We teaches scientific method which we should in the lessons.
question” form of experimentation as the new, updated version of the Scientific Method. Indeed, I came to believe that this was the way all science was done. I was therefore wholly unprepared for what awaited me when I began teaching the introductory biology laboratory.

Our introductory biology course is given to 300-400 students each semester. It is taught by a faculty member, a laboratory coordinator, and 16-17 graduate teaching assistants. The course covers a great breadth, attempting to integrate ecology and evolution with biochemistry and molecular biology. Some of the graduate assistants are in our molecular biology graduate program, and some are in the ecology and evolution program. This seems like an ideal mix to develop and present the course material.

And yet, we found ourselves disagreeing. The most profound moment came when one of the graduate assistants approached me during the weekly instructional meeting, and said, rather quietly so he wouldn’t offend too badly, “José, you’re doing this wrong. This is not how you do science.” It took us two hours to figure out what was going on, because neither of us knew the traditions of the other’s field.

This was how I again encountered the Scientific Method. The graduate assistant was horrified that I was asking our students to collect data, and then use the data to understand the system under investigation, without first formulating a hypothesis. In his field, he said, it was required that one present a hypothesis first, or else, “It’s not science.” Many of the graduate assistants agreed: if it doesn’t use the Scientific Method, it’s not science. But, I thought, if it’s not science, what is it that my colleagues and I have been doing for the last two decades? How did they decipher the genetic code, if it wasn’t science?

The simple answer is that we’ve all been doing science, but the formal logic of designing the experiment varies among fields. Each scientific field has developed an approach to thinking about science, and to designing experiments, that works best within that field. As I mentioned above, in molecular biology, the most effective method appears to be that of asking a question, with the data providing an answer. This is not the most effective method in ecology.

In fields such as ecology, where we are examining complex systems with many variables, it is exceptionally difficult to define all the interactions that may take place. Here, the most effective method of designing experiments is to use the available information to develop an understanding of the system, and to present that understanding as a hypothesis. We then test our understanding experimentally, comparing the actual observations to the predictions based on the hypothesis. Here, it would be naive merely to ask a question, for the data could be explained in many different ways, and could be compatible with many potential answers.

In ecology and organismal biology, the tradition is to “remove personal bias” by making a formal statement of the hypothesis at the outset. In molecular biology, the tradition is to remove personal bias by refusing to guess the answer before you start. They both work, but in different contexts, with different kinds of experiments.

It has become traditional for molecular biologists and ecologists to disagree on many things. Some think this is merely the “politics of science.” I suggest that it derives, instead, from a fundamental difference in how we each perceive the practice of science. Our traditions color our thinking so profoundly that we have trouble communicating with others who have different traditions.

I have described two different “Scientific Methods,” one of which is used by each field. There are likely to be many more Scientific Methods, within biology, most are probably somewhere between these extremes (or so I surmise from the fact that there is less disagreement among other biological fields). The surprise, at least to me, is not that different approaches exist. It is that we are so profoundly unaware of the differences.

As I mentioned above, I developed as a scientist thinking that the Scientific Method had been abandoned in favor of a different mode of inquiry. In contrast, some of my graduate assistants have developed in a tradition in which the Scientific Method is the only valid mode of inquiry. Apparently, we become so specialized in our training, and learn so much by “osmosis” that we can very easily fail to recognize that the rest of the world exists.

Of what value is this discussion for science teachers? I believe that there is a very profound message here. It is that some kinds of experiments can follow the classic Scientific Method quite well—but others cannot, and can be forced into this paradigm only at great peril. The problem is that textbooks typically present only one Scientific Method, and imply that it is universal.

I offer two kinds of worries. First, what will be the response of the budding biochemist when asked to force an experiment (for example, the one referred to above—deciphering the genetic code) into the logic of the Scientific Method? Such a student will have little choice but to conclude that the Scientific Method is outmoded and should be abandoned, since it clearly requires a “silly” hypothesis. This undermines the Scientific Method, and makes the student less able to recognize its validity where it is truly needed.
My second worry concerns the steady decline in students’ interest in science as they progress through school. Some groups show a more marked decline than others, particularly those in which self-esteem is fragile. Young students are ill-equipped to develop a good hypothesis, simply because they lack sufficient observations or experimental data upon which to base a hypothesis. To many students, being asked to form a hypothesis feels like being asked to guess how the experiment is going to come out. Maybe this is why so many students define “hypothesis” as “an educated guess.” To them, it is.

Furthermore, young students are also ill-equipped to carry out a well-controlled experiment. They rarely have the background, and even more rarely have the instruments and facilities. Their data quite frequently fail to support the hypothesis. For many students, science becomes a matter of making guesses, and then proving oneself wrong. It is a steady diet of negative reinforcement, and may well be partly responsible for the loss of interest that we observe. I have talked to several non-scientists (my wife among them) who revealed that this was one of the reasons they chose to shun science in high school and college.

We, as teachers, need to recognize that the official Scientific Method is appropriate for only some types of investigation. We need to present the Scientific Method in the context of experiments for which it is ideally suited, and explain that it serves to check our own understanding of complex systems. For this kind of analysis, it is perhaps the only way to do the science without bias. We must keep in mind, however, that this approach requires that the students have enough preliminary information to be able to propose a provisional interpretation of the data. The Scientific Method serves to check the validity of that provisional interpretation (which we call a hypothesis).

We also need a substitute for other types of investigation, for which stating a hypothesis is ill-advised. From my experience in biochemistry and molecular biology, I suggest that it is effective to ask a question, and use the data to begin to answer the question.

I have presented these two Scientific Methods as if they are different. However, they are fundamentally similar. In each, the investigator follows a cycle, as illustrated in the figure:

- Method A
  - hypothesis → data → hypothesis → experiment → data → hypothesis → experiment ...
- Method B
  - experiment → data → hypothesis → experiment → data → hypothesis → experiment ...

In each tradition, the hypothesis is our statement of how we think the system we are studying works. In each case, it is based on prior observations or experimental data. The only difference is that we stop and think (or write our lab report, or our research paper) before or after we present the hypothesis, so that the hypothesis either leads into the experiment, or ties the results together. Both methods work because they are really just different ways of thinking about the same process.

For young students, it is probably much easier to ask a question than it is to develop a sound hypothesis. Partly, this reflects the simple fact that young students have limited scientific backgrounds, and have fewer resources to draw upon in attempting to formulate hypotheses. I suggest that, for these students, we might be most effective as teachers if we present science to them as a way of asking questions. As they develop scientifically, we can introduce them to the notion of testing their own understanding by using the formal Scientific Method.

I would hope that this approach will not undermine the Scientific Method, but rather reinforce its value in situations where it is indispensable. At the same time, this approach can decrease many students’ frustration with science. While it might be emotionally devastating for some students to find that data repeatedly prove them to be wrong, these same students might find it quite acceptable to learn that their first experiment does not fully answer their question. They might even be interested in doing another experiment that’s better. If we can engage these students in the process, asking their questions differently and with more precision, we may be able to build their scientific sophistication and self-confidence more easily.

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