First Among Errors

If we could only teach one science lesson, what would it be?

by Douglas Allchin

Imagine you are stranded on a deserted isle and you can only take one science lesson with you: what would it be? It's a variant of a familiar game. Pointlessly unrealistic, of course. No matter. As with many thought experiments, the purpose is more deeply philosophical. Namely, the question invites reflection—not about favorite books or music or interesting people—but about what, ultimately, is the most important element in science education.

Yes, really. Take a moment to reflect.

OK: evolution, hands down. That would be the answer — if what mattered was content. "Nothing in biology makes sense except in the light of evolution."

Yet others may surely contend that the core of science is not the content, but rather the process. "Give a student a concept and they can learn for a day; teach a student how to investigate, and they can learn for a lifetime." Teaching the *process* of science seems so much more fundamental and enabling.

What a potent conclusion. Imagine what this priority would imply about state-wide multiple choice exams! What havoc! Yet I would wager most science teachers would feel quite liberated if teaching process of science was their primary charge from the public. One could stop rushing through the textbook and cramming lectures with facts students could find equally well on the internet, given a bit of savvy "how-to" and critical thinking, so fundamental to effective research itself. One could focus on scientists themselves, their compelling stories, the route to discovery, the celebration of creative insight, the processes of reasoning: that is a science lesson that is both satisfyingly human and concretely useful.

So: process of science? Hardly an original answer, but surely provocative enough to start us pondering why this is not more central or dominant in state standards—and/or the tests derived from them. Perhaps teachers and educational researchers need to reflect more thoroughly on how one demonstrates this form of understanding, so that it is not so easily shunted to the periphery when adminstrators and political demagogues scream "Accountability."

But with only a single lesson, one should choose carefully. Ultimately — call me an optimist, perhaps — I have faith that if reliable information is important, someone will seek it. Eventually, they will find how to sort the reliable information from rubbish. If they care. That is, they will figure out all the scientific methods that have emerged from centuries of meta-scientific learning: the role of empirical evidence, the virtue of accurate measurements, the need for controlled experiment, double-blind studies, statistical analysis of error, honest reporting, etc. Science will be able to re-assemble itself on a deserted isle, if knowledge is important at all.

That might mean that the primary lesson should be an appreciation of science, respect for truth and enthusiasm for seeking knowledge: more affective than cognitive. Indeed, I esteem this goal to be high among many teachers reasons for teaching—although reward may be scarce for acknowledging so publically. Parents, however, often seem mindful of the value of this lesson, possibly the occasion for the most frequent unsolicited expressions of gratitude that teachers receive—and that fuels their continued efforts. Honoring this third option as the #1 science lesson may be as revolutionary as the former. Imagine the core of science being more about emotion than reason or intellect. Wow, that would step on some sacred bovine toes.

My own candidate for "Most Important Science Lesson" (MISL), however, departs from all these fine proposals. Foremost, it shifts focus from the process of science one layer deeper to the "nature of science"—that sometimes vague set of concepts *about* science and how science works. —Or, in this case, how science *doesn't* work.

The "nature of science," or NOS, was (re)established as an important benchmark in science education in several important reform documents in the 1990s, from the National Research Council (1996) and the American Association for the Advancement of Science (1993) to BSCS (1993). But declaring its importance did not mean that characterizing it was easy, nor that we knew well how to teach it, let alone assess student understanding of it. Accordingly, the recommendations are still winding their way through the system, surfacing in many state standards, but leaving many, including classroom teachers, uncertain about how best to proceed.

What do students need to know about the nature of science? Characterizations of NOS have varied over the past century, leaving one to wonder if it is all subject to cultural whims and shifting popular attitudes about science. Yet one element has persisted as central throughout: typically expressed as "the tentativeness of science" (Lederman, Wade & Bell1998; Osborne, Collins, Ratcliffe, Millar & Duschl, 2003). Namely, scientists can be wrong. Even Nobel-Prize winners. Yes, even Darwin (*Sacred Bovines*, Oct. 2008, Feb. 2009).

Declaring that "science is tentative" alone, however, is vacuous. Critics of evolution, for example, frivolously dismiss the robust evidence and denounce Darwinians as "dogmatic" (Allchin 2001) while appealing to a principle of tentativeness. Likewise, naysayers believe that it justifies denying global climate change: purportedly an unreliable overstatement of uncertain data amplified by uncertain models. Such cases indicate that merely asserting that "science is tentative" doesn't help. One needs to understand how or why science, or scientists—or any individual, for that matter—can err in thinking.

This is the MISL I propose: recognizing how we can each err in our thinking and, more importantly, developing skills to counterbalance or remedy the tendency to err. In scientific practice, this is embodied in a habit of searching for, and addressing, sources of error.

The potential sources of error in science are many. Some are experimental: an uncalibrated instrument, a missed control, inadequate sample size. Some are observational: when our senses play tricks on us, or our expectations bias our perceptions. Some errors occur in reasoning: jumping to a conclusion before sufficient data warrants it, or interpreting correlation as causation.

