# Paradigms in Research and Parables in Teaching

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Research and teaching have a natural kinship that deserves emphasis. In both, the basic aim is to attain new perspectives. In both, factors often crucial are the choice of topics to be pursued and the strategy adopted. Knowledge and logic do not suffice; intuition and verve may be decisive. Success is judged chiefly by impact on the thinking of colleagues/students, and usually depends greatly on context, scope, and comprehensibility.

## Emphasizing Exploration and Excursion

Science teaching should put less stress on derivations and manipulations, more on exploration and artistic excursions. Particularly in introductory courses, students are often handicapped by fear that they "won't know how to get it right." Studies in cognitive science show that even able students cannot solve problems only slightly different from those they have done before, *unless* they have a qualitative understanding. To foster this and build confidence, we need to emphasize the use of analogy and guesswork. We also should exhibit how error and failure are prevalent in science, yet welcome if "wrong in an interesting way." The truth waits patiently and the path to it is often discovered by unsound but illuminating excursions.

Parables are well suited to such themes. By presenting science in a more humanistic mode, parables can disarm fears, put technical concepts in a more meaningful context, and induce students to relate the tales to others. In my freshman chemistry lectures, I now try to introduce each major topic with a story. Many deal with current episodes or research discoveries. Some are fanciful. Here I will mention two historical examples.

## Using Historical Examples

The lecture on gas laws begins with *"How Aristotle and Galileo were stumped by the water pump."* After illustrating how such a pump works (because few students have seen one nowadays!), I note that Aristotle "explained" it by his famous dictum that "Nature Abhors a Vacuum." Then I raise the question why the pump will not pump water above a height of 34 feet. This empirical fact was known in Aristotle's day (as evident from artwork that depicts a series of pumps lifting water from a deep river gorge). Curiously, he said nothing about why a tall drink seems to quench Nature's abhorrence. Two thousand years later, Galileo considered specifically that question and suggested that the pump ceases to function because a taller column of water would break of its own weight. That answer is also quite wrong (as evident from fire hoses). The right idea was proposed by Torricelli, one of Galileo's students–just as some of today's students are destined to solve problems that have long stumped their professors. Then, of course, I demonstrate Torricelli's barometer and use it in a series of measurements exemplifying the gas laws.

Another favorite tale, also with transcendent lessons, occurs in my lecture on polymer chemistry. This I whimsically title, *"How nylons won World War II."* In brief, the Japanese conquest of Singapore in early 1942 deprived the United States and Britain of virtually their sole supply of rubber. As stated in a report by Bernard Baruch: "Of all critical and strategic materials, rubber presents the greatest threat to the success of the Allied cause. . . . If we fail to secure quickly a large new rubber supply, our war effort and our domestic economy both will collapse." This report launched a crash program to produce synthetic rubber, using a method developed and implemented in Germany. In effect, our enemy had mapped the route to salvation. All told, some 50 plants were quickly built. (Some still are in operation today). The Allied victory could not have been achieved without this enormous rubber project. But for it to succeed on such an urgent timescale, we had to have a sufficient population of polymer chemists and engineers. It was actually the pursuit of artifical silk started 15 years before and culminating in nylon that largely created those vital human resources.

## Broadening Perspectives with Parables

The mode of posing questions and broadening perspectives, fostered by use of parables, as well as the emphasis placed on qualitative reasoning and guessing, simply carries into the classroom the approach naturally adopted in research. This approach, if good in lectures and discussions, is more important yet in other components of a science course. Some exercises, particularly in the homework or lab, should be described to students as merely acquainting them with useful, prototype techniques. However, others should be designed as opportunities for personal discovery. These invite students to devise, by trial and error, their own approach to formulating questions and experiments. On homework and exams and in the lab we habitually should ask students first to record the expected direction or sign of an effect and when feasible to estimate its rough magnitude, before undertaking an actual calculation or measurement. In short, we should encourage our students to learn in the personal, artistic way scientists pursue research. This aim has implications for exam and grading policies, because these greatly influence student attitudes and morale. I strongly recommend two precepts adopted in my course:

(1) Competition among students is *not allowed;* and
(2) on hour exams and quizzes, *no points can be lost.*

To implement (1), we simply adopt an absolute grading-scale, defining at the outset how many points from exams, homework, and labs are needed to reach each grade level. This enables us to encourage students to help each other and to assign some homework and quizzes as team problems, again emulating how most real science is done. In

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principle "everyone can get an A," in contrast to the customary mindless "grading on the curve," which guarantees to humiliate a fair fraction of the class.

I call (2) a "resurrection" policy. Any points a student fails to earn on an hour exam are added to the corresponding section of that student's final exam, so the student gets a second shot at earning those points. This reduces anxiety about a subpar performance on an hour exam and helps students to view the exams as trial runs indicating what to focus on most diligently in preparing for the final.

The resurrection policy also is a paradigm for later life. The pursuit of research or the development of a career in science is not a series of one-shot trials. It is not even desirable, much less possible or necessary, to be right at each stage. Because the truth waits patiently, and we must grope for it, wrong steps are intrinsic to the search. But with sustained, ardent effort marvelous advances can be achieved by ordinary human talent. Parables and policies can help deliver this "user-friendly" message. It may be the most important message we can give to our students.