



# THE SCIENCE EDUCATION REVIEW

Ideas for enhancing primary and high school science education

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## Did you Know?

### *Mole Day*

Many recognize October 23 as Mole Day. The date follows from Avogadro's number,  $6.02 \times 10^{23}$ , and the fact that a mole is the amount of a substance that contains Avogadro's number of units of the substance. Indeed, some have also suggested a Mole Minute, 6.02 a.m. that day.

To help students appreciate the very large magnitude of Avogadro's number, invite them to estimate the space (length of side of a cube, say) required to hold a mole of sand particles. Answers, for the side of the cube, with an order of magnitude around that of 40 km may result.

## Communication for Inquiry and Access: Teaching Techniques From Discourse Research

Susan Staats, Irene Duranczyk, Randy Moore, Jay Hatch, Murray Jensen,  
and Charles Somdahl

*University of Minnesota, Minneapolis, MN, USA*  
[staats@umn.edu](mailto:staats@umn.edu)

### *Abstract*

Adopting inquiry-based science and mathematics pedagogies changes traditional classroom communication patterns. Linguistic research in science and mathematics classrooms has identified communication techniques that help teachers manage classroom discussions to increase student interaction and a sense of student responsibility for learning. These communicative techniques strengthen access for underrepresented populations in science and mathematics while enhancing learning for majority population students.

### *Introduction*

The shift towards inquiry and problem-based pedagogies in both science and mathematics has changed expectations for classroom communication. Reducing reliance on lectures increases the complexity of conversational exchanges among instructors and students. Science Teaching Standard B (National Research Council, 1996) states that:

Teachers of science guide and facilitate learning. In doing this, teachers . . . orchestrate discourse among students about scientific ideas . . . teachers of science constantly make decisions, such as when to change the direction of a discussion, how to engage a particular student, when to let a student pursue a particular interest, and how to use an opportunity to model scientific skills and attitudes. (p. 32)

The mathematics standards (National Council of Teachers of Mathematics [NCTM], 1989, 2000) also recognize verbal communication as an activity that supports mathematical learning. Still, simply stating that classrooms should be interactive gives teachers no guidance on how to make lively, productive, and sustained discussions happen. Linguistic studies of the discourse--the patterns and habits of communication that prevail in a given social setting--of successful science and mathematics teachers have identified techniques of leading full class discussions that can help teachers create inclusive discussions that promote higher-order thinking. For many instructors, adopting new speech habits may seem awkward and difficult, because personal and professional identities, and even the intellectual values that motivate the choice of a teaching career, are frequently expressed through one's manner of speech. Science and math teachers often model the disciplinary principles of clarity, evidence, and reason through their speech by explaining concepts fully. Still, contemporary teaching standards call for teachers to leave gaps in their explanation as learning opportunities for students. Teachers who deliberately plan the timing, phrasing, organization, and other qualities of their speech can enhance teaching for inquiry and access because communicative expectations significantly influence students' sense of intellectual responsibility. This article reviews major results of linguistics research on the discourse of science and mathematics teachers with commentary on implementing these results to enhance teaching for inquiry and access.

### ***Communication and Responsibility***

Linguistic anthropologists working in a variety of cross-cultural communicative contexts find that "the allocation of responsibility is . . . a centrally important aspect of social meaning, in this case, constructed in interactional processes" (Hill & Irvine, 1993, p. 4). Social meaning, in the context of science and mathematics classes, can be understood as criteria of validity recognized by scientists and mathematicians; for example, assessing hypotheses through data analysis, and in mathematics classrooms, proof techniques and the correct manipulation of variables. In this interactional model, a particular framework of verbal exchange establishes roles for all participants (Heath, 1983; Philips, 1983), and these roles allocate different types of responsibilities to the participants. Responsibility is not simply an intrinsic personal quality nor an academic attitude that can be taught to students through explicit expectation; it is also a behavior that students internalize as they participate in the communicative patterns of a classroom.