Some are social: the reputation of a famous researcher overshadowing counterclaims, or a fraudulent study undetected in peer review. Some are cultural: gender or race shaping how one interprets what are ultimately indefinite results, or sources of funding supporting some research that eclipses work on alternative theories. The methods of science are, in many ways, our hard-won historical heritage of ways to prevent, mitigate or accommodate such errors.

Yet among all possible errors, one seems more severe—and diabolical—than the rest. The error is cognitive. That is, it seems to reflect how our brains work, unmonitored. The error is widely documented by psychologists, who generally frame it as one of our basic cognitive flaws, fundamental to a wide range of other cognitive mis-steps. The MISL error is this: adopting the first available idea, which then subtly governs subsequent perceptions, analyses and conclusions. It is known typically as confirmation bias, sometimes also as the availability error, the primacy effect, belief persistence, positivity bias and the congruence heuristic (Gilovich 1991, Sutherland 1992, Nicherson 1998). First impressions matter immensely.

The error's effect is far reaching. Prior beliefs and information are powerful filters. For example, using earlier mental patterns, we select or highlight confirming examples, and discount or peripheralize counterexamples. The very evidence we collect in an effort to be objective may be inherently biased. Also, we will tend to draw conclusions before all the relevant evidence is available. Indeed, we will not even notice that the evidence is incomplete. Typically, we entertain or pursue only one hypothesis at a time, shuttering off awareness of alternative interpretations of the same information. In all these ways we tend to mislead ourselves. And all these lapses appear in the history of science.

None of this is conscious, of course. The whole process is quite insidious. The functioning brain hides one of its greatest weaknesses. It is a cognitive blindspot. We may not be thinking straight, even when we think we are. Individual scientists, too. As champion-skeptic Michael Shermer notes, smart people, in particular, are very good at rationalizing their beliefs—ironically, more effectively than others, and so their ill informed beliefs can become exceptionally well entrenched (2002, 296-302). Learning about this handicap for oneself is unlikely. —And for this very reason, the error is a prime lesson in science education.

Philosopher Karl Popper did not seem to have confirmation bias in mind when he profiled a role for falsification in science, yet his ideas resonate with the problem. Confirmation, by itself, is susceptible to error, both logically *and* psychologically. We need to search mindfully for exceptions and counterevidence: potentially "falsifying" examples. Popper thus advocated *severe tests*: rigorously designed to really help expose one's own errors, if they were present (Mayo 1996). That was how to achieve confidence in scientific findings. Engaging criticism and alternatives is essential—and requires deliberate action.

The negative effect of prior beliefs permeates all types of thinking. Consider one psychologist's assessment in introducing a comprehensive review of the research literature:

> If one were to attempt to identify a single problematic aspect of human reasoning that deserves attention above all others, the *confirmation bias* would have to be among the candidates for consideration. Many have written about this bias, and it

> appears to be sufficiently strong and pervasive that one is led to wonder whether the bias, by itself, might account for a significant fraction of the disputes, altercations, and misunderstandings that occur among individuals, groups, and nations. (Nicherson 1998, 175).

Wow. MISL, indeed.

So, how does one cope with this awesome cognitive challenge? First—and this is the foremost reason for placing it squarely at the heart of a biology curriculum—one needs to be aware of how one's own brain works and of its potential for mistakes. Even at the very point where we think the evidence is most secure, we may be mistaken. Too often, imagined justification is merely superficial rationalization. In addition, we tend to attribute bias to others, not ourselves. We need to instill a deep appreciation of the fallibility of our minds. *Our* minds, not other people's minds. That opens the way to critical self-analysis and self-regulation.

Second, one needs to "test" conclusions not against the evidence alone, but against the evidence presented by others. Alternative perspectives matter. Sound conclusions may involve some hefty listening. (And that, in turn, may involve tolerance, valuing heterogeneous perspectives, and even a habit of seeking contrasting views.) Responsible claims include engaging critics. "Critical thinking" relies less on being "critical" than on listening well to criticism. Yes, error can be exposed and weeded out: most likely socially, through a system of checks and balances. Scientific knowledge edges forward.

Teaching about error may seem counterintuitive. Isn't a central goal of most education to teach how to think *well*? —how to analyze and trust evidence? Why waste precious time dwelling on the opposite? But imagine practicing medicine without understanding disease, or enforcing law without understanding crime. This is the sacred bovine: the assumption that we can learn to think well . . . well, without thinking. —That our brains function normally without error. And that science is thus inherently and spontaneously self-correcting.

Becoming aware of unconscious cognitive biases seems essential to good analytical, fully informed thinking. Indeed, learning how preconceptions shape all our thinking seems a critical tool for leveraging effective learning of everything else. The tool is worthless, of course, if you do not know about it or know how to use it.

To my mind, every prospective thinker deserves a user's guide: *Your Brain & How to Use It*. Of course, every owner's manual also needs a section on Troubleshooting. That's where the lessons on error fit. Confirmation bias seems to merit a whole chapter on its own. Fixing mistakes takes work. Only through using methods-beyond-the-methods can science effectively correct itself.

Ultimately, the simple MISL game helps underscore the poverty of curent content-based mass examinations. It may also help invigorate efforts to displace them with concrete skills in "personal and social decision making" that involves science. Learning to think is a valuable first step. But not enough (do the math?): students also need to learn how to "think *twice*."

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