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# THE SCIENCE EDUCATION REVIEW

Ideas for enhancing primary and high school science education

## Did you Know?

### *Mole Day*

Many recognize October 23 as Mole Day. The date follows from Avogadro's number, 6.02 x $10^{23}$, 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

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### *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?"[1] 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<br>“What is your prediction?”<br>“What is your hypothesis?”<br>“What do you think will happen?” |
| 2. Summarizing and clarifying results | Summarizing results<br>“What did you find out?”<br>“What were your results?” |
| 3. Coordinating data and hypothesis | Check that evidence supports the hypothesis<br>“Where did you find your hypothesis in your data?”<br>“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***

[1] 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.

# Student Activity

***Reminder:*** Appropriate risk assessment, supervision, and guidance are necessary.

## *Crystal Ball Power*

This activity may be used to help students distinguish science from pseudoscience, which is an explanation or method that is doubtfully or mistakenly held to be scientific.

***Needed.*** Access to the World Wide Web.

***Invitation.*** Tell students that the apparent power of a crystal ball is most impressive, and demonstrate with a volunteer student using the activity at Naughton (n.d.). Ask for a show of hands by those who believe in the psychic power of the crystal ball just demonstrated, those who are skeptical, and those who are uncertain.

***Exploration.*** Invite the class to design and carry out one or more investigations to test this claim; that is, is the phenomenon just witnessed a demonstration of the real power of a crystal ball, or is there perhaps some trickery at play? (How students proceed will depend upon whether there is only one demonstration computer in the room or students can work, in smaller groups, at computer stations.)

***Concept introduction.*** By repeating the experiment numerous times, and comparing the initial numbers chosen with the answers to the computation, students will observe a pattern emerging; the answer is always a multiple of 9, between 9 and 81 inclusive. (More specifically, the answer is nine times the first digit of the two-digit number originally selected, and older students might determine this by choosing to represent the original number as xy and seeing that the computation asked for is of the form $10x + y – [x + y] = 9x$.)

Further, notice that in the website chart, the same symbol is matched to all of the above multiples of 9, thus making the outcome of the process certain and predictable. Also, the number/symbol match cleverly changes from trial to trial, thus making it more difficult for a casual observer to identify a pattern. Students should conclude that this activity does not provide evidence for the ability of a crystal ball to read the mind of a person.

***Concept application.*** Invite students to identify another pseudoscientific claim (e.g., astrology, telepathy, clairvoyance, aura reading, and telekinesis) and devise a test(s) for it.

*Reference*


Naughton, A. (n.d.). *The flash mind reader*. Retrieved October 3, 2006, from http://trunks.secondfoundation.org/files/psychic.swf .


# Critical Incident

## *An Invitation*

Readers are invited to send, to the Editor at editor@ScienceEducationReview.com , a summary of a critical incident in which you have been involved. A critical incident is an event, or situation, that marks a significant turning point, or change, for a teacher. The majority of critical incidents are not dramatic or obvious, but are rendered critical through the analysis of the teacher (see Volume 3, p. 13 for further detail). You might describe the educational context and the incident (please use pseudonyms), analyse the incident (e.g., provide reasons to explain your observations), and reflect on the impact the incident made on your views about the learning and teaching process. Upon request, authors may remain anonymous.

We have undoubtedly all done things about which we were very pleased, and perhaps done other things about which we did not feel so pleased, and we all need to remain reflexive of our practice. While teachers will view an incident through the lenses of their own professional experiences, and may therefore explain it differently, this does not detract from the potential benefits to be gained from our willingness to share our experiences and thus better inform the practice of other teachers.

## *Writing Prompts in the Classroom: Magic for Learning Science*

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"Can you post this teacher to our school, Sir?" exclaimed a Grade 9 pupil as I sat down to observe a lesson of one of our pre-service teachers. This exclamation caused huge applause in the whole class. The incident informed me that pupils were happy about the pre-service teacher and they wished him to be there permanently. Also, they thought that I would possibly initiate a process for a teaching post in the school.

To understand the situation in rural schools in South Africa, we need to look at the country's history and the present state of the schools. Rural schools here were characterised by a lack of basic resources and well-qualified science teachers and little has changed since independence in 1994. Although English language is the medium of instruction in secondary schools, many pupils from rural schools use English as a second or third language. This explains, in part, why Grade 9 pupils in this particular school could not answer questions in English as required for that grade. A few tried, but they were discouraged because they failed to give satisfactory answers. The final state of affairs was that every pupil in the class was unmotivated to do homework. The pre-service teacher on teaching practice identified English language as the learning barrier and he planned the use of writing prompts in order to enhance the process of learning science. These writing prompts turned everything upside down for the better.

The following are some of the writing prompts that were used by the pre-service teacher (Warwick, Stephenson, & Webster, 2003):

We are trying to find out . . . .
The results tell me that . . . .
I could test this by . . . .
During this experiment we are trying to measure . . . .
We will use this experiment to . . . .
We will record our measurements like this: . . . .
By carrying out these measurements we are able to find the connection between . . . and . . . .
From my graph I can see that . . . .
I can check the accuracy by . . . .
There may be some errors in the results I collected because . . . .
I would like to test this again, but this time I would . . . .
My results are accurate and reliable because . . . .

Before the end of the teaching practice, I saw beautiful notes and statements made by this class. Everyone in the class agreed that they had improved, and that they like the subject as well as their pre-service teacher. Again, during a casual chat, many pupils wished that they could continue using the writing prompts in their science classes. This idea was also appreciated by their regular science teacher.

Writing prompts engage pupils in dialogue with themselves, and with others, in order to enhance the learning of science. Pupils in this Grade 9 class improved greatly in both science content and conceptual understanding, as well as in writing skills. Indeed, writing prompts provide a social learning environment where pupils gain confidence in completing ideas and at the same time learn to write complete sentences (Lave & Wenger, 1991; Light & Littletorn, 1999; Wray & Lewis, 1995). Finally, I found out that there were another 4 pre-service teachers using writing prompts in Grade 9 classes in the province and that their pupils did well in the Continuous Assessment Test (CAT) on both content and conceptual evidence questions, which regular science teachers said was unlike the situation in the past. This suggests that writing prompts can act as the magic for learning science; in this context, at least.

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# Results of a 16-Year Study of Cheating in Introductory Science Classes

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***Abstract***

In a 16-year study involving more than 4,800 students, fewer than 2% of students were caught cheating in introductory science classes. The most common type of cheating was plagiarism in lab reports (50% of incidents), followed by altering exams (41%) and submitting falsified lab data (9%). Cheating occurred among students earning all grades in the course. When the penalties for cheating were ignored, the overall course letter-grade distributions for cheaters and non-cheaters were similar. The results indicate that cheating in introductory science classes is not as prevalent as has often been reported, and that cheating has no clear benefit in terms of percentage grades.

To read the full text of this article (7 pages), please **click here**.

# Science Poetry

Reading and/or listening to poems composed by other children their own age can inspire and reassure students as to their ability to understand and write poetry, and the science poems in this regular section of *SER* may be used for this purpose. Please find information about the *International Science Poetry Competition* at http://www.ScienceEducationReview.com/poetcomp.html .

## Rainforests

Rainforests are so lush and green,
Like nothing I have ever seen.

From green tree frogs and sugar gliders,
To cockroaches and icky spiders.

If you ever get to see one,
You'll know that something must be done.

If we do not do something very soon,
Rainforests all over the world will be doomed.

With today's machinery and pollution,
We just have to come up with some sort of solution.

Just think of the trees and the birds and the bees,
And crystal clear water right up to your knees.

What will we do if it all disappears?
That will top off the worst of your fears.

So stop and think about what you can do,
Because the only thing rainforests need now is . . .

You!

*Emily Olditch, 11 years*
*Australia*

## Mr Thorpe

My science teacher, Mr Thorpe
Is oh! So very cool.
By far the smartest teacher
Residing at my school.

He's never short of funny tales
His stories are terrific.
Complete with underlying facts
And theories scientific.

I know my way around the lab
Equipment A through Z.
The Periodic Table
Is implanted in my head.

I know what happens when I add
An acid to a base.
A salt and water should result
In every single case.

I can classify an animal
From kingdom down to species.
I know the scientific names
Of sundry little beasties.

My scientific knowledge
Can be traced back to one source.
That paragon of teachers
Mr Thorpe, of course!

So, please accept this poem, in lieu
Of other forms of praise.
And if the spirit moves you
Reward me with some A's!

*Jack Burnham, 12 years*
*Australia*

# Students’ Alternative Conceptions

Students’ alternative conceptions have been variously called misconceptions, prior conceptions, preconceptions, preinstructional beliefs, alternative frameworks, naive theories, intuitive ideas, untutored beliefs, and children’s science. The tasks in this regular section of *SER* are based on the literature and may be used at the beginning of a constructivist learning segment to arouse the curiosity of students and to motivate them, while simultaneously eliciting their ideas or beliefs. They are designed to address areas about which students are likely to have an opinion, based on personal experiences and/or social interactions, prior to a specialist learning sequence, or areas that might be considered important for the development of scientific literacy.

