.

Smith, J. P., diSessa, A., & Roschelle, J. (1993/1994). Misconceptions reconceived: A constructivist analysis of knowledge in transition. *The Journal of the Learning Sciences, 3*, 115–163.

The Regents of the University of California. (2005). *Full option science system (FOSS)*. Nashua, NH: Delta Education.

Tobin, K., Briscoe, C., & Holman, J. R. (1990). Overcoming constraints to effective elementary science teaching. *Science Education, 74*, 409–420.

Tobin, K., & Tippins, D. (1993). Constructivism as a referent for teaching and learning. In K. Tobin (Ed.), *The Practice of constructivism in science education*. Washington, DC: American Association for the Advancement of Science.

van Dijk, T. A. (1996). Discourse, power and access. In C. R. Caldas-Coulthard & M. Coulthard (Eds.), *Texts and practices: Readings in critical discourse analysis*. London: Routledge.

van Dijk, T. A. (2003). Critical discourse analysis. In D. Schiffrin, D. Tannen, & H. E. Hamilton (Eds.), *The handbook of discourse analysis*. Malden, MA: Blackwell.

van Zee, E. H., Iwasyk, M., Kurose, A., Simpson, D., & Wild, J. (2001). Student and teacher questioning during conversations about science. *Journal of Research in Science Teaching, 38*(2), 159–190.

van Zee, E. H., & Minstrell, J. (1997). Reflective discourse: Developing shared understandings in a physics classroom. *International Journal of Science Education, 19*(2), 209–228.

Vygotsky, L. S. (1978). *Mind in society*. Cambridge, MA: Harvard University Press.

Wang, J. (2006). Questions and the exercise of power. *Discourse and Society, 17*(4), 529–548.

Wells, G. (1999). Putting a tool to different uses: A reevaluation of the IRF sequence. In G. Wells (Ed.), *Dialogic inquiry: Towards a sociocultural practice and theory of education*. Cambridge: University Press.

Wertsch, J. V. (1998). *Mind as action*. New York: Oxford University Press.