As an example, consider the single most common pattern of classroom interaction, one that accounts for up to 70% of the communicative exchanges between students and instructors across disciplines (Wells, 1993). The IRF (Initiation, Response, Feedback) sequence (Mehan, 1979), or Triadic Dialogue (Lemke, 1990), begins when a teacher initiates a conversational exchange, usually with a question. A student responds to the question and then the teacher evaluates this response by indicating whether the student's answer is correct or not. While this classroom ritual is efficient and orderly, it establishes several unproductive attitudes toward learning in students. Students have the responsibility to supply facts, but not to imagine or to offer novel ideas or hypotheses. The responsibility for evaluation is firmly held by the instructor, so that students rarely practise the critical evaluation of ideas. North American research suggests that the IRF sequence corresponds to middle class, Euro-American patterns of speech, which are markedly

different from those found in the homes of many other students (Cazden, 2001; Mehan, 1998). Consider, as an example, a teacher who questions students using the IRF sequence in order to assess whether they completed and understood homework readings. These factual questions for which the speaker (the teacher) knows the answers were comparatively rare in working class African-American homes in the Appalachian foothills of North Carolina (Heath, 1983). African-American students entering classrooms led by Euro-American teachers simply didn't recognize them as serious questions: Why should someone expect a response to a question when they already know the answer? Another well-recognized case-study of a Native American reservation in Central Oregon showed that answers to questions in public discourse on the reservation were often supplied after many subsequent speakers took turns at talk (Philips, 1983). Native American students were therefore unaccustomed to the rapid resolutions typical of the IRF sequence. Both of these communities were rich discourse environments for children, but their patterns conflicted with the communicative expectations of traditional classrooms. The IRF sequence relies on culturally-based assumptions about participant responsibilities, the timing of conversational exchanges, and the purpose of questioning. It can often fail to establish an inviting and intelligible classroom environment for many working class and minority students.

Moving beyond the IRF sequence is a goal for teachers globally, too. Oh (2005), for example, reports on a Korean science teacher's attempt to develop constructivist learning experiences in an Earth science class. At times he used a modified IRF sequence leaving off the feedback phase, directing students to address their questions and answers to the class or leaving a student's misunderstanding unresolved until a later class. Similarly, the IRF sequence figured prominently in the discourse of a Brazilian chemistry teacher (Mortimer & Machado, 2000). This study distinguished between evaluative and elaborative IRF sequences. Elaborative IRF sequences invite further analysis from students rather than providing a correct and complete interpretation of an academic topic. The teacher used shifts from elaborative to evaluative IRF sequences to improve the precision of students' terminology and to consolidate improvements in understanding. These analyses suggest that teachers can effectively increase inquiry learning opportunities without completely modifying traditional forms of discourse. Relatively small shifts in phrasing and timing expand a teachers' repertoire of communicative techniques.

### ***Wait-Time***

A well-recognized discourse technique to create inclusive classrooms is wait-time. All teachers are familiar with the eternity that often passes after we ask a question. Our words hang in the air, uncomfortable silence descends upon the room until we conclude that the students have nothing to say, and we continue, either with an answer, or a follow-up question. Classroom recordings, however, show that this eternity often lasts only about 0.9 seconds (Sadker & Sadker, 1994). Increased instructor pauses may help students form a coherent or more complex answer and give the instructor time to reflect on students who may have been overlooked in the day's discussion. Wait-times of 3 to 6 seconds are commonly recommended. Teachers with eager students who blurt out answers can manage this by prefacing their question with a behavior that qualifies students to speak, as in "raise your hand when you've had a chance to think about this . . . ." Because wait-time helps uncomfortable students develop their answers and helps teachers allocate response opportunities equally to all students, this communicative technique is an equity teaching strategy.

### ***The Zig-Zag Path***

Lampert's (1990) discussion model, based on Lakatos' (1976) treatment of mathematical problem solving, replaces the IRF sequence with a classroom conversation that is a crooked pathway moving back and forth among empirical observation, conjecture, refutation, and (in mathematics)

proof. The greatest challenge for most teachers who adopt this instruction format is to speak less frequently and less authoritatively. To foster deeper classroom interactions, teachers will rarely evaluate the correctness of student responses, and instead use communicative techniques to increase interaction between students and to clarify a student's thinking for the rest of the class. In this style of discussion, we are not so much masterful actors who dramatize the field of science but rather bridge players who make a strategic move so that our partners, the students, can play a winning hand.