## *Fossil Fuels*

*By:* Audrey Rule, State University of New York at Oswego, New York, USA
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Which of the following statements about fossil fuels are correct?

a. The main use of petroleum is lubrication of motors and vehicles.
b. Petroleum (oil from oil wells) comes from dead dinosaurs.
c. The purpose of a tower on an oil derrick is to keep the oil from spilling out on the ground and to provide a viewpoint to oversee machinery.
d. Petroleum is not found under forests or in places with a sub-zero climate.
e. Gasoline stations are located above gas wells and gasoline flows from these wells into a car’s tank.
f. Petroleum takes about a million years to form.
g. Coal beds sometimes contain diamonds.
h. Coal and charcoal are names for the same thing.
i. Gasoline and natural gas are names for the same thing.
j. Petroleum and other fossil fuels play a large role in pollution, global warming, and wars between countries.
k. Oil from oil wells is sold as cooking oil.

*Answer*. All except f and j are misconceptions.

*Comment*. The multiple meanings of the words *oil*, *gas*, and *coal* confuse people. a. The main use of petroleum is energy. Many people think of oil wells producing oil for lubrication and are not aware that gasoline and fuel oil also are products of petroleum wells. b. Petroleum originates in ancient plankton and sea life. People often wrongly associate petroleum with dinosaurs because of the dinosaur symbols on some gasoline stations such as Sinclair. c. The purpose of an oil derrick is to support long drilling pipe as it is lowered into the ground. d. Petroleum has been found under forests, oceans, and deserts and under areas of all climates. The current surface conditions have nothing to do with petroleum in the rocks far below the surface. e. Gasoline is usually stored in large underground (or above-ground) tanks and flows from the tank to the pump and into a car’s gas tank. Large tanker trucks deliver the gasoline. Petroleum comes from oil (petroleum) wells and is a refined product. Gas wells produce methane (natural gas). f. Petroleum is a non-renewable resource because it takes so long to form. g. Diamonds form under very high pressure conditions within the Earth’s mantle. Coal forms from plant material in ancient swamps that is buried in the Earth’s crust. Although coal and diamonds are composed of carbon, they are not found together because they form under different conditions. h. Charcoal is made from partially burned wood. It is not the same material as coal, although both may be burned as fuels. i.Gasoline and natural gas, though both fossil fuels, are not the same. Natural gas is methane gas and is burned in its gas state as a fuel. Gasoline is a refined product of petroleum and is a liquid fuel. j. Oil spills are responsible for much damage to the environment. The burning of fossil fuels in vehicles, homes, electric plants, and factories causes much air pollution and increases the carbon dioxide content of the atmosphere, causing global warming. Disputes over scarce resources such as oil reserves play a large part in many political disputes such as the Gulf War. k. Cooking oil is usually composed of plant oils from pressed seeds such as olives, sunflowers, and corn. Some animal fats (lard, bacon grease) are also used for cooking.

*Source:* Rule, A. C. (2005). Elementary students' ideas concerning fossil fuel energy. *Journal of Geoscience Education*, *53*, 309-318.

# Teaching Techniques

This regular section of *SER* describes thinking, cooperative learning, and other teaching techniques.

## *Think-Alouds*

Use Think-Alouds to increase student comprehension and higher-thinking skills during reading, demonstrations, and other activities. Stop periodically, ask students what they are wondering about at that time, and write one or more responses, in the form of a question(s), on the board. To introduce the technique, the teacher might model the process by articulating their own questions.

Return to the list of questions at a later time, identify those that have been answered, and consider how any others might be answered. The latter may lead to further investigation.

*Source:* Martin-Hansen, L., & Johnson, J. C. (2006). Think-alouds in inquiry science. *Science and Children*, *44*(1), 56-59.

## *Less-Than-Ideal Procedure*

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One way to aid the transition from Level 2 inquiry to Level 3 (Eastwell, 2006) is to ask students to first analyse a less-than-ideal procedure, and suggest improvements to it, before carrying out the activity using an improved methodology. This approach allows for both desirable design considerations and common methodological flaws to be addressed, and the following is an example.

*Aim*. To determine the thickness of the paper used to produce a given book.

*Procedure*. Choose a sheet near the middle of the book and measure its thickness with a micrometer.

It would be better to measure, with the micrometer, the thickness of a number of sheets and then divide by that number of sheets to determine the average thickness of the paper. This procedure takes into account the variation in paper thickness both within, and between, sheets and will produce a final result with a lower percentage uncertainty. (There is no significance in mention, in the given procedure, of choosing a sheet "near the middle of the book," although this does represent a misconception some students may have whereby they confuse the middle of the book with some notion of averaging.) To see this, and to determine how many sheets should be used, consider the following.

The uncertainty in a single micrometer reading is typically $\pm 0.01$ mm, and the aim is to adopt a procedure that minimizes (and ideally makes negligible) the percentage uncertainty in the final result. Whereas $\pm 0.01$ mm in 0.08 mm (a typical single-sheet thickness) represents $\pm 12\%$ uncertainty, $\pm 0.01$ mm in 8.05 mm, say (a typical 100-sheet thickness) represents only $\pm 0.1\%$ uncertainty, which is negligible. In the latter case, the thickness of a single sheet would be expressed as $8.05 \times 10^{-2} \pm 0.1\%$ mm. If we were to consider a percentage uncertainty of $< 0.25\%$, say, to be negligible, then this type of analysis leads us to conclude that we would need to use 50 or more sheets.

For comparison, students could be asked to similarly determine the thickness of a single sheet using a ruler. Typically, 100 pages might measure $8.7 \pm 0.5$ mm = $8.7 \pm 6\%$ mm, giving a single-page result of $8.7 \times 10^{-2} \pm 6\%$ mm; 60 times less precise than the corresponding micrometer determination.

*Reference*

Eastwell, P. H. (2006). Levels of enquiry. *The Science Education Review*, *5*, 61-63.

# The Future of Student Grouping Systems in Science 14-16

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***Abstract***

Ability grouping is a contentious issue in high school science education, and one that divides teachers, parents, and policymakers alike. However, it may be that current grouping systems are founded on ideas that are failing to provide for the best interests of students at any ability level. This article aims to review current practice and its effects on student and teacher outcomes, and suggest a new direction for student grouping polices based on the ideal of "science for all" through curriculum reform and choice-based modular course systems. The article is based largely on the British education system.

## *Introduction*

Recent research into the effects of setting (subject-specific ability grouping) and mixed-ability grouping in British schools has yielded mixed results and painted a confusing picture of how these influence teaching and learning in science. One thing has become certain, though; setting is associated with both high- and low-ability student achievement and self-concept in some way and to some degree. In one study, it was even suggested that the set a student is placed in has more bearing on the student's eventual achievement than the school being attended (Wiliam & Bartholomew, 2004).

Setting by ability has been suggested by the Office for Standards in Education (Ofsted, 1998) as a method for improving performance in schools, and the Department for Education and Employment

(DfEE, 1997) state that setting should be the norm in secondary schools in England. Benn and Chitty (1996) report that 40% of secondary comprehensive schools use some form of setting in Year 9, and that it is virtually certain to be taking place in one or more subjects in Year 10 and above.

Setting has been a feature of the British education system for at least 100 years, and in its historical incantation was based upon theories, such as those of Spearman and Pearson, relating to the fixed, immutable, and genetically-determined nature of intelligence. These theories relate to the transmission model of learning, whereby some minds are more receptive to knowledge than others and will therefore achieve more highly in the future, and vice versa. It also reflected, to some degree, stratifications that existed (and indeed still do exist) in society. However, more modern theories typically categorise different types of intelligence, such as linguistic, logico-mathematical, spatial, musical, and so forth (Gardner, 1993, 1999).

Systems of pupil placement, whether they be mixed or set by ability, must be in accordance with, and indeed ought in some measure to support, the espoused goals of good educational practice. These might come under the banner of achieving “science for all” and fulfil the high ideals of inclusivity via differentiation, authenticity, constructivism, agentive learning, dialogic discourse, social interaction, flexibility of approach, effort based assessment, motivation, equality, diversity, and valuing each other.

### *Review of Research*

*Effects of mixed-ability grouping on teaching and learning*. Pupils' abilities vary across, and indeed within, different subjects. *Launch Pad 3* (2000) concludes that therefore “it is inadvisable to group students identically across the curriculum . . . [and] grouping identically within one subject may have limitations too” (p. 2).

