BOILING FOR SCIENCE

BY TOM GARRISON

IN THIS COLUMN we customarily deal with philosophical issues in ocean education. At the suggestion of a few readers, I'd like to turn to a practical demonstration of some ways to invite critical thinking and introduce beginning students to the logic of the scientific method.

Teaching professors face a body of students increasingly biased against the principles of scientific inquiry. Our world is based in critical thought, and we need to demonstrate these ideas in our lab courses from Day One. Students are usually confident there is a Right Answer to every question. When presented with a high-profile public spat (as between "intelligent design" and organic evolution, or whether vitamin C cures colds, or whether global warming is happening), students tend to pick the answer represented by the person or group they like most and doggedly stick with it. They almost never question The Truth about anything of concern. Ask a typical freshman about one of the potential asteroid strikes that occasionally float through the popular media, and he might respond, "I heard we're all going to die." "Where did you hear that?" "On the Internet." "From whom?" "I forget, but they *definitely* said we're all going to die." Sure. Any minute.

As quick as our students are to latch onto an appealing (or scary) idea, they are contrastingly slow to question the principles on which those results are based. I have discussed most students' lack of statistical comprehension in a previous column—remember how many of your students drink expensive bottled water because they don't want to be exposed to bad stuff in the water supply, yet smoke or eat unhealthy foods? Sadly, logical thought is often not their strong suit. A negative attitude on my part? No, a realistic one.

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So, here is how I approach the nature of scientific logic at the first meeting of my honors oceanography laboratory course.

After the usual opening-day roll-taking and introductions, I ask my new students to see if seawater and freshwater boil at different temperatures. We provide a whole bunch of inexpensive thermometers, hotplates, 250-ml beakers, jugs of water, and safety glasses. We watch what happens.

Invariably, before any planning or discussion, each group of students (we seat four at a lab table) will switch on the hotplate, place beakers of seawater and freshwater side by side on its surface, and put one thermometer in each beaker. After a short interval, questions arise: Should we have the same amount of water in each beaker? Should the bulb of the thermometer rest on the bottom of the beaker, or should we hold it above the bottom? When is the water actually boiling? Should we record the highest temperature, or the temperature at which boiling begins? My TAs and I nod sagely, and restate their questions, but do not provide answers. After a while, I ask for the groups to put their data on the board.

Naturally, the numbers are all over the place. Some groups have seawater at a higher boiling point; some have freshwater there. We ask: What's The Truth? At what temperature does freshwater boil? Seawater?

The discussion stalls.

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We say nothing—Zen-like, we only restate the question.

Then, with a little luck, a student will look at the rest of the thermometers sitting idly on the table. Each reads a slightly different room temperature. Or somebody will look at the two thermometers resting on the table next to their hotplates—the now-cool thermometers used to take the recent measurements. They are not reading the same room temperature either! Could this be a problem?

Astonishment!

Hesitant at first, a student will ask why the thermometers are reading different temperatures in identical conditions? Another student will ask "which one is *right*?" Then, a breakthrough: "Is there an accurate thermometer that could be used to calibrate all the thermometers for error?"

The student who has brought up this beautiful idea is asked to go to a large piece of blank cardboard taped to the board. On its reverse, beautiful to see, the word "calibration" is written in huge letters. Celebrating this breakthrough, the TAs pelt the lucky student with hot sauce packets liberated from the on-campus Taco Bell.

I then march into the prep room and return with a fancy mercury reference thermometer. We talk about this development!

The students return to their tables with new thermometers, each calibrated to the newly revealed standard. Again, with a little luck, some additional questions will arise. During the experiment, Table 1 had been watching Table 2. Table 2 held their thermometer bulb off the bottom of the beaker, but Table 1 didn't. Table 3 had their beakers full. Table 4 didn't. Tables 5 and 6 were using a different brand of hotplate. And what about the thorny question of "What do you mean by boiling? What is Right, Dr. G.?

Silence.

Frustration.

But now the mood has subtly changed. Students are beginning to think about solutions, not problems. Thinking begins.

A student will ask if a *procedural* standard exists—a parallel to the instrumental standard. "Nope," we reply. If we're lucky, this student (or another) will address the next table (and, with a little urging, the lab group as a whole): "We've got to decide on *one* way to do this, and all do it the same way." Bravo! This student is asked to turn over a second cardboard to reveal the lovely word "standardization." More hot sauce packets are launched.

We tell everybody to go back to their

tables and boil the water again. There's a surprisingly large amount of excitement in the air.

Data on the board look better.

There is still one more sign to unveil.

"Well, now what?" the students ask. "Are we done?" No, there's still about 45 minutes left in the lab period. What might we do with that time—nobody leaves!

Now, again with luck, yet another student will step forward: "Should we do it again and get more data?"

The word "replication" is revealed behind the cardboard. Hot sauce flies.

Now, near the end of the allotted time, when we ask for The Truth, we get a satisfyingly qualified reply: "Well, we know the boiling points only if we have calibrated the thermometer, and then only if the calibration is correct." "Well, we know the boiling points only after we all do it the same way, and *other* methods might yield other results." "If we do it a bunch of times, our error will usually be less."

More boiling; great-looking data. Quite a contrast to the first set (still posted).

The period nearly complete, we've arrived at the "so what" moment! Now I can reveal to my lab students the Theme of the Lab, the idea pursued in all of the extensive written work we will require for the next fifteen weeks: "The search for, and minimization of, experimental error." There is no Right Answer, grasshopper[1]; no Absolute Truth in Science.

We're off to a good start. Lao Tzu[2] would be pleased.

Next week we'll see if the students can find the pause in freezing representing water's latent heat of fusion. As you can imagine, their approach will be completely different than what it might have been. They are starting to think like scientists.

"*Not so fast*," you say. "You've used the word *luck* many times in this paper." True enough. What happens if the students just sit there waiting for somebody to do something? Moving things forward is up to you and your TAs, but you must be subtle. The leaders in the class will have revealed themselves in the first half hour. If you get no response, you might whisper a hint to one of them. Or, if one of them solves the problem of calibration, you might ask, "Are you going to keep that idea to yourself?" I'm not beyond a little coercive guidance. Remember the ultimate teaching maxim: "Somebody showed it to me, and I found it by myself."

[1] "Grasshopper" was Master Po's nickname for his apprentice, the young Kwai Chang Caine, in the 1970s TV show *Kung Fu*.

[2] The sixth century B.C.E. Chinese Taoist philosopher.