Analysis of pivotal moments in science classroom discussions revealed a similar conversational structure, termed transformative communication (Polman & Pea, 2001). In this version of the zig-zag discussion, a student makes a conversational move that a teacher does not expect. The teacher recognizes that the student's line of thinking may have unintended consequences in their laboratory exploration, and uses questions, suggestions, and discussion of materials to help the student revise their interpretation of the scientific scenario.

Perhaps the most important feature of preparing for a zig-zag discussion is to develop a sequence of questions, problems, and feedback techniques, rather than a lecture, that allow students to build and evaluate ideas. One format for guiding a discussion involves shifts between students' explanations and polling (by show of hands) to determine whether a consensus has been reached. Teachers can use various instructional sequences, such as:

- a) posing a question or problem,
- b) collecting conjectures (both correct and incorrect),
- c) inviting explanations for all conjectures,
- d) polling students for level of consensus,
- e) eliminating conjectures, and
- f) asking clarifying questions and re-polling until a strong (and correct!) consensus is reached.

This sort of discussion requires substantial planning. Questions that are provocative rather than leading must be planned; they seldom happen in the heat of the classroom moment! Other key strategies include devising problems with multiple solution pathways and encouraging students to express multiple conjectures and explain them. Explaining incorrect conjectures is particularly important because it encourages the speaker and classmates to evaluate his/her own thinking and it allows other students to learn to critique in supportive and respectful ways. Instead of asking the class "Is that right?" a teacher might plan to ask "Do you agree with this student's conjecture (or hypothesis)?" "Can anyone explain that?" "Why would that make sense to someone?" (Lampert, 1990, pp. 40-41), or "Douglas, why did Kenny say that?" (O'Connor & Michaels, 1996, p. 88), commentary that facilitates students' responses to each other and reserves the evaluative role for the students. At times, student explanations fail to generate consensus, either because most of the class fails to understand key points or because a student offers an exceedingly compelling, yet incorrect, explanation. For these situations, teachers must come to class prepared with clarifying problems or scientific scenarios that are simpler than the main discussion to help students focus on central ideas. Guided discussion techniques like these allow students to practise and internalize the behaviors of active, responsible, learners with problem-solving skills.

Moshkovich (1999) echoes many of these principles in her summary of discussion strategies designed to implement the NCTM's 1989 mathematics standards:

- a) Model desired participation and talk; support these when displayed by students.
- b) Encourage student conjectures and explanations.

- c) Call for explanations and evidence for students' statements.
- d) Focus on the process, not only the product.
- e) Compare methods, solutions, explanations.
- f) Engage students in arguments for or against a statement (move beyond *agree* or *disagree*).
- g) Encourage student-to-student talk.
- h) Ask students to paraphrase each other's statements.
- i) Structure activities so that students have to understand each other's methods.

While it is not at all apparent from her recommendations, Moshkovich's primary concern is to develop teaching recommendations to support bilingual learners. She cautions that some monolingual teachers may focus on issues of vocabulary and grammar with their bilingual students, overlooking their correct academic insights. Strategies for teaching bilingual students--providing a verbally varied and interactive environment--are often simply good strategies to teach all learners. Careful design of discourse patterns can scaffold learning for students with a variety of ethnic and linguistic backgrounds.

It is important to note, however, that the politics of education sometimes conflicts with discussion-based teaching standards, particularly in multilingual classrooms. In South Africa, for example, teachers and students alike often prefer to carry out mathematical discussions in English rather than in African languages that the teachers and students share, because English is viewed as the language of power (Setati, 2006). Fluency in English is valued more highly than fluency in mathematics. Teachers who are committed to transforming the communicative dimensions of their classrooms may need to become strong advocates of active learning in order to overcome these political pressures.