Although it is clear from some research that mixed-ability grouping benefits the low-ability students academically, some of the same evidence points to the fact that high-ability students do better, and take science further, when placed in high-ability sets (Boaler, Wiliam, & Brown, 2001; Farrar, Evans, & Kirk, 2003; Ireson, Hallam, & Hurley, 2001). Would mixed-ability grouping reduce the number of future scientists and hence be contrary to the goal of science for all? Is it possible to justify holding back one group of learners in order to benefit another? Doctor Linda Silverman, of the Gifted Development Centre in Colorado, USA thinks not. In her treatise on the importance of selective education for high-ability learners (Silverman, n.d.), she states that it is undemocratic not to provide for the needs of high-ability learners and that “it is misguided to believe that holding back the brightest students magically helps the slowest ones; bringing the top down does not magically bring the bottom up” (p. 4).

There is little evidence to suggest that mixed-ability groups really do receive differentiated work, and in fact some research suggests that both high- and low- ability students are not being taught at appropriate levels in mixed-ability groups at secondary school (Department for Education and Science [DES], 1992). Successful mixed-ability teaching requires skilled teachers who are flexible, employ a variety of teaching methods, approaches, and resources, and have good formal and informal relationships with students. Current opinion is turning against mixed-ability grouping, as reported by the BBC news service (BBC, 2001). A survey of 1500 teachers revealed disruptive behaviour and a more taxing teaching environment resulted from mixed-ability classes. Science is particularly unsuitable for mixed-ability grouping as all students must have mastered the basics of one concept before they can move on.

On the other hand, Farrar et al. (2003) have shown that low-ability students sometimes feel that they benefit from the presence of their high-ability counterparts, voicing such sentiments as “I worked with smart people. When I didn’t understand something they nicely explained it to me” (p. 54). Vygotskyian theories see learning as taking place through interaction with others, and it would be a shame to separate these students and hence lose this discourse. In addition, the high-ability learners could be developing other facets of their intelligence and understanding by interacting with low-ability learners in this way. However, such outcomes are seldom, if ever, measured in attainment tests, which rely more on coverage of curriculum content; and this almost certainly proceeds more slowly in mixed-ability groups than in top sets.

*Setting systems*. Ireson, Clark, and Hallam (2002) used questionnaires to determine setting considerations used by schools. The most common responses were:

- Internal tests and examinations
- End of year tests
- The Cognitive Abilities Test
- Teacher opinion or “gut feeling”
- Student behaviour and motivation
- Social factors (e.g., avoiding problematic student combinations)
- Gender (balancing/single sex setting)
- The provision of special educational needs (SEN)

Ethnic group was never mentioned, despite bottom sets continuing to contain disproportionately high numbers of ethnic minorities, and particularly afro-caribbeans (Ireson, Clark, & Hallam, 2002). The same study found disproportionately high numbers of students of low socio-economic status, boys, and children born in the summer (youngest in the age group) in the bottom sets. Interestingly, the students’ own choice never appeared to influence the set they were allocated to in the UK.

Movement between ability groups is seen as crucial, by Ofsted (1998), to the successful operation of structured grouping systems and would certainly be necessary if the principles of equality, motivation, recognition of effort, and flexibility were to be satisfied. Ireson, Clark, and Hallam (2002) report a great deal of variability between schools as to how students are moved between sets. Reasons range considerably, but all are related to those used for set allocation in the first place. In reality, however, there is little movement between sets in the UK, often due to gaps between the work undertaken by the different sets. This is a problem particularly when lower sets study the foundation tier syllabus at Year 10 and students are unable to move up in Year 11 to sets where the higher syllabus has been studied (Gillborn & Youdell, 2000). There are also often problems of higher sets becoming oversubscribed and thus requiring that students move down in order to make room for those coming up (Ireson, Hallam, & Plewis, 2001). Someone must always be at the bottom of the top set, and this individual may feel negative self-concept effects as a result of being moved down.

*Effects of setting on teaching and learning*. Several questionnaire-based studies have shown that a majority of students aged 14-16 years prefer setting to mixed-ability grouping (Hallam & Deathe, 2002; Ireson et al., 1999) and therefore there must be something about setting that appeals to them. Research by Farrar et al. (2003) involving high school Biology students in the USA suggested that, in practical work, high-ability students preferred to work with other high-ability students. This seemed to be because, while working with lower-ability students, they ended up doing the “lion’s share” of the work.

Hallam and Deathe (2002) conducted a study into how grouping affected students’ self-esteem and attitude, and found that:

- Students in bottom sets experience negative effects on aspects of their self-concepts, such as self-esteem and sense of self-worth.
- The longer a student remains in a bottom set, the greater the negative effects on all aspects of their self-concept.
- Top-set students may also experience negative self-concept effects as a result of peer-pressure factors.

Further work by Hallam and Ireson (2003) showed teachers believed that:

- Setting prevents brighter children being inhibited by negative peer pressure (presumably from less able classmates).
- Being in a low set leads students to “give up.”
- Setting pupils stigmatises them in some way.

Boaler et al. (2001) suggest that many of these negative effects stem from the ways that teachers behave towards the students in the sets themselves, and Hallam and Ireson (2003) concur, suggesting that teachers’ attitudes towards teaching low-ability groups may have contributed to the alienation of those pupils. In other words, it is not a case of simply being in a certain set, it is how you are treated once you are there. Boaler et al. describe factors which could be responsible for the erosion of student self-concept, such as excess pressure and pace, demotivating language use by teachers, and threats of set demotion.

Several studies have shown that setting tends to increase the achievement of high-ability students at the expense of low-ability learners (who perform better in mixed-ability sets), thus polarising the achievement of the year group (Boaler et al., 2001, Farrar et al., 2003). Ireson, Hallam, and Hurley (2001) researched 45 mixed secondary comprehensive schools in England and came up with some interesting data. They found that schools that set by ability encouraged a greater number of students to take science at a higher level, with 36% of students going on to take a science A-level compared to 25% at non-set schools. However, 17% of students from set schools were totally disaffected with science, stating that they never wanted to do science again after age 16, compared with 14% in schools with mixed-ability classes. This may be further evidence of polarisation of attainment and attitude. From a sociological perspective, in a world where the rich are getting richer and the poor getting poorer, perhaps this outcome of setting is merely echoing one of the more disappointing aspects of our society today?

Setting procedures should enable science teachers to lead their students to develop a deeper understanding of the subject via social and cultural constructivism, through dialogic discourse that promotes cognitive conflict in situations where the material is authentic and relevant and the learners are motivated and empowered. Ireson et al. (1999) canvassed the opinions of 1601 teachers as to their opinions of setting and discovered the following:

- Setting is beneficial for high-ability learners.
- Setting makes teaching easier.
- Low-ability classes suffer from more discipline problems, as do mixed ability groups.

- Low-ability classes tend to access less of the curriculum, have more repetition, and have less homework, independent work, responsibility, and discussion and analysis than higher- or mixed-ability groups.

Some of these outcomes are consistent with the aims of science education, but these seem to be limited to the high-ability groups. If the teachers are right, then the low-ability groups are not being given equal access to quality learning experiences.

A very interesting and candid survey, of high school history teachers in Zimbabwe, threw up some startling results (Chisaka, 2002).

- "Ability grouping is meant to avoid the pupils who are above average being disturbed by pupils who have discipline problems. It is also an attempt to motivate teachers in the sense that, when they go to that class (high ability), they have the hope that that particular class is capable of making it every day" (p. 28).
- "Teachers don't prepare much for the lower streams--they don't research much . . . but with the upper streams they really work" (p. 28).
- "Teachers give more work to A classes than to B classes" (p. 28).
- "These top classes are the classes on which we bank when it comes to (final) results" (p. 29).
- "Because of unavailability of resources, teaching the lower streams becomes a nightmare" (p. 29).
- "The teacher is negatively motivated when he is going to a dull class" (p. 29).

Lacey (1970) reported that, in a selective school, the top set received better resources and more teacher attention, to the detriment of the lower groups. It may, or may not, be that this is still the case today. Teachers generally prefer high-ability groups, feeling more efficacious and interacting more frequently and positively than with low-ability groups (Hallam & Ireson, 2003). The same authors describe teachers of low-ability sets becoming gradually demoralised in an atmosphere of negative attitudes towards school and poor behaviour.

Boaler et al. (2001) present some disturbing evidence of poor-quality teaching methods taking place in bottom math sets in the UK. The article reveals unprofessional, unkind, and demoralising behaviour on the part of the teachers, with remarks such as "you're the bottom group, you're not going to learn anything" (p. 638). Other such statements in the report reveal low expectations, a lack of differentiation in low-ability groups, more tedious teaching methods, such as copying, being employed, and less investigation; in other words, plain bad teaching practice.

Studies suggest that bottom sets are typically assigned to younger, less-qualified, and less-experienced teachers (Boaler et al., 2001; Wiliam & Bartholomew, 2004,). This is contrary to the best interests of the students, as there is also evidence that bottom sets experience the most benefit from high-quality instruction (Black & William, 1998). Students in low sets for maths in the UK have remarked that "our group keeps changing teachers . . . [because] they don't think they have to bother with us . . . . They get say a teacher who knows nothing about maths . . . a PE teacher or something . . . They think they can send anyone down to us" (Boaler et al., p.637).

There are no government guidelines as to how teachers should be assigned to sets, and this seems to be carried out, for the most part, on a very ad hoc and unregulated basis. It is unsurprising that teachers do not like being given bottom sets, as current indices of educational success often focus on the production of grades that lower sets seldom achieve, often because they study the foundation tier. Young, inexperienced, or under-qualified staff may often enter bottom-set science lessons ill-prepared, demotivated, anticipating discipline problems, and setting low expectations. They then teach dumbed-down curriculum material (most of which bears no relevance to the students' lives), using inadequate resources in an uninspiring fashion, to students who consider themselves doomed to failure. Discipline problems that have been reported may even be in part caused by the inexperience, lack of motivation, or lack of training of the teachers in those sets.

***Summary of Findings***

Mixed groups are unpopular with staff and pupils and are unsuitable for science as a subject, although they seem ethical on the surface and are easily achieved, requiring little effort on the part of middle management (which is perhaps one reason why they are so commonly used).They also do not allow all students to reach their full potential and reduce the number of students who take science beyond age 16.

Setting systems may be based on inappropriate measures, such as teacher guesswork and behavioural issues, and bottom sets often contain disproportionately high numbers of poor, male, summer-born students and those from ethnic groups. High numbers of students are placed in the wrong sets and are then unable to move due to curriculum and organisational factors. Labels associated with both high and low sets result in the stigmatisation of students, and self-concept is damaged. Student motivation in bottom sets falls, and a sense of failure and disaffection develops as attainment is polarised. High-ability students achieve better grades than they would have in mixed-ability sets and take science further, but it may be at some cost to their lower-ability schoolmates. Teachers prefer the high groups and teaching quality falls in lower sets, which are often taught by ill-prepared and inexperienced staff.

What often results from these systems, particularly in lower sets, is a culture of failure, refusal to engage, symbolic violence, and negative attitudes towards science from a large number of students who have been failed by the system and then fail their examinations. Issues of gender, ethnicity, and class bias arise and the values of society are challenged. Young and inexperienced teachers are demotivated and high-ability students fail to reach their full academic potential.

***Option-Based Setting Systems: A New Perspective?***

Some features that might characterise an improved setting system are:

- Flexibility of movement between sets and regular pupil review.
- Placing more emphasis on effort than on attainment when assigning sets.
- A modular curriculum that allows students to select what they study, giving them greater responsibility and ownership.
- Differentiation within all groups to cater for differences in ability (Ireson et al., 1999).

I would add that a setting system for students aged 14-16 years in science would:

- Take modern educational perspectives on multiple forms of intelligence into account and avoid grouping using inappropriate measures such as behaviour.
- Assign teachers based only on what would be best for the learners in that group.
- Cater to motivated future scientists, and future consumers of science, separately within a choice-based modular context.
- Allow mixed-ability groups to form and avoid "bottom sets," while allowing high-ability learners to achieve their potential in science separately.

- Take into account issues of gender and race to avoid sets where racial groups and/or boys predominate.

*A case study: Sandringham School in Hertfordshire*. Sandringham School has attempted to increase high school student motivation by introducing a system that allows them to pursue their studies via modules, which students choose on the basis that they find them interesting or relevant. This approach has been very popular with both parents and pupils, who enjoy the greater autonomy and ownership that it gives them over their learning. The school's Ofsted report (*Inspection Report: Sandringham School*, 1999) was highly complimentary of their approach, commenting that it helped to "develop a feeling of self worth and success" (p. 29). It also comments on the degree of flexibility in the curriculum being far higher than normal and consider this to have been in part responsible for improving GCSE examination results at the school. The report also finds the children motivated, well-behaved, and responsive in science lessons. Both high- and low-ability students are further catered for in out-of-class "high fliers" and "catch-up" sessions, and ability grouping is not used.

Sandringham is a non-selective, comprehensive school and was formed as a result of the amalgamation of two failing schools. Many such initiatives fail, but Sandringham went on to be hailed by Ofsted as the third best-performing comprehensive school in the country in 1997 and continues to do very well in both pastoral and academic spheres. The Headmaster attributes the school's success to three factors, the first of which is an exciting and motivating curriculum, especially at Key Stage 4 (ages 14-16 years), taught by highly-qualified and dynamic teachers. This case study shows that a student choice-based, non-ability grouping modular approach could be successful in raising standards in science by increasing inclusivity and access to science for all.

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# Ideas in Brief

Summaries of ideas from key articles in reviewed publications

## *The Google Calculator*

*Google* (2006) offers a new tool that numerically evaluates equations while also tending to units and mathematical and physical constants. To get a feel for how the calculator works, google (i.e., type in the Google search bar and press the *Google Search* button) "2*3=" (but without the quotation marks) to find that the answer "6" appears. Then click on *More About Calculator*, which appears under the answer, to learn more about formatting equations for Google.

Google "G" to find the value for the gravitational constant appear. Google "G*mass of the sun*80 kg/(radius of the sun)^2 in pounds force" to determine that a person registering 80 kg (165 pounds) while standing on a bathroom scale on earth would need a scale capable of reading 4,934.55214 pounds on the sun. (Users need to adjust answers to the appropriate number of significant figures.) Further information may be found at *GoogleGuide: Calculator* (2006) and Ward (n.d.).

Ward (2006) believes that future students will leave unit conversions, unit checking, algebra, calculus, and looking up constants to computers, in the same way our generation has passed off arithmetic and the like. And, the sooner they begin, the better, as this will allow time to concentrate on the really important concepts. String theory, for example, could be introduced to high school students before they graduate.

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Ward, D. W. (n.d.). *Physics the Google way*. Retrieved October 24, 2006, from http://google.davidward.org .
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## *How Wide and Deep are our Genetic Roots?*

Among the recent, spectacular advances in the biological sciences is completion of the initial sequence of the chimpanzee genome. The hereditable characteristics of all organisms is determined by the genetic information carried by DNA, and the complete DNA sequence for the human genome, completed in 2001, showed human DNA to contain about 32,000 genes. The chimpanzee DNA turns out to be about the same length, and 98% identical to the human genomic sequence. This supports modern evolutionary theory that humans and chimpanzees are extremely closely related.

Further:

- Sixty percent (60%) of fruit fly genes, 43% of nematode worm genes, and 46% of baker's yeast genes are similar to human genes.
- The genes for basic metabolic functions, such as respiration, found in primitive bacteria are also found in higher organisms, including humans.
- The genetic similarities between humans and other mammals result in organ similarities, making animal experimentation, such as organ transplantation, relevant to humans. Pig insulin protein was used to treat diabetes in humans for 50 years.
- The cells of all species--bacteria to humans--are composed of the same chemical elements.
- All species similarly synthesize proteins, which is the signature of life.

Combined with the other scientific evidence available, this indicates that all species, from bacteria to humans, are related. Bhattacharjee, Janssen, and Gregg (2006) conclude that our genetic roots run very deep indeed.

*Reference*

Bhattacharjee, J. K., Janssen, G. R., & Gregg, T. G. (2006). Human genealogy: How wide & deep do our genetic connections go? *The American Biology Teacher*, *68*(2), 69-71.

*Editor:* Murray (2006) regards the mapping of the human genome to be perhaps the most important scientific discovery during the last 1,000 years. He concludes that humans are not so special, quotes Rev. Kaith Durand as saying that "it also tempers the often inflated human ego to realize that we are not much more complex than the humble fruit fly (¶ 17), and suggests that this work has spiritual, religious, and ethical implications. Ethically, there are implications for the way we view and treat our fellow creatures.

*Reference*

Murray, B. (2006). *Spirituality and the human genome project*. Retrieved September 18, 2006, from http://www.upliftprogram.com/article_genome.html .

## *Accepting Technology, Rejecting Responsibility*

We live in a scientific age, only too willing to accept the benefits that science brings us. However, we are not willing to take responsibility for the deadly side-effects. Hobson (2006) provides the following examples:

- *Life support.* We use medical technology to prolong life, yet have difficulty deciding to allow people to die when that technology becomes counterproductive. Some object to the latter on the basis that it is playing God, yet the development and use of the technology that prolonged life in the first place demonstrates that society has already decided to play God.
- *Overpopulation.* Agricultural and medical technology has allowed Earth to become overpopulated, yet we do not accept the responsibility to limit births.
- *Fossil fuels.* Motor vehicles provide us with a mobility that was unknown only a century ago, yet we won't limit the burning of fossil fuels that is warming the globe and producing pollution that is destroying environments, cities, and lives.