The discourse of effective teachers leading a zig-zag discussion has also been described in terms of communicative modes rather than instructional sequences. A biology teacher guided students to improve the expression of causal relationships as they developed a model of avian population dynamics. Her strategies involved shifts between elaboration prompts for specific and general information (cf. Mortimer & Machado, 2000), restating the primary research question, and synthesizing student comments to model standard scientific expressions. In this particular lesson, the teacher focused more on students' imprecision in stating causal relationships and less on their coordination of evidence with hypotheses, but her communicative method is certainly adequate to handle both instructional goals. A Finnish third-grade science teacher used four modes of responding to students as they developed a discussion-based community of inquiry (Kovalainen, Kumpulainen, & Vasama, 2001). The evocative mode elicited opinions and responses from students, as in "What do you think?" and "Would you like to ask something?" The facilitative mode coordinated student opinions and modeled scientific perspectives with comments including "and the consequence of that was . . .," or "you can still disagree but one has to always think that what (*sic*) is the reason before one disagrees . . ." (p. 21). A collective mode of response allowed the teacher to organize turn-taking and to assert collective responsibility for developing scientific interpretations, as in "What is Esa trying to say?" or "Some were sure of it but some were not, some are still suspicious" (p. 21). The teacher expressed her value of student ideas and her supportive attitude towards them through an appreciative mode of response using statements along the lines of "very good question, does anyone have any thoughts?" (p. 21). Analyzing modes of teacher discourse draws attention to the communicative purposes of particular instructional responses and helps teachers select appropriate responses for given moments in the classroom.

### ***Reflective Discourse***

The objective of developing higher-order thinking should be planned into the overall framework of a zig-zag discussion as well. As a zig-zag discussion evolves, students express several possible viewpoints, evaluate incorrect conjectures, and collaborate to resolve the question at hand. When the instructor senses that most students are in agreement, the moment might be right for a discussion that consolidates the group's accomplishments. Reflective discourse (Cobb, Boufi, McClain, & Whitenack, 1997) is more analytical than a mere review of results. It helps move students from empirical knowledge to a "mathematical disposition" (or a scientific one) through the ability to transform mathematical actions on mathematical objects into mathematical objects themselves. The previous objects of study, for example, computing exponential values or learning a lab procedure, can become tools that students can use to investigate new ideas. This chain of signification (Treffers, 1993; Yackel, Stephan, Rasmussen, & Underwood, 2003) is at the heart of constructivist, inquiry-based learning. Questions that can initiate a reflexive discussion include "How do we know that we've accounted for all the possibilities?" (Cobb, Boufi, McClain, & Whitenack, 1997), "Do our data support our hypothesis?" or "Which of our problem-solving methods is the easiest or most efficient?" Timing is important in shifting the flow of discussion. Students need to have been thoroughly involved in empirical talk, and if they are not able to quickly produce reflections on their prior activity, the teacher should not persist in this line of questioning, so that the discussion doesn't become a "stop me when I'm right" guessing game. Planning to shift the discussion to a reflective discussion is a means of assessing whether students have developed higher-order, nonprocedural, and nonempirical thinking skills.

### ***Reorganizing Classroom Roles***

Because the IRF sequence is so pervasive across disciplines in American education, teachers often face resistance from students when trying to establish classroom rules for active learning. To overcome this obstacle, one research group (Herrenkohl & Guerra, 1998) developed audience roles, or intellectual roles, that correspond with phases of scientific inquiry. Students were expected to develop and test hypotheses without direct instruction on physics topics (e.g., buoyancy). Each group worked together for about 30 minutes per day and presented their findings to the class for 30 minutes. When the audience roles were introduced on the second day of the project, a full-class discussion developed definitions for the roles along with sample questions. During presentations, audience members received cards indicating their audience role for that day (see Table 1). They were able to refer to a Question Board where they listed questions associated with each role.