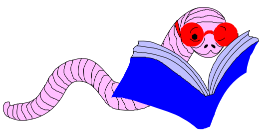
Causes for the harmful uses of technology include:

- *Overly individualistic ideologies.* People are outraged, for example, by the suggestion of policies that would restrict, even slightly, the freedom that the motor car provides, even if it were for the greater good.
- *Cultural habits ( including those expressed by many religions).* Science need not be incompatible with humane and religious values but fundamentalists, basing their beliefs on, for example, the "literal truth" of certain religious texts, tend to obstruct the kind of decision-making required (e.g., in the case of overpopulation, sex education, the education and economic freedom of women, and family planning).

So, here we stand with one foot in modernity and the other in medieval superstition, and if this continues for many more decades, resource shortages, failed nations, terrorism, and environmental collapse will see us with both feet planted firmly back in the Middle Ages. However, the situation is solvable, with education being the place to start. To achieve the quality of education required, though, we will need to overcome the distractions of fundamentalists who, for example, seek to supplement biological evolution with creationism.

*Reference*

Hobson, A. (2006). Science and society: We're not paying our dues. *The Physics Teacher*, *44*, 255.



# Research in Brief

Summaries of research findings from key articles in reviewed publications

## *Investigating Nature While Going to School*

Lindemann-Matthies (2006) used questionnaires to evaluate the Nature on the Way to School program developed by Pro Natura, a Swiss conservation organization. Data was collected from over 3,000 8- to 16-year-olds and 117 teachers.

The program aimed to increase students' first-hand experience with nature, impact positively on their perceptions about the role of nature in their daily lives, and promote an interest in, and tolerance of, local plants and animals. Themes comprised the life of the sparrow; snails, slugs, and earthworms; ladybirds; insects on plants; trees in the city; climbing plants; life in cracks and crevices; lichens and mosses; and native and non-native plants. Teachers, on average, rated the program very highly, and children of all ages enjoyed it.

*Reference*

Lindemann-Matthies, P. (2006). Investigating nature on the way to school: Responses to an educational programme by teachers and their pupils. *International Journal of Science Education*, *28*, 895-918.

### *An STS and Textbook Approach Compared*

In this action research project (as opposed to a formal, experimental one), Yager, Yager, and Lim (2006) compared the outcomes for two sections of middle school science taught by 2 experienced teachers, but with one adopting an STS approach that used constructivist teaching practices while the other used a more typical textbook approach. The STS students were able to master concepts as well as the other group. However, the STS students could better apply concepts to new contexts, exhibited creative skills more uniquely and more often, learnt and used science at home and in the community more, and developed more positive attitudes about science.

*Reference*

Yager, S. O., Yager, R. E., & Lim, G. (2006). The advantages of an STS approach over a typical textbook dominated approach in middle school science. *School Science and Mathematics*, *106*, 248-260.

### *Cognitive Conflict Versus Direct Teaching*

Inducing cognitive conflict (ICC) is a highly-regarded teaching technique. However, the evidence for its effectiveness is equivocal, and Zohar and Aharon-Kravetsky (2005) think they may now know, at least partially, why. They used 121 14- and 15-year-old students, taught by 2 females and divided into four groups in a 2 x 2 experimental design, to compare teaching the strategy of controlling variables to both academically low-achieving (LA) and high-achieving (HA) students by both ICC and direct teaching (DT) methods.

Overall, the two teaching methods were similarly effective. However, while ICC benefited HA students, it hindered LA students. On the other hand, DT hindered HA students but helped LA students, with these conclusions applying both after instruction and 6 months later. In short, the effectiveness of ICC may depend on the academic achievement level of the students involved.

*Reference*

Zohar, A., & Aharon-Kravetsky, S. (2005). Exploring the effects of cognitive conflict and direct teaching for students of different academic levels. *Journal of Research in Science Teaching*, *42*, 829-855.

## Readers' Forum

### *Draw-A-Scientist Test*

I have long had concerns about the validity of the Draw-A-Scientist Test (DAST) for identifying children's perceptions of scientists, so am somewhat surprised to see it continuing to feature in the literature in the way it does (e.g., Finson, Thomas, & Pederson, 2006; Mamola, 2005; Schibeci, 2006). Dawson (2006) has recently expressed the same concern, albeit more strongly: "This test should be consigned permanently to the bin. . . . DAST tells us very little, if anything, about students’ real images of scientists, because the requirements of the test restrict the possible responses” (p. 5).

Ó Maoldomhnaigh and Hunt (1988), McNay (cited in Jackson, 1992), Som, Hill, and Wheeler (1989), Jackson (1992), and Dawson (1997) have all considered that students’ perceptions of scientists could be far broader than the simple drawing required by the DAST can reveal. Bowtell (1996) found that Year 5 and 6 children “said that scientists are normal but still drew the stereotypical standard image” (p. 12). I found that a student can hold two distinctly perceptions about scientists simultaneously (Eastwell, 1998). Also, could a student not possess more than one view of a scientist and therefore draw different images at different times, without their perceptions having been changed, thereby also questioning the reliability of the DAST?

I have been able to find only two references reporting validation of the DAST, and neither is convincing. Kahle (1989) addressed the question of validity by reporting a then-to-be-published study (Tobin, Kahle, & Fraser, 1990) in which she said “when an Australian researcher interviewed Year 10 students after they drew scientists, in most cases their verbal images matched their visual ones” (p. 4). However, I do not find any reference to such a matching process in the published study, and wonder how significant the *most* is in the Kahle quote.

Mamola (2005) wrote that the characteristics appearing in children's drawings of scientists are consistent with comments they make during interviews, and the source of this conclusion was Finson, Beaver, and Cramond (1995), in which they report that "no significant differences were found between interview scores and DAST-C scores" (p. 200) (personal communication, February 22, 2006). However, this conclusion of Finson et al. needs to be interpreted in the context of the interview protocol they employed. "Initially, students were asked to describe a scientist [which simply mimics the considerations they had to make while drawing a scientist], with follow-up questions correlating with checklist items being employed afterwards [which is a narrow focus]" (Finson et al., p. 200). In other words, the interview design was aimed at eliciting (and checking on) very narrow responses only, and certainly not suitable for eliciting the much more complex perceptions that students may hold? In addition, the treatment group comprised only 24 students, which is hardly a sufficient basis for being confident about any generalization.

I’m of the opinion that further investigation would be needed before a decision could be made as to the usefulness, if any, of the DAST, and look forward to what others may have to say. In the interim, let’s guard against assuming that the DAST is valid.

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## *The "Mobius" Effect*

The important question of how to lead students to engage the broader social-scientific issues that surround the material we teach has been raised in this journal. I am reminded of August Mobius, the 19th century mathematician who had seen the "one-sidedness" of a folded strip of paper. There is a tendency to separate the content of a scientific theory and its broader significance; to see them as two different sides. The "Mobius" effect denies that these can, or should, be separated.

Generally speaking, I applaud the Mobius sensibility. Science is not a mere calculus or formal system of inferences. It gives us an image of nature and of ourselves. It is important to address the issues raised by the material we teach, issues that clearly are not going to go away just by ignoring them. And ignoring them seems to be the favored strategy. Too often, we take an end-run around these issues. Consider the host of issues surrounding evolution. There is a real problem here. You don't have to have lived in Tennessee in 1925 to know there is a problem. There are many people, especially in the United States, who are very concerned about teaching evolution to our children. Part of what is going on here is the difficulty of reconciling the apparently competing claims for authority of science and Scriptures. But even here, it is not so straightforward. The hypothesis that the Earth is a planet contradicted the straightforward sense of the Old Testament; yet, there is no sizeable movement challenging the teaching of this notion. Something else is going on with evolution. It's not just a conflict between a scientific theory and Scriptures. It has been hard for people to buy what evolution seems to be saying about life, the universe, and everything else. How do we deal with these issues? For the most part, our biology texts reduce the matter to a question of the facts. Here is molecular biology; see how it works. If we allow this array of molecular entities to run loose for a long time, things will change. We don't need to call it evolution, or any particular theoretical framework. It is just the facts. No one, they seem to say, would deny transfer-RNA. So how can there be an issue?

What this really does, however, is leave our students out in the cold, caught between competing doctrines. The cost here is not only a heightened hostility between opposing camps, but it also collapses the contours of evolution into the flat terrain of simple matters of fact.

But evolution is not a "fact"; nor is Newton's second law, the kinetic theory of gases, plate tectonics, or the fine structure of electron orbitals. I mean this in a pedagogical sense. For our students to understand what we offer them, we need to give them a sense for where it comes from--what arguments carry it--and what issues it raises when we look at the world this way. That is, I believe the key is a matter of context.

I try as much as I can to unfold the material I teach in an historical manner that allows students to see alternative approaches. This means we are routinely evaluating theories and connecting them to the problems they addressed and the evidence they used as support. This has also allowed us to witness contemporary social issues in historic episodes. The issues surrounding evolution are an excellent example.