Audience roles helped students develop communicative tools for scientific inquiry, and they helped the instructor mold a new form of classroom interaction in which students took on more active learning roles. Many of the questions associated with audience roles in this study require students to engage in analytical and synthetic thought, cognitively more complex activities in Bloom's Taxonomy (Bloom, Engelhart, Furst, Walker, & Krathwohl, 1956) than the factual recall and comprehension that is most easily addressed by the IRF sequence and that is characteristic of lower-level science instruction (Yerrick, 2000). Evaluation is the highest level of Bloom's hierarchy of critical thinking. Audience roles could include questions at this level, such as "How could you improve this experiment?" "How would you design an experiment to determine . . . ?" "What was the most important factor in this process?" and "How would you assess this hypothesis?"<sup>1</sup> A study of student-generated questions found that these sorts of higher-order, "wonderment" questions occurred more frequently in inquiry-based activities than in teacher-led or procedurally-oriented lessons and that they contribute to deep learning (Chin, Brown, & Bruce, 2002).

Table 1  
*Participant Roles for Scientific Inquiry*

Intellectual (scientific) roles	Audience roles (with sample student questions)
1. Predicting and building a hypothesis	Checking or helping to construct a hypothesis “What is your prediction?” “What is your hypothesis?” “What do you think will happen?”
2. Summarizing and clarifying results	Summarizing results “What did you find out?” “What were your results?”
3. Coordinating data and hypothesis	Check that evidence supports the hypothesis “Where did you find your hypothesis in your data?” “Did your results support your hypothesis?”

*Note.* The questions in this table are adapted from Herrenkohl & Guerra (1998, p. 448).

Giving direct classroom attention to audience roles or question generation is especially useful for multilingual students or students whose home-based patterns of communicative participation differ from those in traditional classrooms. When teachers and students do not share a home language or discursive expectations, the lower levels of factual recall and comprehension are an easier basis of communication. In Yerrick’s (2000) study, students enrolled in a low-track science class who received guidance in question generation, experimental design, and argumentation improved in several aspects of scientific discussion. After discussion-based inquiry instruction, students gave explanations that were more sophisticated and more tentative; that is, lacking naïve certitude. Post-instruction explanations made better use of evidence as a tool of inference, and they more frequently saw themselves, rather than scientific authorities, as potential creators of scientific explanations. Using audience roles makes higher-order investigative principles explicit and positions them as forms of practice. The deliberate development of communicative skills helps students understand the process that connects scientific knowledge to modes of inquiry.

### ***Revoicing***

Revoicing is a communicative move in which an instructor repeats or paraphrases a student’s words (Forman & Ansell, 2001; O’Connor & Michaels, 1996). This simple maneuver can serve a variety of managerial and pedagogical functions:

- a) Encourage a student to develop an idea.
- b) Reformulate a response with formal vocabulary.
- c) Clarify the thinking in a student’s response.
- d) Align students who agree with each other.
- e) Draw attention to students who disagree with each other.
- f) Lend authority to a shy student’s response.
- g) Broadcast a quiet response more loudly to the full class.
- h) Emphasize an important point.

Instructors can try to improve student responses by learning to phrase their revoicing move in particular ways. As an example, try reading aloud the following exchange in a full-class discussion in a geology lab, to express any of the intentions above:

*Student:* That one must be an igneous rock.

*Teacher:* That one's an igneous rock.

*Student:* Because of how the grains are stuck together.

What differences in intonation did you use to fulfill each intention? In some respects, revoicing as a nearly direct restatement allows teachers to play the IRF role, offering the floor back to the students, without reducing the student's responsibility to think critically. In these instructional moments, intonation can carry significant weight in distinguishing an authoritative, evaluative IRF move from a coaching, elaborative one (Mortimer & Machado, 2000). Instructors can also revoice student comments with mild modifications to reach powerful instructional goals, like the last four listed above. Imagine an algebra class collaboratively solving the linear equation  $6(x - 3) = 2(x + 1)$ :

1. *Teacher:* Ideas for solving this?

2. *Melissa:* Put the 6 under the 2?

3. *Teacher:* Divide both sides by 6 to get the 6 under the 2?

4. *Teisha:* I multiplied both of them through.

5. *Sam:* I did, too, it's easier that way.

6. *Tory:* It's easier if you put the 2 under the 6.