I have, for a long time now, taught a high school course in the historical sciences, and work hard to give evolution the context it deserves. The first step is to shift from modern molecular biology back to Darwin's work. We need to earn the foundation where it makes sense that we would find the workings of molecules like nucleotides and transfer-RNA to be the key to the sweep of life's history, which includes in the popular imagination the rise and fall of the great beasts of the Jurassic; not, I think, an obvious connection.

But even as we take this step, it is clear that it is not yet the context we require; for what we need, as well, is the context for Darwin's work. And so we push even further back to the master work of the great French biologist and geologist, Georges Cuvier. This is not the place to lay out all the wonderful ideas and arguments of early 19$^{th}$ century biology and geology, but I can suggest how it sets up an appreciation of the tensions that continue to surround evolution.

Instead of a theory of gradual development, where life forms would evolve from one type into another, Cuvier saw the history of life as a series of epochs where sets of animals flourished and then were replaced by successive types. The key to this theory was the problem of extinction. Before Cuvier, the fossilized remains of exotic beasts had been seen as unlikely forms that had more or less naturally failed. But Cuvier's re-constructions of these animals had shown them to have been perfectly viable, since they were built according to the same principles of anatomy that characterized existing life. Why then were they no longer around? The answer, Cuvier proposed, was catastrophic violence. These ancient forms had been caught off-guard by events of cataclysmic proportion; mountains raised and seas violently displaced. This violence brought an end to one epoch, and wiped the slate clean for the next (Cuvier, 1813).

If we turn to the Earth's last, most recent great catastrophe or revolution, we find Cuvier bringing together sacred, civil, and natural history. Drawing upon the recent work of William Jones, the first well-formed assertion of the Indo-European hypothesis, several things fell into place. Sanskrit would have been the language of the ancient Hindu and so the language of the Himalayan highlands, the highest settled lands of the world. The last geological revolution would have unleashed a great flood. Perhaps all of humanity had been wiped out except for those who lived in this plateau, and so all modern languages would have developed from ancient Sanskrit; just as all humans would have descended from the survivors. Furthermore, some historical scholarship had already suggested a world-wide concordance, linking the chronologies and myths of various ancient civilizations. Cuvier extended this thesis. Deucalion's flood from Greek myth, and Gilgamesh's from ancient Babylon, for example, had each been, like Noah's flood, an account of a real event, a memory trace left from the last geological upheaval.

Here was a truly grand hypothesis, and an interesting example of the play between Genesis and geology. This is no literal rendering of the Biblical tale. In the first place, according to Cuvier the Earth has a history many times older than the biblical framework would suggest, as Noah's flood connects to only the most recent of an extensive series of epochs, each likely to have been thousands of years long. Furthermore, it is a theory resting on the sturdy planks of natural history and civil history, with only a glancing nod, as it were, toward the Old Testament. And most especially, the Flood had not been God's judgement against a sinful humanity, but rather one of a series of dramatic, natural catastrophes.

We have now sketched in broad strokes a context for Darwin's work, a context that highlights several features of his approach to the history of life. First and foremost is Darwin's dramatic denial of Cuvierian catastrophes. Instead of a succession of steps, punctuated by dramatic violence, Darwin offers changes so gradual they are literally indiscernible. Further, nowhere in the *Origin of Species* does Darwin examine the fossil record. Though we are accustomed to find the "Hall of Evolution" at a natural history museum filled with the sweep of life from trilobites, to the great beasts of the Jurassic, on to the prototypes of the modern lions, tigers, and bears, that is not the "Hall" Darwin gives us. Instead, we find in the house of Darwin a menagerie of short-legged sheep, pigeons, and of course, the finches and tortoises of the Galapagos Islands. Cuvier is the reason for this.

Cuvier's work also sets an important context for the relations between science and religion. While the theory of evolution would excite powerful religious reactions, the interaction between Genesis and the history of nature does not begin with *The Origin of Species*. In Cuvier's work, sacred history is given a foundation outside the authority of Revelation. The Biblical flood is but one of several accounts stemming from a distant catastrophe.

What is the value of this context for our students? It is, first of all, to allow the legitimacy of the concern. For students to see a master scientist like Cuvier engage the connections between Genesis and geology makes it legitimate to be concerned about the issue, and further, it gives the issue itself a certain distance. It has its own contours, and is not a simple matter of whether you are for or against science. Moreover, it raises in a well-framed way the matter of different ways to read what the Old Testament is really about, ways that are respectful and learned and well within the fold, as it were.

At the same time, Cuvier was criticized by only a small number of people for his unorthodox approach to the earth's history, in no way comparable to the reception of Darwin's views one half a century later. Why was Darwin's work greeted by so much controversy? The key here, I believe, was not Darwin's denial of Genesis, but his denial of design and the harmonies which had been so important to Natural Theology. Natural theology was drawn from the book of nature, as scriptural theology was based on the Revealed Word of God. Across the centuries, both texts had been cherished as sources revealing the wisdom and beneficence of God. To study nature was to find its patterns, and in these patterns to discern the purpose of God's handiwork; and so the purpose of our being.

A long-standing central tenet of natural theology was the basic harmony of nature. It is that harmony everywhere witnessed in the extra-ordinary intricacy of life. For every flower, there is a bee; for every bee, a flower. This harmony of ends reveals a degree of organization which dwarfs the imagination.

Darwin denied this harmony, this design-full-ness, and it was this denial that so frightened and offended Victorian sensibilities. He refused to take the harmony of nature as the result of intelligent design. But what agent could have crafted the seeming design-full-ness of nature? Darwin's answer was: Death. Death claimed all those who had not made connection with the web of life; any flower for which there was no bee, every bee for which there was no flower. Harmony was not a Plan; it was a residue. It was the remains of those who had not died.

I have here sought to suggest the value of an historical approach in the teaching of the sciences. Cuvier's masterful work in biology, his sense for the intricate complexities of life, made evolution a difficult case to establish. Pointing to the similarities between species and some broad sense for the great chain of being would not suffice. Further, Cuvier's extension of these principles to the fossil record made evolution equally suspect over the broad sweep of time. These highlight two central features of Darwin's work: his key shift to the processes of heredity--what would become the modern science of molecular genetics--and the complete absence of fossils from his argument.

I have also sought to suggest the natural integration of the fuller meaning of the sciences when we teach using an historical approach, what I have called the Mobius effect. In this case, I have sought to suggest the value of examining Cuvier's work to help students to find a way to negotiate the boundaries between science and religion on this most complex terrain.

*Reference*

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## ? ? ? ? ? Your Questions Answered ? ? ? ? ?

This section of *SER* responds to readers' queries, so please submit your question to The Editor at editor@ScienceEducationReview.com . Have that long-standing query resolved; hopefully!

### *National Curriculum*

*Why doesn't Australia--and other countries, for that matter, with state-based curricula--have a standardised, national curriculum for science (and other school subjects)?* (*Editor*: The following responses show that the term *standardized* can be interpreted in different ways; the same curriculum across states, but with scope to cater for individual differences, or the same learning experiences for every student.)

The easy answer is that a lack of a standard curriculum encourages innovation and provides flexibility so that teachers can adjust their curricula to handle local issues. I've seen cases where this theory really works and many, many more where it fails. The results are highly dependent on the teacher, as well as environmental issues such as class size. In my opinion, we should have greater central control but with flexibility.

From my perspective in the United States, the education standard question is greatly exacerbated. We have fifty states (plus a few other state-like areas) each with its own autonomy. In most of these states, the local school districts also have autonomy. So, we have thousands of independent curriculum-creating bodies. Children who move often find themselves totally out of synchronization with the curricula in their new schools. They may have to do lots of extra studying or may be repeating the same material. For middle schools, they may have come from a school that teaches one area in each of three grades or from one that has mixed threads. Of course, the breadth and depth of one school's (or district's or state's) courses can vary greatly from place to place. Thus, the quality of the education and its value for students' futures varies greatly too.

This story gets even better because individual schools in districts have quite a bit of freedom to alter the district curriculum. Finally, the teachers usually are not checked on whether they're sticking to the curriculum and may add or shorten any portion. A teacher may like earth science and expand that portion of a physical science class while shortening other parts.

The sole check on performance for teachers, schools, or districts is a standard test. Here, the states are giving them at intervals of a few years. So, often all usual instruction stops while everyone crams for the tests. With this perspective, why don't we have one standard curriculum throughout the country? Because we have no way to track its implementation and no way to enforce it; and also because students in Maryland study the Chesapeake Bay watershed, in Florida study hurricanes, in Arizona study desert ecology, and so on.

Still, the adverse effects of a lack of standards should be reduced. New technology now makes tracking and very frequent testing possible so that a real national curriculum is possible and so that checking on progress and success is not relegated to a high-stakes test every few years. Specifically, the Internet, low-cost computers, and powerful (and inexpensive) servers make possible frequent student interaction with web-delivered software that supports learning and tracks progress nationwide with the ability to drill down to any level; state, district, school, teacher, class, or student. Of course, it'll be very hard to get fifty states, let along thousands of schools, to agree on standards; and doubly so because no one really knows the best curriculum for science.