7. *Teacher:* The 2 under the 6, so you think there's an advantage to that? What about you, Melissa?

8. *Melissa:* Yeah, I like Tory's way because you won't have all the coefficients anymore.

In this exchange, the teacher used revoicing twice. In line 3, when the teacher repeated Melissa's suggestion, she both modeled technical vocabulary and lent legitimacy to an unpopular but correct procedural move. In line 7, the teacher's revoicing continued support for a nonstandard procedure, and allowed her to align Melissa and Tory as allies. The teacher also used the word *so*, a "marker of warranted inference" (O'Connor & Michaels, 1996, pp. 80-83) that allows the teacher to position Tory and Melissa's suggestions in terms of a broader mathematical strategy, to achieve a coefficient of one. Using revoicing with warranted inference (alternatively, "you mean that . . .," "Joseph predicts that . . .") also turns the tables on the IRF sequence. Students are asked to evaluate the teacher's formulation of their original ideas. This speaking technique helps instructors assert standards of precision and higher-order thinking while quietly maintaining student responsibility for learning (Tabak & Reiser, 1999).

### **Conclusion**

Interactive teaching in science (Hake, 1998) and mathematics, when well-implemented, can offer substantial learning gains over traditional methods. Interactive inquiry learning can make science and mathematics classrooms more accessible to underrepresented populations of students in several ways. Given the dearth of diversity among science and mathematics teachers, our own students can reduce the cultural bias of traditional classroom patterns, like the IRF sequence, by serving as each others' interlocutors of scientific and mathematical ideas. When students explain disciplinary content to each other, they can present ideas through communicative patterns with which the teacher is not fully fluent. Any imprecision of student discourse need not threaten academic standards, because teachers can model precise terminology and correct means of scientific evaluation through discourse techniques like revoicing, zig-zag discussions, and the collaborative development of audience roles.

Many teachers use techniques like wait-time and revoicing spontaneously, as elements of the communicative toolkit of effective teaching, but still, few speakers reflect on the means by which speech shapes interactions and establishes classroom expectations like student responsibility for learning. By understanding speech as a pedagogical strategy, teachers can learn to use discourse techniques to fulfill specific instructional goals. Science and mathematics teaching may be more effective and more inclusive if teachers tune their ears towards subtle meanings in classroom conversations. The deliberate organization of teachers' and students' speech, attending to the manner, intentions, and outcomes of conversational interaction, is a teaching tool as powerful as technology or lessons with carefully developed content.

#### Note

<sup>1</sup> Many websites, such as Cheelan (2006) and *Using Questions to Enhance Learning* (2006), are designed to help teachers develop questions that stimulate thinking at all levels of Bloom's taxonomy.

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## Demonstration

While the activities in this section of *SER* have been designated demonstrations, some might easily be structured as hands-on student learning experiences. Although some sample lesson sequences may be included, the notes provided both here and in the following section are meant to act primarily as stimuli for classroom activities and to provide teachers with background information, so please modify any sample pedagogy as you see fit.

### ***The World's Simplest Generator?***

**Needed.** A neodymium (NdFeB) ring magnet (i.e., a cylindrical one with a hole through the centre), nail, electric drill, and multimeter.

In Volume 4, Issue 1 we featured the world's simplest motor. Of course, the same apparatus can be used in reverse to act as a generator. In this case, though, it is easier to use a ring magnet instead of the disk one, as this prevents the need to chase a flying magnet all over the room.

Place the nail through the hole in the magnet and fix the nail in the chuck of the drill. Use the drill to cause the magnet to spin, and measure the voltage between the outer edge of the rotating magnet and the shaft of the nail. A reading of tens of millivolts is typical.

The voltage depends on the rate of rotation and the distance between the contact touching the magnet and the axis of rotation. Invert the magnet and observe a reverse in the polarity of the voltage. Knowing the polarity of the magnet, more advanced students could be invited to first predict the polarity of the generated voltage.

*Source:* Clark, R. B. (2006). The simplest generator from the simplest motor? *The Physics Teacher*, 44, 121.