*Harry Keller, USA* www.smartscience.net

The question on why Australia does not have a standardised science curriculum is an interesting one. In Kenya, our science curriculum is centralized, prescribing the content to be taught and the objectives to be achieved in every topic. The number of lessons per week and the duration of each lesson are also predetermined. While the teacher still has an opportunity to look for interesting ways to present content, one of the critical issues affecting the learning of science is exams. Due to limited opportunities at each successive level, teaching for “passing” exams has distorted the whole purpose of learning. Important aspects such as critical thinking, creativity, and learning to love knowledge for its own sake are relegated to the background. That is not to say that all is lost, though. People are now beginning to ask questions about the whole purpose of learning.

*Mwangi Ndirangu, Kenya*

The notion of a standardized curriculum is quite tricky or misleading. In theory, a curriculum with the same content and the same aims and objectives for all students, like a national curriculum, sounds OK. But in practice, such curriculum does not and cannot work. This is especially true of the science curriculum. Why?

The reason is that there are those individual differences. Achieving the goals of the curriculum with all students is a democratic endeavour, but the question is: Do those goals do justice to all students? For some students, those goals could be easier to achieve, while for some others (or even few) the same goals may be far too difficult or even impossible to attain. So the point is that we need a curriculum that promotes individual differences but simultaneously increases (raises) the mean score of student achievement. But such a curriculum needs to be very flexible (and also needs experienced and dedicated teachers who will do their best to raise the mean score of their class by attending at the same time to each student).

A standardized curriculum, on the other hand, is undermined by the hidden curriculum. Although the official (explicit) curriculum may be standardized, the experienced curriculum is a totally different curriculum no matter what. Empirical research findings do support that. If a science curriculum should promote self-directed (not only cooperative) inquiry, then personal interests cannot have a place in a standardized curriculum. So, the point is to achieve the standards without standardization.

*Yannis Hadzigeorgiou, University of the Aegean, Rhodes, Greece*

Australia did "toy" with the concept of a national curriculum some 10 years or more ago, but the politics that came into play eventually saw each state develop its own modification of the initial curriculum framework. However, in view of especially the huge costs involved, some have questioned whether such an effort has been worthwhile (Dawson & Venville, 2006). A national curriculum would certainly have benefits, especially for students who need to relocate periodically, and this issue appears to be again on the agenda in Australia. Our Federal education minister is presently making such "noises," and the President of the Australian Science Teachers' Association has recently written: "We appear to be edging closer and closer to a national curriculum" (Carnemolla, 2006a, p. 6) and "there is considerable merit in identifying common essentials for study across Australia as recommended by the Australian Certificate of Education report" (Carnemolla, 2006b, p. 6). I'm wondering, though. If a national curriculum, comprising a framework that still allows for variability in the learning experiences offered to students and even the assessment used (particularly during the compulsory school years) could be agreed on, why shouldn't we aim for a standard international curriculum?

*References*

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*Peter Eastwell, Australia*

## *Socioscientific Issues*

*What techniques/strategies can you suggest for dealing with controversial socioscientific issues in class? To date, my repertoire has been confined largely to having students do some library research, discuss as a whole class, and submit a report arguing for a particular position, but I'm wanting to do much better in this important area.*

Some De Bono 6 hats work well. Also, the PMI (Plusses, Minusses, and Interesting things) strategy or even an analysis of the issue using Looks Like, Feels Like, and Sounds Like (or some variation to suit the situation).

*Greg Smith, Queensland, Australia*

I sometimes do a hypothetical with these issues, but you need to pick your class and students carefully. The students have responded well to this.

*Laurie Maetam, Queensland, Australia*

Role-play is a good strategy for engaging students in a consideration of controversial socioscientific issues. It makes students understand the controversy as it relates to various perspectives held by different interest groups. Students of the same group could do some library research based on the role they play. They could discuss the claims or evidence they plan to present before the role-playing activity begins in class. After presentation, students in different roles are required to defend their claims. Such a design allows students to experience different sides of an argument, and learn to put themselves in another's place.

*Shu Sheng Lin, National Chiayi University, Chiayi, Taiwan*

I think this teacher is doing a great service to students with this approach. It helps students to understand science in a social perspective and gives them the opportunity to do some real thinking.

If any teacher is up to the challenge, that teacher can engage the class in a Socratic dialog; that is, asking leading questions without providing answers. Ultimately, the students will determine the answer for themselves. Just beware Socrates's fate.

Whether discussing nuclear power or surrogacy, getting the thought processes going should be the main goal. You might keep track of each student's participation and provide incentives for most participation, for most participation by a student who hasn't previously participated, for best response (voted on by class), and so on.

You could also host a debate with students assigned randomly to each side (perhaps more than two sides in some cases). Some students would have to be the audience who decide the winner and must give the reasons for their decision. Again, the real agenda must be stimulating thinking; skeptical, rational, scientific, or any other good thinking. Get the students away from making decisions based on feelings alone. It's great to see a teacher who cares this way.

*Harry Keller, ParaComp, CA, USA* http://smartscience.net

In this group activity, which aims to promote critical and creative thinking by exploring both sides of a science topic, students analyse facts and information and learn to be flexible in their thinking. A topic of interest, for which there are two positions, is selected; for example, Global Warming: Is the Earth Really Heating Up? The class is then organised into groups consisting of two teams, each team representing one point of view on the topic. After reading and finding support for their position, each team argues this position to the other team in their group. The teams then reverse their positions and present the opposing pair's position. To conclude, the evidence and arguments are summarised and each group agrees on the better-substantiated position.

Also, see Oulton, Dillon, and Grace (2004). (*Editor:* Please see Volume 3, Issue 2 of this journal for a summary of this article.) The article begins with a brief discussion on the nature of controversy, including the inherent difficulties associated with controversy resolution and some reasons for differing viewpoints. The issue about whether to vaccinate or slaughter animals following the outbreak of Foot and Mouth Disease (FMD) in the UK in 2001 is then cited as an example of a controversy. From here the article goes on to make a connection between science and controversial issues.

As well as controversy arising from scientific advances, the public is increasingly reluctant to trust scientific advice provided on problems which are controversial. The inclusion of controversial issues in the school science curriculum is advocated as it helps prepare students for the uncertainties of today's world, and allows them to appreciate both the potential and limitations of science in resolving controversies. Next, the article examines some different methods for teaching controversial issues. Current pedagogical approaches to controversial issues which focus on a logical, unbiased presentation of the facts (with the teacher failing to offer their view) are questioned. It argues that a completely rational, unbiased presentation may not be possible and is not in line with the world and its social implications. The use of role-plays and debates to develop an understanding of controversial issues is also queried. Role-plays can demand considerable effort to set up and there is little evidence to suggest that students' attitudes may be changed by taking on a role. Debates often require students to choose a stance prematurely, and they also need prior preparation to ensure that discussions are informed. The article asserts that the teaching of controversial issues should be reconceptualised based on the nature of controversy and presents an alternative model. In this alternative pedagogical approach, an analysis of the different perspectives is central to the study of a controversial issue. Students also learn to identify bias, and are encouraged to critically examine their own viewpoint and to actively seek out information which challenges this viewpoint. The Foot and Mouth Disease controversy is then revisited to show how this pedagogical approach would be implemented.

*Reference*

Oulton, C., Dillon, J., & Grace, M. M. (2004). Reconceptualizing the teaching of controversial issues. *International Journal of Science Education*, *26*, 411-423.

*Jodie Doolan, South Australia*

Here, I describe two strategies I have used for dealing with controversial socioscientific issues, both as a science teacher educator and, prior to that, as a classroom teacher of 13- to 18-year-olds. I have found the activities effective for getting students to focus on science issues and for engaging them in constructing science content. Through these activities, students learn about controversial social issues in science, the science impact on us, and how we impact what science gets done. While geared for 13- to 18-year-old students, the strategies can be modified for younger or older students.

I have decided to use the same content area, or issue, as an example of both teaching strategies. This makes the different learning expectations for the activities, and what I want my students to know about social and scientific issues, a little more apparent. The first strategy, making a Media Collage, focuses on how the general public becomes informed about social issues that rely on a scientific knowledge base. The second, a problem-based learning (PBL) activity, situates students in a dilemma, or problem situation, and asks them as a team to come to understand the science and social implications involved and come to a decision for the situation.

*A Socioscience Media Collage*

This strategy focuses students on how current scientific issues are presented and debated in popular public media. The students find examples of discussions of their issue in newspaper articles, on-line sources, cartoons, editorials (newspaper, TV, or radio), magazines, or other publicly accessible materials. For my Media Collage, I require students to gather at least five different presentations of the issue, and these must come from at least three different forms of media. They must create a display for these media items, conduct an analysis of the different items, and then write a short essay that discusses the quality of the information that is presented and what the public could learn from it. Finally, all students present their media collages as a display for their classmates to view. What follows are the instructions I would give to a class of students aged 13 to 15 years.

## A Sample Assignment

*General Description*
The use of genetically engineered grains in food products, and as feed for animals, has created rifts between US agriculture producers and European consumers of American-made products. There are also Americans who do not believe that genetically engineered foods should be sold in American stores, or at a minimum that they should be labeled. You will make a Media Collage about genetically engineered food products that can be displayed for your classmates. You will also conduct an analysis of how these media items would inform the public and write this up in a short essay that you can present orally to the class.

*Media Collage Requirements*
1. At least five media items that present a view, ideas, and/or information about genetically engineered food.
2. You must have at least three different media forms represented in your collage. This is how I classify different forms of media:

   *Form 1*. News reports in newspapers or magazines.
   *Form 2*. Editorial articles in newspapers or magazines.
   *Form 3*. Editorial cartoons, comics.
   *Form 4*. Radio reports or news stories (presented as audio tape or transcript).
   *Form 5*. TV footage from news shows.
   *Form 6*. On-line news sites or special interest websites.

3. You must be able to display your Media Collage for your peers. Some examples of this include a poster, a computer display (power point or such), your own booklet creation, or a combination display. The display should fit with your media forms.
4. All sources for your different media forms should be correctly cited, so we can tell where you got your sample from.
5. You must have a written analysis, of no more than two typed pages, that includes:

   a. What scientific information is being discussed?
   b. What, if any, sources of information does the author use to base his/her claim on?
   c. How reliable do you believe the information sources are that the author has used? How are you determining their reliability?
   d. Does the author create a compelling argument for his/her point of view? (For example, do you think they will be good at convincing people to agree with them?) Why or why not?
   e. Is this a media source that many people are likely to see and rely on?
   f. You must conclude your analysis with a paragraph that discusses the overall impact that this media collage would have on the general population's ability to make an informed decision about the use and production of genetically engineered foods.

Assignment Due Date: 3 weeks after given.

*Teaching Tips for This Activity*
I like to have students read their essays to the class as they show their display. The oral presentation helps to reinforce the emphasis about being a critical consumer of science ideas. I also find the oral presentations increase the students' creativity and thoughtfulness with the assignment, even at the college level. The lengthy due date is needed to give students time to

locate different media types. One other teaching tip is that if you are assigning the same issue to all students, you may want them to work in groups and increase the number of different sources required. This helps to reduce the amount of overlap in the information sources the students find.

*Problem-Based Learning (PBL)*

This second strategy has a much stronger content focus than the first. It also raises the issue of how science impacts our daily living and that decisions about science and its application are filled with human values. It can touch on the conflict that arises in science between being able to do something and whether we should do something just because we are able. Problem-based learning is typically conducted as a small group activity, where each group is provided with an unstructured problem resembling a real-life situation. In its most open-ended form, students are required to determine what information is needed, establish a work plan for gaining this information, research to gather the information, and then share and compare information to come to a solution.

I have done this as an activity for older students (17 years and up) and required them to conduct the majority of the research. However, for students with limited access to resources, to cut the timeframe, to scaffold the research process, or to use with younger students, the teacher can supply the information resources students will need to conduct their research. It is also advisable to train students in this process with simple problems, so they learn to define roles and delegate tasks. Even if you are requiring the students to conduct the basic research, this activity still requires the teacher to have strong background preparation or knowledge of the topic. The assignment description below is not complete enough to use as is, since it needs a great deal more specific information embedded within it. However, this description provides a general overview of what a problem-based learning assignment might look like.

A Sample Assignment

*Describing the Problem*
You and your 4 group-mates are a development team that has been sent information about the isolated community Whey. The Whey community is suffering from a food shortage due to an infestation that attacks their grain crops (both what they eat and what is used as feed). The community would like to move from donor support to become food subsistent. The primary crops that the Whey community is able to grow are millet and maize, both of which have seen diminishing yields due to a parasitic fungus. Your research team consists of 2 agricultural geneticists, a botanist, a parasitologist, and an environmental specialist. In order to determine if you can create genetically altered grains in this area your will need to know the following information.

1. The genetic make up of maize and millet, and their life cycles.
2. Fungi that typically attack maize and millet, and their life cycles.
3. An analysis of the proteins attacked in the grains by the fungi and the mechanism by which the fungi attacks the grains.
4. Other plants and animals in the surrounding community, their life cycles, and their likely susceptibility to the fungi or a changed maize and/or millet crop.
5. Background seasonal information including major weather patterns, growing season, rain patterns, and other large scale environmental factors.
6. Nutritional information for humans, cows, and chickens as it relates to the maize and millet.

Once your team has compiled as much of this information as possible, you must determine if it is possible to alter the grains to be resistant to the fungus. If it is possible, you must then determine if you have enough information to be certain this is the desirable course to take, or if it risks the greater human and ecological community.

*A Work Breakdown for Your Team*

| | |
|---|---|
| Days 1 & 2 | Determine which roles team members will take, what these scientists do, and their training in the field. |
| Day 3 | Assign each team member, based on their role, one of the primary information gathering points listed above. Not all jobs will line up exactly, so you may want to split points. Determine which information packets you will read. These packets are available from the teacher. |
| Day 4 | Complete a work plan page for your group. Include on your work plan what each team member will do, what product they will be responsible for, and when you will have team meetings to share information for each of week. |
| Days 4 – 10 | Research from reading packets and other research sources, and plan checks and revisions. |
| Days 11 – 14 | Share learned information, discussing the overall problem. Identify new information needed. |
| Days 15 – 17 | Research additional information, developing your report to the Whey community. |
| Days 18 -20 | Each group presents their report and recommendations to the Whey community. |

*Teaching Tips for This Activity*

As a teacher, you need to be sure that you either have the resources available for the students to use, or that they have access to them. I have suggested in this project that a good deal of the information would be obtained from the teacher in the form of a reading packet. For this activity, I would have the following reading packets available:

a. A maize packet, that included information about three different varieties of maize, their growing requirements, their genetic sequences, major parasites, life cycles, and basic genetic engineering and selective breeding information.
b. A millet packet, with parallel information to the maize packet.
c. An information packet on Whey that included resources, habitat information, cultural background to the community, and other major plants and animals to be considered. (This would be taken from an existing location, rather than creating a “new” community.)
d. A parasitology packet with relevant information about three different fungi: one that attacks only maize, one that attacks only millet, and one that attacks both.
e. A climatology packet for the area that deals with weather patterns, averages such as temperatures, precipitation, and sunlight indexes, and any changes in these weather patterns.

Each of these information packets would also include note-taking activities, information organization charts, maps, and other research tools to keep the students focused on gathering the information that will be most useful to them. Depending on your students’ ability and familiarity with PBL, these support materials can be reduced. It is also likely that students will need some support worksheets for compiling the information gathered by each person, so when they share what they are learning they can begin to organize a big picture of the ecosystem and the genetics.

The benefit of a problem-based-learning situation is that it provides students with experiences in the complexity of many social issues that are impacted by increasing scientific knowledge and technical skill. However, PBL requires a large time investment for students to allow them to really work through the problems and a very large planning investment by the teacher. Once in the classroom teaching a PBL unit, the teacher needs to be able to support the students in group work, organization, and understanding the information they are reading.

*Conclusion*

The two strategies I have described for helping students deal with socioscientific issues provide teachers and students with flexibility in how they address science in the public sphere. Both activities are structured to help students think about, and process, science as a human endeavor, and by doing so they provide students with skills for decision making as well as science learning. The first activity is one that can be completed by the students primarily outside of class teaching time. It makes a nice enrichment project or extension activity that connects learning about genetics and gene replication to the lives of the students. The second activity is a replacement to classroom lecturing and teaching and is not something students can attend to independently or as a homework assignment. PBL requires a commitment to allowing students to take responsibility for learning, and actually constructing, their own understanding about content.

*Helen Meyer, University of Cincinnati, OH, USA*

## Further Useful Resources

***Fascinating Science: Step-by-Step*** (http://www.fascinatingscience.com) Supplement classroom learning with this e-learning program comprising step-by-step audiovisual slide presentations in chemistry.

***The Early Years*** (http://science.nsta.org/earlyyearsblog/) An ongoing conversation on early childhood resources and issues.

***Kids Can Press*** (http://www.kidscanpress.com) New children's book titles include *How Animals Defend Themselves, How Animals Use Their Senses, Jurassic Poop: What Dinosaurs (and Others) Left Behind, Science Detectives: How Scientists Solved Six Real-Life Mysteries, Who Likes the Snow?*, *Change It! Solids, Liquids, Gases and You*, and *Build It! Structures, Systems and You*. Visit the Web site to find a full book list, sample pages from books, educator resources, author and illustrator biographies, and downloadable activities.

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